SURPRISE
ARIZONA

Water Design Standards and Technology Assessments

City of Surprise Project No. COS08-053

Water Technology Assessment

Carollo Project No. 8267A.00

FINAL REPORT

APRIL 2011

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City of Surprise
Water Design Standards and Technology Assessment
Project No. COS08-053

WATER TECHNOLOGY ASSESSMENT REPORT

FINAL
April 2011

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City of Surprise
Water Design Standards and Technology Assessment
Project No. COS08-053

WATER TECHNOLOGY ASSESSMENT REPORT

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LIST OF ABBREVIATIONS

µg/L	micrograms per liter
AA	Activated Alumina
AAC	Arizona Administrative Code
ADEQ	Arizona Department of Environmental Quality
BAT	Best Available Technologies
BMP	Best Management Practices
BOD	Basis of Design
CAP	Central Arizona Project
CASS	Central Arizona Salinity Study
CAWCD	Central Arizona Water Conservation District
CCL	Contaminant Candidate List
CCR	Consumer Confidence Report
CCT	Corrosion Control Treatment
CFR	Code of Federal Regulations
CoC	Constituents of Concern
Cr	Chromium
CT	Concentration x Time
CWS	Community Water Systems
D/DBP	Disinfection/Disinfection Byproduct
D/DBPR	Disinfection/Disinfection Byproduct Rule
DBP	Disinfection Byproduct
EDCs	Endocrine Disrupting Compounds
EDSTAC	Endocrine Disruptor Screening and Testing Advisory Committee
FBR	Filter Backwash Rule
GAC	Granular Activated Carbon
GFH	Granular Ferric Hydroxide
GIM	Granular Iron Media
GPM	Gallons per minute
GWR	Groundwater Rule
GWUDISW	Groundwater Under the Direct Influence of Surface Water
HAAs	Haloacetic Acids
HPC	Heterotrophic Plate Count
IDSE	Initial Distribution System Evaluation
IMM	Iron Modified Media
IWMP	Integrated Water Master Plan
IX	Ion Exchange
LCR	Lead and Copper Rule
LCRMR	Lead and Copper Rule Minor Revisions
LOX	Liquid Oxygen
LRAA	Locational Running Annual Average
LSLR	Lead Service Line Replacement
LT2ESWTR	Long Term 2 Enhanced Surface Water Treatment Rule
MCESD	Maricopa County Environmental Services Department
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MFL	Million Fibers Per Liter
MF/UF	Microfiltration/Ultrafiltration
mg/L	Milligrams Per Liter
mgd	Million Gallons Per Day

MIB	2-methylisoborneol
MIEX	Magnetic Ion Exchange
MMM	Multimedia Mitigation
MPA	Microscopic Particle Analysis
MRDL	Maximum Residual Disinfectant Level
MRDLG	Maximum Residual Disinfectant Level Goal
MTBE	Methyl Tertiary Butyl Esther
NAS	National Academy of Sciences
NDMA	N-Nitrosodimethylamine
NF	Nanofiltration
NOM	Natural organic matter
NTNCWS	Non-transient, Non-community Water Systems
NTU	Nephelometric Units
O&M	Operation and Maintenance
PFD	Process Flow Diagram
POE	Points of Entry
PPCPs	Pharmaceuticals and Personnel Care Products
PWS	Public Water Systems
RCRA	Resource Conservation Recovery Act
RO	Reverse Osmosis
SDWA	Safe Drinking Water Act
SFBW	Spent Filter Backwash Waste
SMCLs	Secondary Maximum Contaminant Levels
SMF	Standardized Monitoring Framework
SMP	Standard Monitoring Program
SPA	Special Planning Area
SSS	Site-specific Study
SUVA	Specific Ultraviolet Absorbance
SWTR	Surface Water Treatment Rule
TBD	To Be Determined
TC	Total Coliform
TCLP	Toxicity Characteristics Leaching Procedure
TCR	Total Coliform Rule
TDS	Total Dissolved Solids
TOC	Total Organic Carbon
TON	Threshold Odor Number
TT	Treatment Technique
TTHMs	Total Trihalomethanes
UCMR	Unregulated Contaminants Monitoring Rule
USEPA	United States Environmental Protection Agency
UV	Ultraviolet
WQ	Water Quality
WQP	Water Quality Parameter
WSF	Water Supply Facility
WTP	Water Treatment Plant
ZLD	Zero Liquid Discharge

EXECUTIVE SUMMARY

INTRODUCTION

Like many communities in the Phoenix metropolitan area, the City of Surprise (City) has experienced unprecedented growth over the last decade. While growth has slowed with the recent downturn in the economy, it is only a matter of time before growth returns and development expands into new areas of the City. In order to accommodate this future growth, the City has taken a proactive approach to developing plans for new water and wastewater infrastructure including water production, storage and distribution facilities, and wastewater collection, treatment, and effluent disposal/recharge facilities. In an effort to better define their future water and wastewater infrastructure and provide planning level information for selecting the most appropriate technologies, the City completed detailed Water and Wastewater Technology Assessments.

The goals of the Water Technology Assessment included the following:

- Provide the foundation for uniformity in approach to future City of Surprise water treatment facilities and infrastructure.
- Provide a mechanism to obtain consensus from all sectors and levels of City management on City water treatment and infrastructure policy.
- Provide technically feasible, cost-effective, and reliable approaches to meet the regulatory requirements for water treatment facilities and infrastructure.
- Establish a position which enhances the City's control over the planning and implementation process for its future water and treatment facilities and infrastructure.

The scope of work for the Water Technology Assessment included review of the City's current water quality data, review of regulatory requirements, evaluation of appropriate treatment technologies for the City's water supply, and development of tools and implementation packages that assist the City in developing its future water supply facilities and infrastructure. The project objectives were achieved through completing the following specific tasks:

- Reviewing the current, proposed, and future water quality regulations and requirements.
- Collecting and reviewing the City's current water quality data for its drinking water sources.
- Establishing and achieving consensus with the developers regarding the City's drinking water quality standards.

- Establishing and achieving consensus with the developers regarding criteria that will be used to identify and evaluate viable treatment technologies.
- Reviewing, screening, and evaluating selected treatment technologies based on their benefits and challenges, capital, and operational and maintenance (O&M) costs.
- Providing the City and the developer with multiple cost-effective and technically feasible treatment technology alternatives that can achieve the City's drinking water quality standards while meeting the associated residuals disposal requirements.

The City of Surprise Integrated Water Master Plan (IWMP) - Water Infrastructure (2009, Final), and IWMP - Water Resources (2008, Final) define the City's current and future water system boundaries. These documents provide a master planning interface and platform for the Water Technology Assessment Report. Recommendations from the IWMP are incorporated directly and used to establish criteria for the technology assessment. Data contained in the IWMP is validated to confirm that the parameters used in the technology assessment are accurate and consistent with the established goals of the City. Based on information presented in the IWMP, the following project constraints have been adopted as part of the Water Technology Assessment Report:

- The focus period for the technology assessment is approximately the next five to ten years. It is anticipated that this document will be reviewed and updated every five to ten years (in conjunction with the IWMP) to address changing growth patterns, regulations, treatment technologies, capital and O&M costs, etc.
- The technology assessment assumes the City will be treating groundwater supplies only. Surface water treatment was not evaluated, as the City does not foresee surface water treatment in the near future (i.e., for the next five to ten years).
- The technology assessment is based on the available water quality information. The conclusions of the assessment can be interpolated to new sources with similar water qualities using the SurpriseTree™ Water Model - a Water Treatment Technology Assessment model developed specifically for this project (see Section 7.0). The Water Technology Assessment focuses on treatment technologies required to address the validated Constituents of Concern (CoC) (nitrate, arsenic, and fluoride). Refer to Section 5.0 of the Water Technology Assessment Report for more discussion).
- The IWMP will be updated periodically (i.e., every five years) to reflect changes in water sources (both quantity and quality) and water treatment facilities and infrastructure. Changes to the IWMP may affect the validity of the technology assessment results. It is recommended that the Water Technology Assessment Report be reviewed and updated following each IWMP update. This approach will allow the City to improve the accuracy of planning and budgeting associated with water treatment facilities and infrastructure.

The Water Technology Assessment Report focuses on the evaluation of centralized treatment technologies that are applicable for the City's water supply facilities, assuming there is no treatment avoidance alternative available to provide reliable and safe drinking water. Proper selection of source water and optimization of the well design should be evaluated to avoid treatment wherever possible. This may include proper casing and sleeving design to limit production from areas of the aquifer which contribute to water quality concerns.

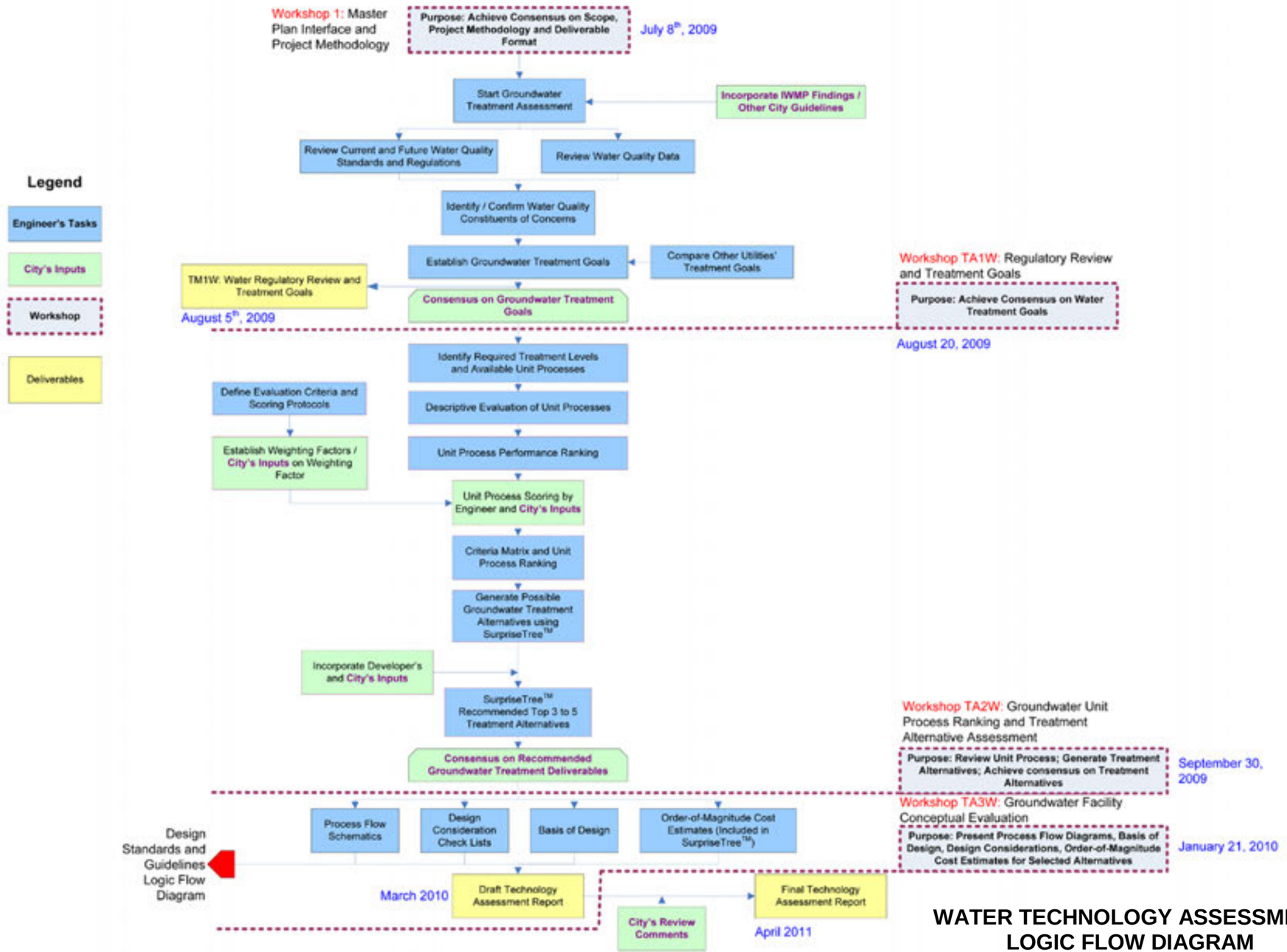
PROJECT METHODOLOGY OVERVIEW

The methodology proposed to meet the City's current and near term needs is systemic, as illustrated in the logic flow diagram outlined in Figure ES.1. The Water Technology Assessment logic flow diagram was developed by the project team and includes the proposed tasks and the strategy for completing the Water Technology Assessment.

The logic flow diagram includes an overview of the primary tasks associated with the Water Technology Assessment. In short, the Technology Assessment began with a drinking water regulatory review and establishment of the City's water quality treatment goals (presented in Section 3.0 of the Water Technology Assessment). These activities were performed in parallel with a review of available water quality data associated with the City's water sources (see Section 5.0 of the Water Technology Assessment). Through comparing the water quality data and the treatment goals, water quality CoC and levels of treatment required to address these CoC were identified (see Section 4.0 of the Water Technology Assessment).

Section 6.0 of the Water Technology Assessment presents the prescreened treatment technology alternatives, which were evaluated for each level of treatment. This evaluation addressed questions for each technology including what it is, what it does, how it works, and what are the associated pros and cons. The technology alternatives were then compared in tabular format and ranked using evaluation matrixes. The evaluation matrixes utilized a set of evaluation criteria developed by the City staff and developer representatives. Nine individuals (City and developer) participated in assigning weighting factors for these criteria. The averaged weighting factors were used for the final ranking evaluation.

A conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges associated with the unknown water quality of the City's future water sources. To provide the City with a useful tool that can assess available treatment alternatives for a given set of water quality inputs and site-specific conditions (such as present CoC, competitive ions, facility size), the team developed an innovative approach. The core of this approach is an advanced macro-based Excel model called SurpriseTree™ Water. Refer to Section 7.0 of the Water Technology Assessment for detailed descriptions regarding how the model works and how/when it should be used.



WATER TECHNOLOGY ASSESSMENT LOGIC FLOW DIAGRAM

FIGURE ES.1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT EXECUTIVE SUMMARY

Using SurpriseTree™ Water, the results of the technology alternative assessment represent a dynamic and customized solution, which automatically responds to the water quality and site-specific condition inputs for future facilities. Through incorporating the City's institutional and technical knowledge, the model was "calibrated" and improved to better represent potential future conditions.

The Water Technology Assessment Report is designed to provide the City and the developer with useful planning level design information for the most common and effective treatment alternatives for implementation at the City's future water supply facilities. The treatment alternatives presented are viable options for the City's facilities, based on their technical feasibility and cost effectiveness. Process flow diagrams, basis of design, and design considerations were developed for each of the selected treatment alternatives.

DRINKING WATER TREATMENT STANDARDS

To ensure the provision of safe drinking water to its customers, the City of Surprise established uniform water quality treatment standards for all water supply facilities within the City limits. All future water supply facilities shall be designed to achieve these water quality requirements. The Water Technology Assessment Report establishes these standards and provides policy justifications and regulatory basis for each.

As part of the Technology Assessment, the City's original water quality standards were revised to incorporate updated regulatory information, current City direction, and input from participating developer's representatives. These revisions established a new set of water quality standards, which balance protection of water quality for City residents and the treatment costs (both capital and O&M) required to achieve the desired quality. The standards will help the City to attract development and investment within the City limits by providing established and consistent requirements and strengthen the partnership with the developers without compromising customer's confidence in the City's drinking water.

The following water quality standards were established for the City of Surprise:

- 100 percent of the MCL for all regulated contaminants, unless otherwise noted
- Secondary MCL for fluoride
- 80 percent of the MCL for arsenic and nitrate
- 80 percent of the MCL for TTHMs and HAA5 (based on LRAA)
- No standards on non-regulated contaminants, unless specific evidence exists to indicate a goal will be established in the next five to ten years

Table ES.1 provides a summary of the policy justifications and regulatory basis for the recommended water quality standards.

Table ES.1 Justification of City of Surprise Water Quality Standards Water Technology Assessment Report Executive Summary City of Surprise	
Water Quality Standards	**Justifications**
100% MCL	Required to comply with the current federal or state primary MCLs requirements.
Secondary MCL for fluoride	Required to avoid public notification triggered by current alert levels.
80% MCL for arsenic and nitrate 80% MCL for TTHM and HAA5 (based on LRAA)	Recommended standards "below" the MCLs are focused specifically on the City's identified constituents of concern. The City's standards for these constituents are set to allow a reasonable process control buffer considering technology specific and operational variations. The standards are consistent with typical engineering and the State and MCESD practices.
No standards on non-regulated contaminants	Standards for non-regulated contaminants are not required. It is not anticipated that the City's groundwater sources will be impacted by any future regulations during the 5 to 10 study timeframe.

GROUNDWATER QUALITY REVIEW

Water quality data for the City's existing wells was summarized in the IWMP-Water Infrastructure Report. As part of the Water Technology Assessment, additional water quality information, including 2009 water quality data, along with well completion reports from many of the existing wells within the City limits, was evaluated. Based on previously identified CoC in the IWMP and a review of all available existing water quality data, three critical CoC were identified: arsenic, nitrate, and fluoride. For these parameters, the source water contaminant levels exceeded or approached the MCLs or the City's established water quality standards (see Section 4.0 in the Water Technology Assessment Report). Consequently, design of the City's future water treatment facilities should be designed with removal of these constituents in mind. Table ES.2 summarizes these CoC and their treatment standards. The Water Technology Assessment focuses on the most efficient and effective treatment processes to address these critical CoC.

Table ES.2 City of Surprise Drinking Water Quality Critical Constituents of Concern Water Technology Assessment Report Executive Summary City of Surprise				
Water Quality Parameters	**USEPA MCL**	**USEPA SMCL**	**City of Surprise WTP WQ Standards**	**Occurrences in City's Existing Water Supply Wells(1)**
Critical Constituents of Concern				
Arsenic	0.010 mg/L	NS	0.008 mg/L	9 out of 12 wells exceeded the MCL for arsenic and 11 out of 12 wells exceeded the City's Water Quality Standard.
Fluoride	4.0 mg/L	2.0 mg/L	2.0 mg/L	2 out of 12 wells exceeded the SMCL for fluoride and 2 out of 12 wells exceeded the City's Water Quality Standard.
Nitrate As Nitrogen	10 mg/L	NS	8 mg/L	0 out of 12 wells exceeded the MCL or the City's Water Quality Standard for nitrate. However, nitrate levels at many facilities are nearing levels which would require treatment.

Note:

(1) Data from Well Completion Reports summarized in Table WT.19 in the Water Technology Assessment Report.

Abbreviations:

MCL = Maximum Contaminant Level. The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

NS = No Numerical Standards.

WQ = Water Quality.

Other CoC, such as turbidity, total coliforms, and virus can be concerns for groundwater supply systems. These parameters are not necessarily directly tied to numerical standards for groundwater supplies, but are a critical indicator of the treatment effectiveness relative to other contaminants or pathogens.

Other parameters, such as TTHMs, HAAs, total coliform, and virus are of critical importance to public safety. Although they are most commonly concerns for surface water supply systems and are not typically major issues for the City's groundwater supply, they do drive the treatment technology assessment for disinfection. The City's existing groundwater supplies have a relatively low TOC. As a result, disinfection byproduct (DBP) formation is not expected to be a concern as long as the City continues to use groundwater as its primary source of drinking water.

Other potential CoC were identified including salinity (TDS), chloride, sodium, iron, manganese and NDMA. These COC may potentially become a concern for the City's future water supply. Iron and manganese is present in many wells in the Valley. High levels of iron and manganese deteriorate the drinking water quality and interfere with many treatment processes (e.g., fouling adsorption media, ion exchange resins, and membranes).

The list of critical, potential, and other CoC should be revisited when updating the IWMP and the Water Technology Assessment Report in the future.

TREATMENT PROCESS EVALUATION

For a given water supply facility, several categories, including pre-oxidation, coagulation and flocculation, filtration, advanced treatment (e.g., adsorption, ion exchange, desalination) and disinfection, may be required to treat the identified critical, potential, and other CoC in the City's groundwater source and achieve the established finished water standards. Residuals handling may also be required.

In order to determine the most applicable and beneficial water treatment technologies for the City of Surprise, four principals were used to prescreen each of the treatment technology alternatives:

1. Technology alternatives must be capable of achieving the established treatment standards for the City.
2. Technology alternatives must be established, proven technologies that can be reliably implemented at full-scale without significant additional testing.
3. In general, technology alternatives were evaluated based on the contaminant removal mechanism. Individual manufacturers/equipment/commercial names were referenced, but generally not evaluated individually.
4. Technology alternatives that have specific local experience/application or which the City has indicated specific interest in were generally included in the evaluation.

Based on the detailed evaluation in Sections 6.4 through 6.10 in the Water Technology Assessment Report and input from the City and developer representatives, the original alternatives were further narrowed to a list of recommended alternatives for potential implementation. These recommended treatment technology alternatives were further evaluated using the SurpriseTree™ Water Model (see Section 7.0 in the Water Technology Assessment Report) by comparing the treatment processes using a three-tier evaluation consisting of performance based criteria evaluation, implementation based criteria evaluation, and financial evaluation criteria.

The performance based criteria evaluation utilizes a set of criteria established to identify the effectiveness of a treatment process in removing target CoC. The implementation based criteria evaluation focuses on the ability to effectively implement each treatment technology.

The City and the developer representatives participated in the development of these criteria. Compared to the performance-based criteria, the implementation based criteria are more comprehensive, covering technical, environmental, economic, and social aspects. The financial based criteria evaluation focuses on the financial impacts of each treatment technology. Treatment technologies are compared to each other based on a “dollar per gallon of water treated” basis.

A list of the treatment technology alternatives evaluated as part of the Water Technology Assessment Report, along with the recommended treatment technology alternatives further evaluated using the SurpriseTree™ Water Model, are included in Table ES.3.

Table ES.3 Treatment Technology Alternatives
Water Technology Assessment Report Executive Summary
City of Surprise

Treatment Categories	Prescreened Treatment Technology Alternatives	Evaluated in Water Technology Assessment Report	Evaluated in the SurpriseTree™ Water Model
Pre-oxidation	Aeration Pre-oxidation / Stripping	X	-
	Chlorine Pre-oxidation	X	X
	Chlorine Dioxide Pre-oxidation	X	X
	Ozone and Advanced Pre-oxidation	X	X
	Potassium Permanganate Pre-oxidation	X	X
Chemical Pretreatment	Coagulation	X	X
	Enhanced Coagulation	X	X
	Enhanced Lime Softening	X	X
Filtration	Granular Media Filters	X	X
	Microfiltration / Ultrafiltration	X	X
	Oxidizing Filters (Green Sand Filters)	X	X
	Drinking Water Biological Filtration	X	X
Advanced Treatment Operations (Adsorption, Ion Exchange, Desalination)	Granular Iron Media Adsorption	X	X
	Activated Alumina and Iron Modified Activated Alumina	X	X
	Granular Activated Carbon	X	-
	Ion Exchange	X	X
	Nanofiltration / Reverse Osmosis	X	X

Table ES.3 Treatment Technology Alternatives Water Technology Assessment Report Executive Summary City of Surprise			
Treatment Categories	**Prescreened Treatment Technology Alternatives**	**Evaluated in Water Technology Assessment Report**	**Evaluated in the SurpriseTree™ Water Model**
	Electrodialysis / Electrodialysis Reverse	X	X
Disinfection	Gaseous Chlorine Disinfection	X	X
	Sodium Hypochlorite On Site Generation Disinfection	X	X
	Sodium Hypochlorite Bulk Disinfection	X	X
	Chloramines Disinfection	X	X
	Ozonation	-	-
	UV Disinfection	-	-
Residuals Handling – Thickening Processes	Reclamation Ponds	X	-
	Gravity Thickeners	X	-
	Lamella Gravity Settler and Thickener	X	-
	Dissolved Air Flotation Thickening	X	-
	Gravity Belt Thickeners	X	-
	DensaDeg™ Thickener	X	-
	Microsand Enhanced Settling Process	X	-
Residuals Handling – Dewatering Processes	Belt Filter Press	X	-
	Centrifuge	X	-
	Plate and Frame Filter Press	X	-
	Reclamation Ponds	X	-
	Solar Drying Beds	X	-

EVALUATION OF GROUNDWATER TREATMENT ALTERNATIVES USING THE SURPRISETREE™ WATER MODEL

Based on a review of the available data from the City's current wells in SPA 1 and SPA 2, groundwater quality varies significantly. It is anticipated such variations could be even more significant when development in other special planning areas occurs in the future. As discussed throughout the Water Technology Assessment Report, the optimum groundwater treatment technology for a new well greatly depends on the specific water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size. There is likely no single technology that can fit the exact needs of the all of the City's future WSFs. In order to

provide a useful tool for the City in selecting the optimum treatment technology for future WSFs, a more holistic and flexible approach must be provided.

The Water Technology Assessment Report is designed to serve as a water quality and technology master planning document that governs future efforts such as site-specific planning, technology selection/feasibility studies, preliminary design, and detailed design. At this master planning level, the main objectives of the effort were identifying current and future key water quality concerns, establishing water quality treatment standards, identifying multiple technology options that could be used collectively to meet the City's drinking water treatment standards, and providing high-level implementation guidelines associated with applicable technologies.

In general, this planning document was created to assist in establishing a mechanism and an evaluation methodology for the City to perform site-specific evaluations when actual water quality and other site information are more clearly defined for a given facility. It provides a baseline for technology selection and outlines the general required design criteria and considerations for a specific application in an effort to give the City confidence in their ultimate treatment technology selection. However, it leaves detailed design decisions, facility layouts, and other site-specific decisions to the design engineer to promote more informed and effective decision making.

To provide the City with a useful tool that can assess available treatment alternatives for a given set of water quality inputs and site-specific conditions, the team employed an innovative, advanced macro-based excel model named SurpriseTree™ Water. Using SurpriseTree™ Water, the results of the technology alternative assessment are not limited to a single fixed set of recommendations. Instead, the model provides a dynamic and customized solution, which automatically generates the most technically feasible and cost-effective treatment options in response to the water quality and site-specific condition inputs.

The SurpriseTree™ Water Model computerizes the documentation of the evaluation methodology in a logical way. Criteria established by the City staff and developer representatives (referred to as implementation-based criteria) are utilized in the SurpriseTree™ Water Model, supplemented by performance-based evaluation and capital, O&M, and lifecycle cost analysis developed by engineers. Weighting factors for the implementation-based criteria were developed by averaging the City staff and developer representatives' inputs. All weighting factors, ranking scores, and unit costs are fully adjustable by the City, providing significant flexibility to adjust to changing future conditions. The model employs a user-friendly spreadsheet structure, powered by macro-based selector buttons to make the site-specific analysis prompt and easy.

RECOMMENDED TREATMENT TECHNOLOGIES

The SurpriseTree™ Water Model recommendations are dynamic, based on water quality and site-specific inputs. Based on the review of applicable treatment technologies for the City's groundwater supply and the SurpriseTree™ Water Model output results for treating the identified City of Surprise constituents of concern, the four most common recommended treatment technologies were identified, including:

- Coagulation, flocculation, and granular media filtration for arsenic and/or fluoride (high concentration) removal.
- Adsorption process using granular iron media, activated alumina or iron modified media for arsenic and/or fluoride removal.
- Ion exchange process for arsenic, fluoride and/or nitrate removal.
- Nanofiltration/reverse osmosis for arsenic, fluoride, and/or nitrate removal.

The four most favorable treatment technologies were reviewed with City personnel. These treatment technologies represent the best unit process components for removing any combination of the City's established CoC and are viable options for the City's facilities, considering their technical feasibility and cost effectiveness. While the four technologies may not remove each of the CoC individually, various combinations of the technologies can be used to remove all three constituents, depending on water quality. Process flow diagrams, basis of design, and design considerations were developed for each of these selected treatment alternatives as a part of an implementation package for use by the City and developers.

Bulk sodium hypochlorite and onsite-generated sodium hypochlorite are the most favorable disinfection alternatives, as identified by the SurpriseTree™ Water Model. Residual handling alternatives should be evaluated on a case-by-case basis based on their applicability for each of the primary water treatment processes. The implementation packages created for the recommended treatment alternatives include recommended residuals handling treatment options for the respective treatment process.

SUMMARY

As growth continues to occur within the City of Surprise, the Water Technology Assessment Report will provide the City with a foundation for uniformity in approach to their future water treatment facilities and infrastructure; assist in obtaining consensus from the City and developers on water treatment and infrastructure policy; provide technically feasible, cost-effective, and reliable approaches to meet the regulatory requirements and City standards for water treatment facilities and infrastructure; and enhance the City's control over the planning and implementation process for its future water and treatment facilities and infrastructure.

1.0 INTRODUCTION

1.1 Project Objectives

Like many communities in the Phoenix metropolitan area, the City of Surprise (City) experienced unprecedented growth over the last decade. While growth has slowed with the recent downturn in the economy, it is only a matter of time before growth returns and development expands into new areas of the City. In order to accommodate this future growth, the City has taken a proactive approach to developing a variety of new water and wastewater infrastructure including water production, storage and distribution facilities, and wastewater collection, treatment, and effluent disposal/recharge facilities.

The goals of this Water Technology Assessment included the following:

- Provide the foundation for uniformity in approach to future City of Surprise water treatment facilities and infrastructure.
- Provide a mechanism to obtain consensus from all sectors and levels of City management on City water treatment and infrastructure policy.
- Provide technically feasible, cost-effective, and reliable approaches to meet the regulatory requirements for water treatment facilities and infrastructure.
- Establish a position which enhances the City's control over the planning and implementation process for its future water and treatment facilities and infrastructure.

The scope of work for the Water Technology Assessment included the review of the City's current water quality data, review of regulatory requirements, evaluation of appropriate treatment technologies for the City's water supply, and development of tools and implementation packages that assist the City when developing its future water treatment facilities and infrastructure. The project objectives were achieved through completing the following specific tasks:

- Reviewing the current, proposed, and future water quality regulations and requirements.
- Collecting and reviewing the City's current water quality data for its drinking water sources.
- Establishing and achieving consensus with the developers regarding the City's drinking water quality standards.
- Establishing and achieving consensus with the developers regarding criteria that will be used to identify and evaluate treatment viable technologies.

- Reviewing, screening, and evaluating selected treatment technologies based on their benefits and challenges, capital, and Operational and Maintenance (O&M) costs.
- Providing the City and the developer with multiple cost-effective and technically feasible treatment technology alternatives that can achieve the City's drinking water quality standards while meeting the associated residuals disposal requirements.

This Water Technology Assessment Report focuses on the evaluation of centralized treatment technologies that are applicable for the City's water supply facilities, assuming there is no treatment avoidance alternative available to provide reliable and safe drinking water. Proper selection of source water and optimization of the well design should be evaluated to avoid treatment if possible. This may include proper casing and sleeving designed to limit production from specific areas of the aquifer with associated water quality concerns. Readers can refer to Appendix A - EPA Arsenic Treatment Technology Evaluation Handbook Small Systems (July 2003) for a summary of potential non-treatment alternatives (Decision Tree 1). Although this document was intended to help small drinking water systems (<1.4 mgd) make treatment decisions to comply with the revised arsenic rule, the procedures considering or excluding the non-treatment alternatives can also apply to the City's water supply facilities.

1.2 General References

The following documents were used as reference when developing the Water Technology Assessment Report:

- City of Surprise Documents:
  - Integrated Water Master Plan - Water Infrastructure (July 2009, Final Report, Malcolm Pirnie, Inc.)
  - Integrated Water Mater Plan - Water Resources (November 2008, Final Report, Malcolm Pirnie, Inc.)
  - Engineering Development Standards (2009, City of Surprise)
  - City of Surprise Water Quality Data including well completion reports and various water quality monitoring data (1999-2009)
  - Water and Wastewater Facility Guidelines (September 2010, Carollo Engineers)
- Drinking Water Regulations:
  - U.S. Environmental Protection Agency (USEPA) Regulations and Arizona Department of Environmental Quality (ADEQ) Drinking Water Regulations
    - Primary and Secondary Drinking Water Regulations
    - Lead and Copper Rule (1992)
    - Total Coliform Rule (1989)
    - Radionuclides Rule (2009)
    - Unregulated Contaminant Monitoring Rule (1999)

    - Unregulated Contaminant Monitoring Rule 2 (2006)
    - Arsenic Rule (2001)
    - Sulfate Health Affect Study (Pending)
    - Radon Rule (Pending)
    - Total Coliform Rule Review (Pending)
    - Aesthetic Requirements
    - Surface Water Treatment Rule (1990)
    - Interim Enhanced Surface Water Treatment Rule (2001)
    - Stage 1 Disinfectant / Disinfectant Byproduct (D/DBP) Rule (Stage 1 D/DBPR) (2002)
    - Long Term 2 Enhances Surface Water Treatment Rule (2005)
    - Stage 2 Disinfectant / Disinfectant Byproduct (D/DBP) Rule (Stage 2 D/DBPR) (2005)
    - Filter Backwash Rule (2001)
    - Groundwater Rule (2009)
    - Groundwater Under the Direct Influence of Surface Water (2006)
    - Arizona Administrative Code Notice of Final Rulemaking Title 18: Environmental Quality
    - Title 40: Protection of Environment 142.60 through 142.63 - National Primary Drinking Water Regulations Implementation Subpart G - Identification of Best Technology, Treatment Techniques or Other Means Generally Available
    - Title 40: Protection of Environment 142.201 Subpart Q - Public Notification of Drinking Water Violations
    - USEPA Revised Public Notification Handbook (2007)
    - USEPA The Standardized Monitoring Framework: A Quick Reference Guide (2004)
    - USEPA 2006 Edition of the Drinking Water Standards and Health Advisories (2006)

- Other References:
  - Carollo Research Group Drinking Water Regulation Review Documents
  - City of Phoenix Western Canal WTP Master Plan (2006)
  - City of Phoenix Water Quality Master Plan Update (2005)
  - City of Phoenix Lake Pleasant Water Quality Sampling and Testing Study Phase II-A Report (2001)
  - Central Arizona Salinity Study Phase II Report Appendix C: Appraisal Level Study of A Brackish Water Treatment Plant, City of Goodyear, Arizona, (CASS, 2005)
  - United States Code of Federal Regulations, Title 40 Protection of the Environment

- Appendix B: Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, Final Rule (USEPA, 2002)
- Drinking Water Standards and Health Advisories (USEPA 2006)
- Technologies and Costs for Removal of Arsenic from Drinking Water (USEPA 2000)
- City of Scottsdale Water Master Plan (2008)
- Town of Gilbert Surface Water Treatment Plant Expansion Study (1999)
- City of Yuma Water Quality Management Plan (2005)
- City of Mesa Water Master Plan (2004)
- City of Chandler Water Master Plan Update (2008)
- Arizona Water Company Valley Vista Well Head Arsenic Treatment Facility Preliminary Design Report (2008)
- Salt River Pima Maricopa Indian Community Zone 2 Arsenic Treatment Technical Memorandum (Final, 2006)
- South Tahoe Arrowhead Arsenic Removal Engineering Report (2008)
- Town of Gilbert Turner Ranch Arsenic Removal Project Report (2005)
- Case Study - Arsenic Treatment Technologies Scottsdale, AZ (2003)
- Case Study - Arsenic Treatment Technologies Tucson, AZ (2003)
- Cost Estimating Manual for Water Treatment Facilities (2008)

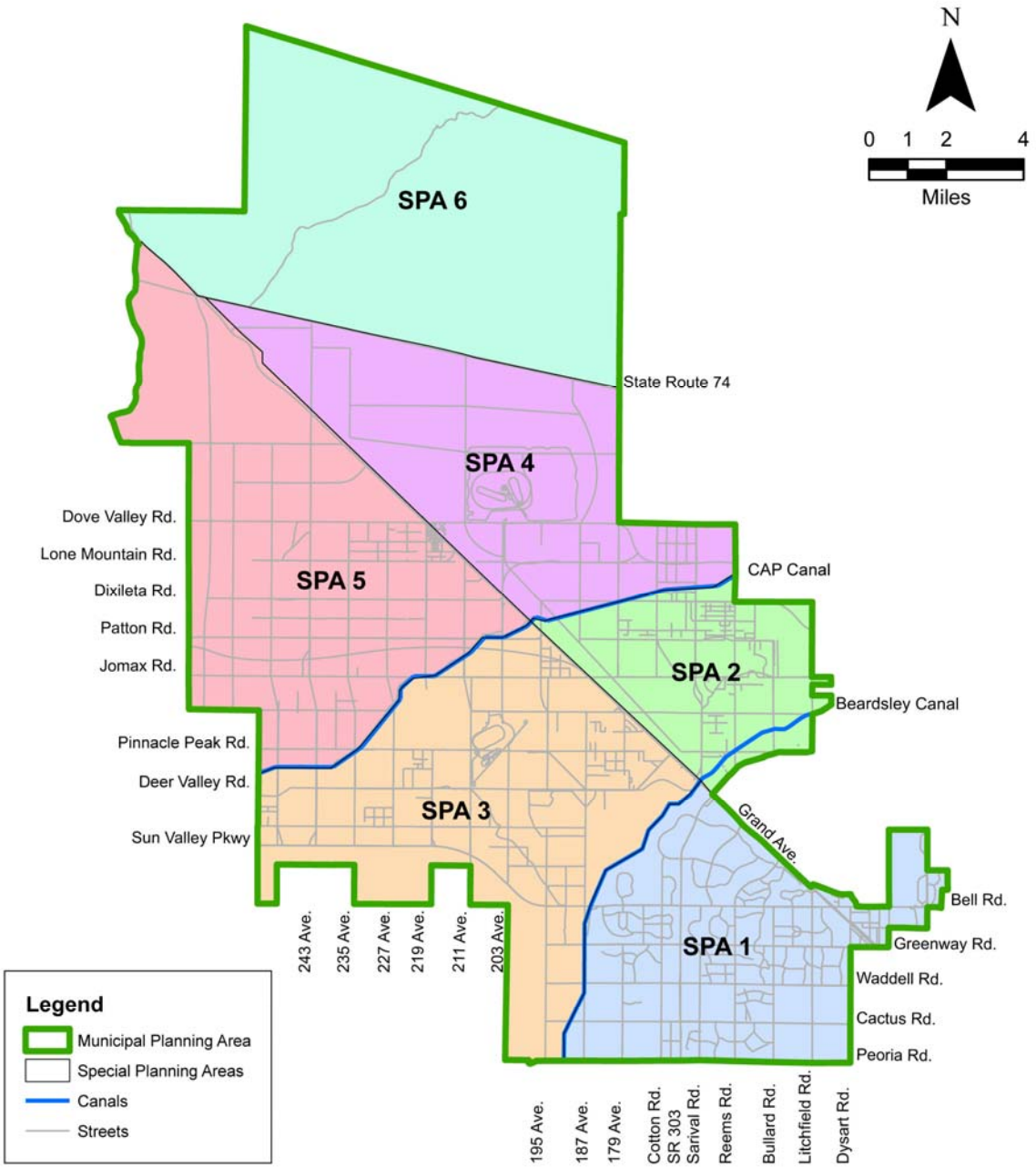
2.0 PLANNING INTERFACE AND STUDY AREA DOCUMENTATION

2.1 Integrated Water Master Plan

The City of Surprise Integrated Water Master Plan (IWMP) - Water Infrastructure (2009, Final), and IWMP - Water Resources (2008, Final) define the City's current and future water system boundaries. These documents provide a master planning interface and platform for the Water Technology Assessment Report. This section summarizes the IWMP conclusions directly and indirectly associated with this project.

2.2 Current and Future Water Supply Facilities

The City of Surprise is divided into six special planning areas (SPAs), as shown in Figure WT.1. Figure WT.2 illustrates the locations of the existing water supply facilities within SPA 1 and SPA 2. The capacity of each water production well is shown in Table WT.1, while the location and water supply facility (WSF) capacity are outlined in Table WT.2.

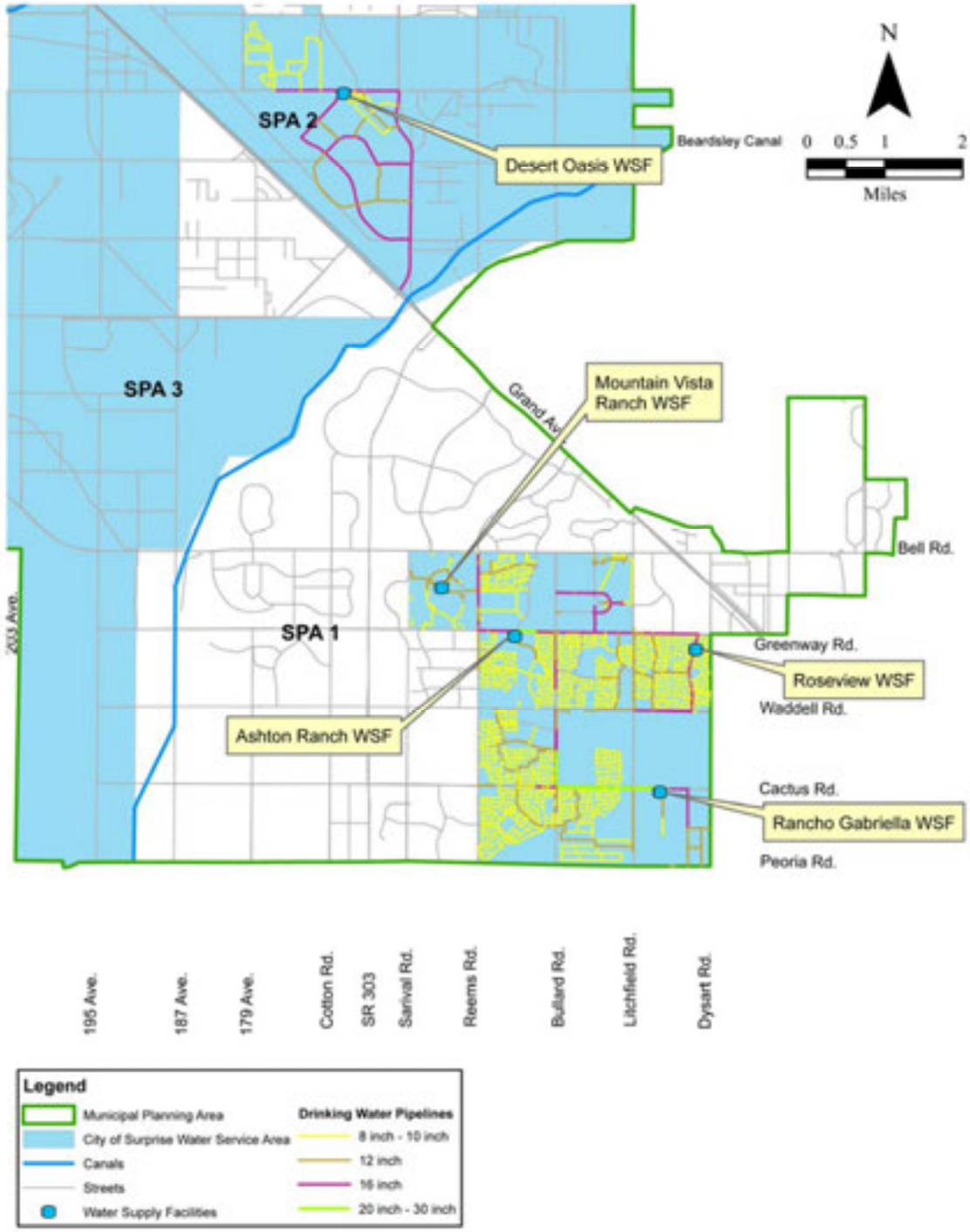


Note: Figure data adapted from Figure 1-1 in the IWMP-Water Infrastructure (Final 2009)

STUDY AREA

FIGURE WT.1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT



Note: Figure data adapted from Figure 3-3 in the IWMP-Water Infrastructure (Final 2009)

EXISTING DRINKING WATER INFRASTRUCTURE

FIGURE WT.2

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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Table WT.1 Groundwater Production Wells Water Technology Assessment Report City of Surprise				
		Well Capacity		Permitted Well Capacity[2]
Site Name	Status	(gpm)	(mgd)	(acre/foot)
SPA 1				
Mountain Vista Ranch WSF				
Mountain Vista Ranch 1	Existing	1,260	1.81	2,015.00
Mountain Vista Ranch 2	Planned	TBD	TBD	-
Ashton Ranch WSF				
Ashton Ranch 1	Existing	1,180	1.70	3,064.00
Orchards	Existing	1,780	2.56	4,816.44
City of Surprise Well	Existing	1,700	2.45	1,460.00
Royal Ranch	Existing	1,470	2.12	1,872.00
Sierra Verde	Existing	1,270	1.83	893.40
Future	Planned	TBD	TBD	-
Future	Planned	TBD	TBD	-
Roseview WSF				
Roseview	Existing	1,900	2.74	839.00
Litchfield Manor	Existing	800	1.15	710.20
Rancho Gabriela WSF				
Rancho Gabriela 1	Existing	1,250	1.80	1,290.00
Rancho Gabriela 2	Existing	1,270	1.83	971.40
Marley Park 1	Existing	1,150	1.66	4,032.00
Marley Park 2	Planned	TBD	TBD	-
Marley Park 3	Planned	TBD	TBD	-
Marley Park 4	Planned	TBD	TBD	-
Surprise Point	Planned	TBD	TBD	-
Nitta /Cyburt Hall	Planned	TBD	TBD	-
Future	Planned	TBD	TBD	-
Future	Planned	TBD	TBD	-
SPA 2				
Desert Oasis WSF				
Desert Oasis 1	Existing	1,400	2.02	702.00
Desert Oasis 2	Existing	1,280	1.84	702.00
Desert Oasis (Lancer)	Planned	TBD	TBD	-

Table WT.1 Groundwater Production Wells Water Technology Assessment Report City of Surprise				
		Well Capacity		Permitted Well Capacity[2]
Site Name	Status	(gpm)	(mgd)	(acre/foot)
Asante WSF [2]				
Asante 1	Planned	TBD	TBD	-
Asante 2	Planned	TBD	TBD	-
Asante 3	Planned	TBD	TBD	-
Asante 4	Planned	TBD	TBD	-

Notes:
(1) Data adapted from Table 3-1 in the IWMP-Water Infrastructure (FINAL 2009).
(2) Additional information provided by the City, which was not included in the IWMP-Water Infrastructure (FINAL 2009).

Table WT.2 Existing Water Supply Facilities Water Technology Assessment Report City of Surprise				
Water Supply Facility	Address	SPA	Maximum Capacity (mgd)	Approx. Service Area (sq. miles)
Mountain Vista Ranch	15951 W. Tasha Drive	1	8.6	1
Ashton Ranch	15151 W Greenway Road	1	7.5	4
Roseview	13280 W Country Gables Drive	1	6.5	1
Rancho Gabriela	12116 W 136th Avenue	1	10.8	6
Desert Oasis	16849 W Jomax Road	2	10.8	1

Note:
(1) Data adapted from Table 3-3 in the IWMP-Water Infrastructure (FINAL 2009).

Currently, only SPA 1 and SPA 2 are serving drinking water to existing developments. Each WSF consists of centralized treatment, storage, and distribution associated with between one and five production wells. General water quality data has been collected for the individual well sites. Water quality data used in the IWMP is discussed in Section 5.0 of this document.

As the City continues to expand, the IWMP recommended that water demands be met through a combination of additional well water supply and a larger, interconnected water supply system. The larger, interconnected system is proposed to include 13 new water supply facilities, in addition to improvements to the existing water supply facilities in SPA 1 and SPA 2. Each new water supply facility will be equipped with new groundwater wells, well transmission pipelines, storage tanks and booster stations, one off-site storage

reservoir, 4 inline booster stations, and additional distribution system pipelines. The master plan assumed that each new well had a capacity of approximately 1,500 gpm and that treatment would be required for contaminants present above 70 percent of the maximum contaminant level (MCL). These water supply facilities, as well as the associated distribution system improvements required to meet future demands, are illustrated in Figure WT.3 and Figure WT.4, respectively. Table WT.3 outlines the projected drinking water demands for the six SPAs. This information provides the preliminary basis for the water technology assessment.

Table WT.3 Drinking Water Demand Projections
Water Technology Assessment Report
City of Surprise

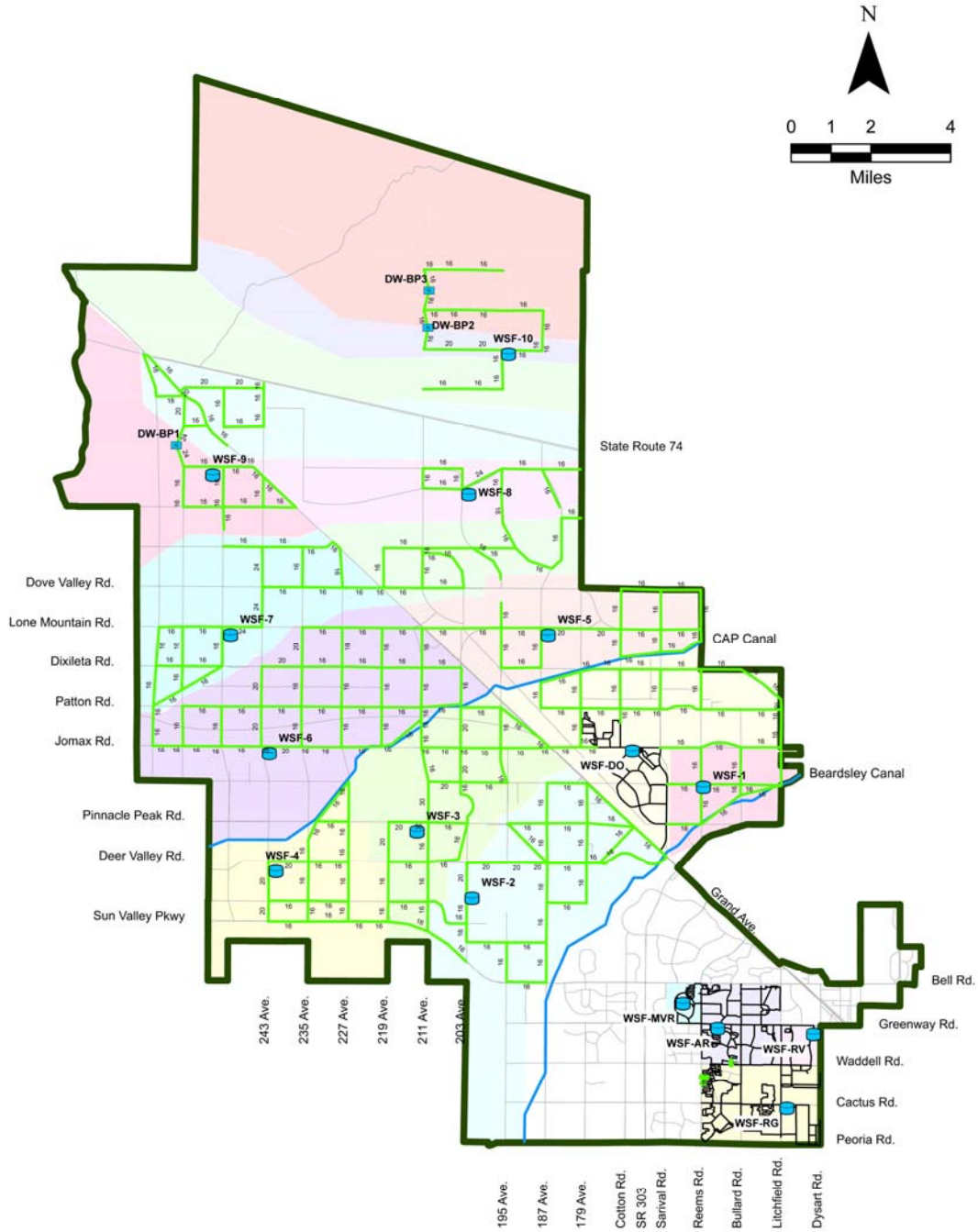
	Drinking Water Demand	
SPA	**2020 (mgd)**	**Buildout (mgd)**
1	7.3	8.8
2	4.8	13.7
3	9.5	28.0
4	3.5	19.1
5	6.4	23.6
6	0.5	16.3
Totals	**32**	**109.5**

Note:
(1) Data adapted from Table 7-1 in the IWMP-Water Infrastructure (FINAL 2009).

As part of this project, significant data gap was identified for the City's drinking water sources. There are currently no water supply facilities in SPAs 3, 4, 5, or 6 and very sparse water quality data for the water sources in these SPAs. The available water quality data outlined as a part of this report are primarily representative of the water quality for SPA 1 and SPA 2, and may not necessarily represent the entire City of Surprise future service area. The limited water quality information for these future sources posed a challenge to the development of the technology assessment. The technology assessment approach implemented for this project had to be capable of addressing this challenge.

2.2.1 Water Supply Alternatives Evaluation

The IWMP evaluated four specific drinking water infrastructure alternatives. The alternatives were selected with consideration for the source of the drinking water (all groundwater or a groundwater and surface water blend), the spacing of Water Supply Facilities (smaller service areas vs. larger, interconnected service areas), and potential Central Arizona Project (CAP) water recharge locations (local City-owned or regional).



Legend

- Municipal Planning Area
- Service Areas
- Canals
- Streets
- Water Supply Facilities
- Distribution System Booster Stations

Distribution System Pipelines

- Existing
- 2009 - 2020 (New)
- 2009 - 2020 (Improved)

NEAR TERM (2009 – 2020) DRINKING WATER INFRASTRUCTURE IMPROVEMENTS

Note: Figure data adapted from Figure 7-4 in the IWMP-Water Infrastructure (Final 2009)

FIGURE WT.3

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WATER TECHNOLOGY ASSESSMENT REPORT

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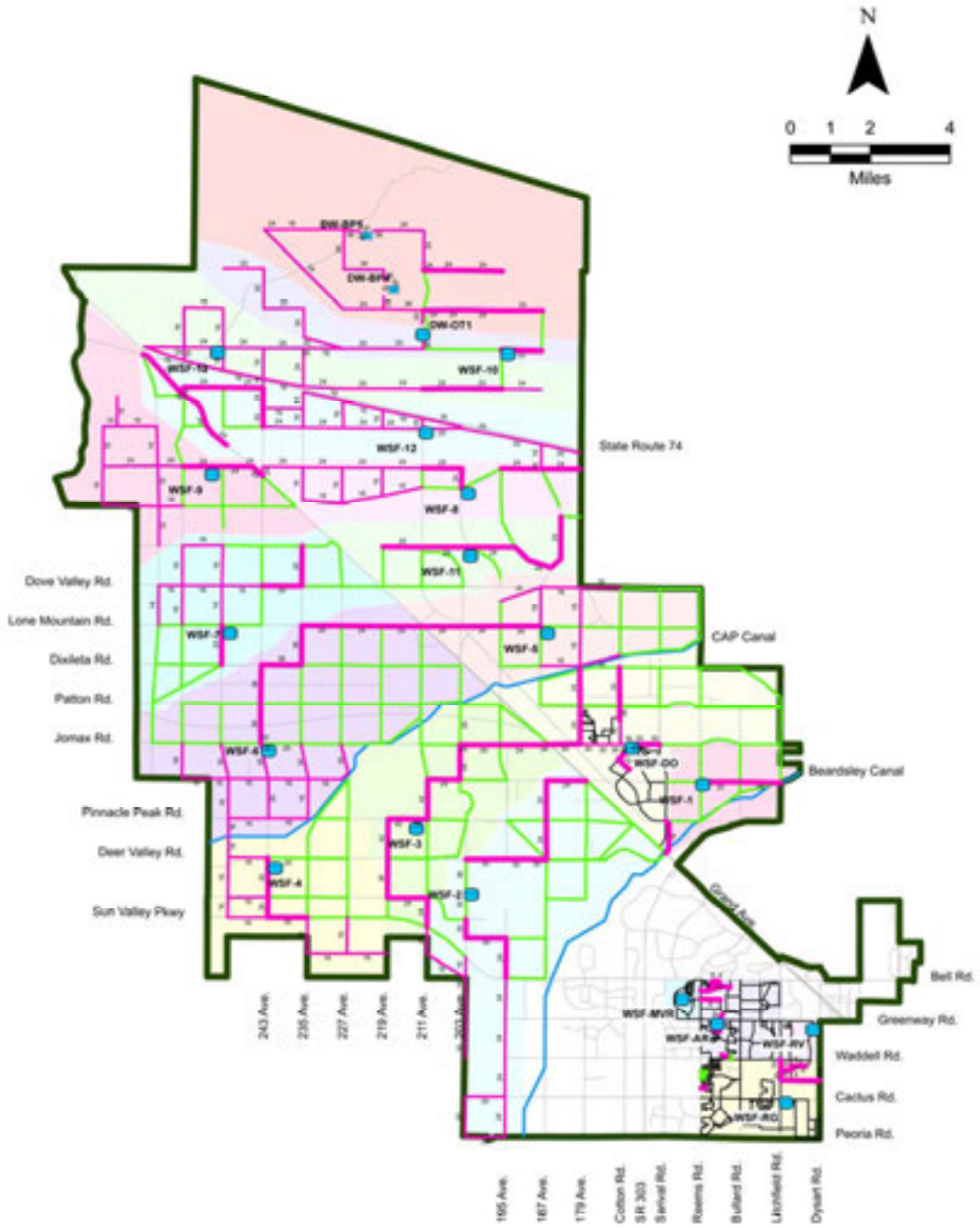

Legend

- Municipal Planning Area
- Service Areas
- Canals
- Streets
- Water Supply Facilities
- Distribution System Booster Stations

Distribution System Pipelines

- Existing
- 2009 - 2020 (New)
- 2009 - 2020 (Improved)
- 2021 - Build-out (New)
- 2021 - Build-out (Improved)

LONG TERM (2021 – BUILD-OUT) DRINKING WATER INFRASTRUCTURE IMPROVEMENTS

Note: Figure data adapted from Figure 7-5 in the IWMP-Water Infrastructure (Final 2009)

FIGURE WT.4

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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Based on a comparison of the alternatives, the IWMP recommended an all groundwater supply with fewer water supply facilities and a larger interconnected system. This alternative provided the following benefits:

- The lowest capital, operation and maintenance (O&M), and total present worth costs because fewer production wells, water supply facilities (reservoirs, booster stations, and arsenic treatment facilities), and City recharge facilities were required.
- The Central Arizona Water Conservation District (CAWCD) has already built affordable capacity for recharging CAP allocations. Based on the City's recent agreement with CAWCD, the CAWCD has the flexibility to recharge the City's CAP water at any of three facilities: the Tonopah, Hieroglyphic Mountains, and Agua Fria Recharge Facilities. Water banking options are available, which could allow the City to replenish the groundwater supply using its CAP water allocations.
- This alternative did not preclude the construction of a CAP Water Treatment Plant (WTP) in the future. That is, the decision of whether to build a CAP WTP can be deferred to future updates of the IWMP when additional information may promote more informed decision making.

2.2.2 Current Water Treatment Strategies and Practices

As described above, the City currently utilizes groundwater as its primary drinking water source. Groundwater is pumped from wells throughout the service area and delivered to water supply facilities for storage, treatment, and distribution. Groundwater is currently disinfected using either tablet chlorination processes or a sodium hypochlorite solution prior to distribution. The City has historically utilized tablet chlorination processes to disinfect water at its water supply facilities. However, in recent years the City has begun replacing the tablet systems with on-site sodium hypochlorite generation systems.

The City's groundwater has elevated levels of arsenic, nitrate, and/or fluoride. While the City does not currently treat for fluoride or nitrate, several wells have fluoride levels approaching or slightly above the City and state fluoride MCL. For those wells that exceed the MCL, the City currently uses blending as a means of compliance.

To address elevated arsenic levels, the City has utilized direct filtration with ferric chloride at two WSFs (Rancho Gabriela WSF and Ashton Ranch WSF), along with a temporary installation at the Desert Oasis WSF and recently completed the construction of one additional facility using this technology for the Asante WSF. The construction of an arsenic adsorption system using granular ferric oxide was recently completed at the Roseview WSF. Arsenic treatment facilities are typically designed for split-stream treatment such that the final blended arsenic concentration is below the target concentration. The City currently designs arsenic treatment facilities to treat the average day demand. In order to prevent the treatment capacity from limiting the WSF production capacity, the IWMP recommends that treatment facilities be sized to treat the maximum day demand.

The IWMP - Water Infrastructure Report has preliminarily identified arsenic, nitrate, and fluoride as Constituents of Concern (CoC). This Water Technology Assessment Report reviews available groundwater quality data, validates the CoC list, and analyzes technologies that can address these CoC.

2.3 Study Area Boundaries and Constraints

The IWMP established the groundwork for the development of this Water Technology Assessment Report. Recommendations from the IWMP are incorporated directly and used to establish criteria for the technology assessment. Data contained in the IWMP is validated to confirm that the parameters used in the technology assessment are accurate and consistent with the established goals of the City. Based on information presented in the IWMP, the following project constraints have been adopted as part of this Water Technology Assessment Report:

- The focus period for the technology assessment is approximately the next five to ten years. It is anticipated that this document will be reviewed and updated every five to ten years (in conjunction with the IWMP) to address changing growth patterns, regulations, treatment technologies, capital and O&M costs, etc.
- The technology assessment assumes the City will be treating groundwater supplies only. Surface water treatment will not be evaluated, as the City does not foresee surface water treatment in the near future (i.e., for the next five to ten years).
- The technology assessment is based on the available water quality. The conclusions can be interpolated to new sources with similar water qualities using the drinking water treatment technology assessment model developed for this project (see Section 7.0). Various issues, including the regional groundwater salinity and groundwater recharge / pumping around the City, could potentially impact the City's groundwater quality and quantity in the future. However, it is expected such adverse impacts would not occur in the near term (i.e., the next five to ten years).
- The IWMP will be updated every five years to reflect changes in water sources (both quantity and quality) and water treatment facilities and infrastructure. Changes to the IWMP may affect the validity of technology assessment results. Therefore, as noted above, it is recommended that the Water Technology Assessment Report be reviewed and updated following each IWMP update. This approach will allow the City to improve the accuracy of planning and budgeting associated with water treatment facilities and infrastructure.
- The proposed capacity range of each WSF impacts the results of the technology assessment. For example, a technology may be more economical at smaller scale (i.e., less than 1 mgd) than at larger scale and vice versa. Such factors should be considered in the treatment technology selection. The IWMP identified water supply facilities of varying capacities are necessary to meet the City's future needs. These capacities will be used directly as part of the technology assessment.

- The technology assessment focuses on treatment technologies required to address the validated CoC (nitrate, arsenic, and fluoride). Refer to Section 5.0 for more discussion).

In summary, this Water Technology Assessment Report will build on the master planning platforms established in the 2009 IWMP.

It should be noted that the City is currently developing a list of preferred equipment manufacturers. This information will be included in the appendices of this report when available.

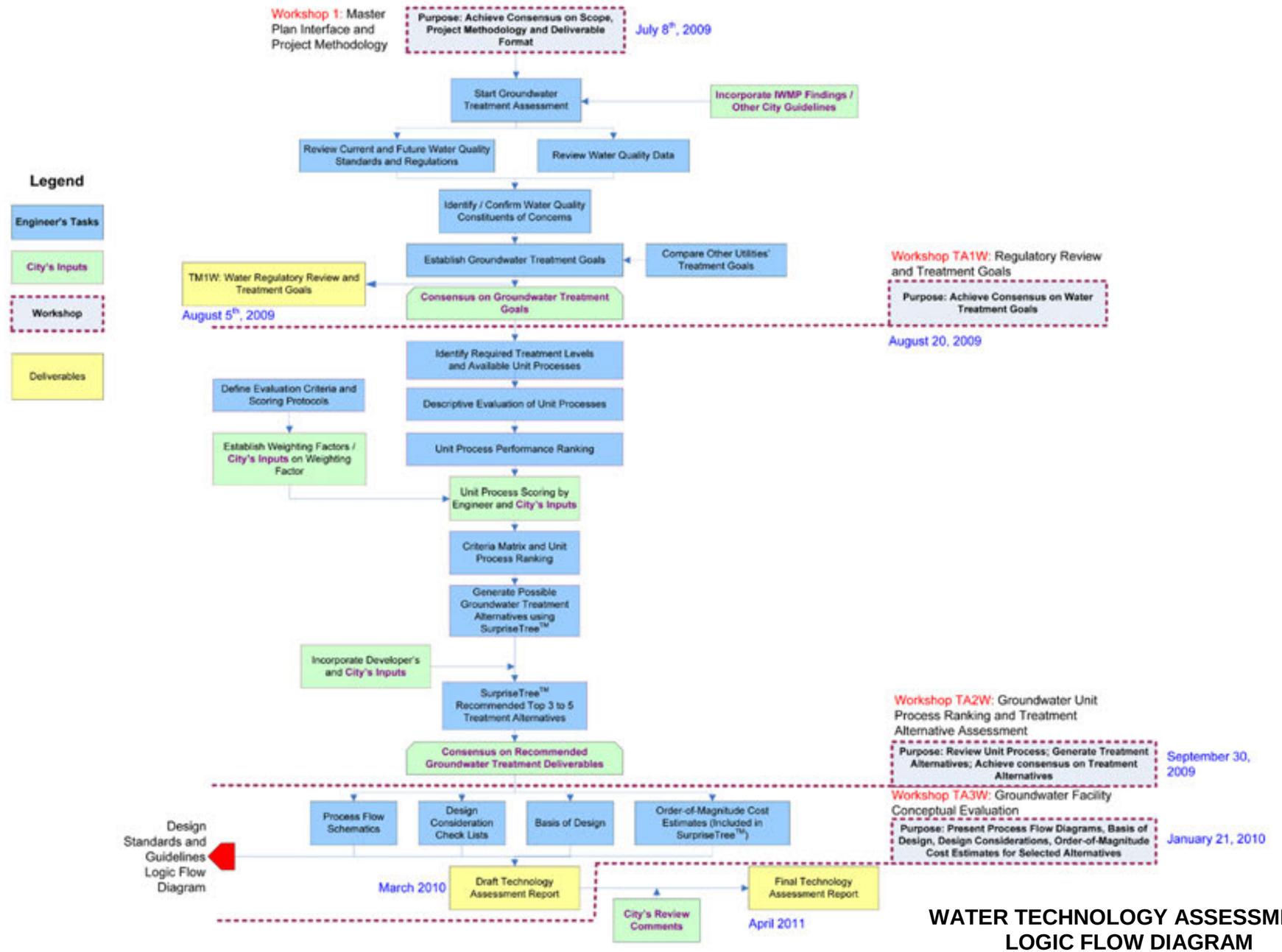
2.4 Project Methodology Overview

The subsequent sections of this report present the methodology for the technology assessment. The methodology proposed to meet the City's current and near future needs is systemic, as illustrated in the logic flow diagram outlined in Figure WT.5. The Water Technology Assessment logic flow diagram was presented at Workshop 1 - Project Methodology and Master Plan Interface, held on July 8, 2009. As part of the workshop, the project team agreed on the proposed tasks and the strategy for completing the technology assessment.

The logic flow diagram includes an overview of the primary tasks associated with the water technology assessment. It outlines the order of tasks, how the results from individual tasks relate directly and indirectly to other tasks, and how the individual tasks results incorporate into the final report. As illustrated in the logic flow diagram, input from the City is critical at several key points during the assessment.

The logic flow diagram was revised to reflect changes in project deliverable format and progressing timeline. Such changes were necessary to help achieve consensus between the City and the developer representative and to assist in overcoming the project challenges associated with limited water quality data and site-specific conditions.

In short, the technology assessment began with a drinking water regulatory review and establishment of the City's water quality treatment goals (presented in Section 3.0). This was performed in parallel with a review of available water quality data for the City's water sources (see Section 5.0). Through comparing the water quality data and the treatment standards, water quality CoC and levels of treatment required to address these CoC were identified (see Section 4.0).



WATER TECHNOLOGY ASSESSMENT LOGIC FLOW DIAGRAM

FIGURE WT.5

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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Section 6.0 presents the prescreened treatment technology alternatives, which were evaluated for each level of treatment. This evaluation addressed questions for each technology including what it is, what it does, how it works, and what are the pros and cons. The technology alternatives were then compared in tabular format and ranked using evaluation matrixes. The evaluation matrixes utilized a set of evaluation criteria developed by the City staff and developer representatives. Nine individuals (City and developer) participated in assigning weighting factors for these criteria. The averaged weighting factors were used for the final ranking evaluation.

A conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges associated with the unknown water quality for the future City's water sources. To provide the City with a useful tool that can assess available treatment alternatives for a given set of water quality inputs and site-specific conditions (such as present CoC, competitive ions, facility size), the team developed an innovative approach. The core of this approach is an advanced macro-based Excel model called SurpriseTree™ Water. A copy of this model is located on a CD attached with this report. Refer to Section 7.0 for detailed descriptions regarding how the model works and how/when it should be used.

Using SurpriseTree™ Water, the results of the technology alternative assessment represent a dynamic and customized solution, which automatically responds to the water quality and site-specific condition inputs for future facilities. Through incorporating the City's institution and technical knowledge, the model was "calibrated" and improved to better represent potential future conditions.

The Water Technology Assessment Report aims at providing the City and the developer useful planning level design information for the most common treatment alternatives to be implemented at the City's future WSFs. These treatment alternatives are viable options for the City's facilities, considering their technical feasibility and cost effectiveness. Process flow diagram, basis of design, and design considerations were developed for each of the selected treatment alternatives. This information is presented in Section 7.0.

3.0 WATER QUALITY STANDARDS AND REGULATORY REQUIREMENTS

This section reviews and summarizes the current, pending, and future rules and regulations associated with drinking water quality. Both groundwater and surface water regulations are discussed to provide a complete review of drinking water quality regulations.

3.1 Water Supply and Distribution System Regulations

This section presents the current, pending (short-term), and future (long-term) water quality regulations for both surface water and groundwater supply and/or distribution systems. The section outlines the following regulations:

- Current Regulations:
  - Primary and Secondary Maximum Contaminant Levels (MCLs and SMCLs)
  - Lead and Copper Rule (LCR)
  - Total Coliform Rule (TCR)
  - Radionuclide Rule
  - Unregulated Contaminant Monitoring Rule (UCMR)
  - Arsenic Rule
- Pending Regulation:
  - Sulfate Health Effect Study
  - Radon Rule
  - TCR Revisions
  - Pending Regulations on Distribution System Water Quality Changes
- Future Regulations
  - Emerging Inorganic and Organic Contaminants
    - Endocrine Disrupting Compounds (EDCs), Pharmaceuticals and Personal Care Products (PPCPs)
  - Hexavalent Chromium
  - Perchlorate
  - MTBE
  - Contaminant Candidate List (CCL)
  - Emerging Pathogens
- Aesthetic Considerations
  - Taste and Odor
  - Hardness
  - Total Dissolved Solids
  - Color

The best available technologies (BAT), treatment techniques (TT), or other means identified in the Safe Drinking Water Act are also reviewed in Section 3.4, with a focus on the potential CoC for the City's water supply.

3.1.1 Current Regulations

3.1.1.1 Primary Maximum Contaminant Levels

For most contaminants, USEPA sets a health goal (based solely on human health considerations) and/or a legal limit. The health goal is quantified as a Maximum Contaminant Level Goal (MCLG). At this level, a person can drink two liters of water containing the contaminant every day for 70 years without incurring any unacceptable health effects due to the contaminant. Water systems are not legally required to meet MCLGs. For known carcinogens, USEPA sets the MCLG at zero, assuming that any exposure to a cancer-causing agent presents a cancer risk.

Enforceable legal limits are specified in most rules as MCLs. USEPA strives to set MCLs as close to health goals as is practical, considering technical and financial challenges. The primary drinking water standards current MCLs for Microorganisms, Disinfection Byproducts, Disinfectants, Inorganic Chemicals, Organic Chemicals, and Radionuclides are listed in Table WT.4. For some contaminants, a proven treatment technique (TT) is specified as part of the rule in place of an MCL in order to reduce the contaminant level in drinking water while minimizing the financial and monitoring requirement burden on utilities.

Table WT.4 National Primary Drinking Water Standards Maximum Contaminant Levels
Water Technology Assessment Report
City of Surprise

	USEPA	
Contaminant	**MCLG(1) (mg/L(2))**	**MCL or TT(1) (mg/L(2))**
Microorganisms		
Cryptosporidium	0	TT(3)
Giardia lamblia	0	TT(3)
Heterotrophic plate count	--	TT(3)
Legionella	0	TT(3)
Total Coliforms	0	5.0% samples positive in a month (4)
Turbidity	--	TT(3)
Viruses	0	TT(3)
Disinfection Byproducts		
Bromate	0	0.10
Chlorite	0.8	1.0
Total haloacetic acids	--	0.060
Total trihalomethanes	--	0.080
Organic Contaminants		
Acrylamide	0	TT(5)
Alachlor	0	0.002
Atrazine	0.003	0.003
Benzene	0	0.005

Table WT.4 National Primary Drinking Water Standards Maximum Contaminant Levels Water Technology Assessment Report City of Surprise		
	USEPA	
Contaminant	MCLG[1] (mg/L[2])	MCL or TT[1] (mg/L[2])
Benzo(a)pyrene	0	0.0002
Carbofuran	0.04	0.04
Carbon Tetrachloride	0	0.005
Chlordane	0	0.002
Chlorobenzene	0.1	0.1
2,4-D	0.07	0.07
Dalapon	0.2	0.2
1.2-Dibromo-3-chloropropane	0	0.0002
o-Dichlorobenzene	0.6	0.6
p-Dichlorobenzene	0.075	0.075
1,2-Dichloroethane	0	0.005
1,1-Dichloroethylene	0.007	0.007
cis-1,2-Dichloroethylene	0.07	0.07
trans-1,2-Dichloroethylene	0.1	0.1
Dichloromethane	0	0.005
1,2-Dichloropropane	0	0.005
Di(2-ethylhexyl) adipate	0.4	0.4
Di(2-ethylhexyl) phthalate	0	0.006
Dinoseb	0.007	0.007
Dioxin	0	0.00000003
Diquat	0.02	0.02
Endothall	0.1	0.1
Endrin	0.002	0.002
Epichlorohydrin	0	TT[5]
Ethylbenzene	0.7	0.7
Ethylene Dibromide	0	0.00005
Glyphosate	0.7	0.7
Heptachlor	0	0.0004
Heptachlor Epoxide	0	0.0002
Hexachlorobenzene	0	0.001
Hexachlorocyclopentadiene	0.05	0.05
Lindane	0.0002	0.0002
Methoxychlor	0.04	0.04
Oxamyl	0.2	0.2
Polychlorinated Biphenyls	0	0.0005
Pentachlorophenol	0	0.001
Picloram	0.5	0.5

Table WT.4 National Primary Drinking Water Standards Maximum Contaminant Levels Water Technology Assessment Report City of Surprise		
	USEPA	
Contaminant	**MCLG(1) (mg/L(2))**	**MCL or TT(1) (mg/L(2))**
Simazine	0.004	0.004
Styrene	0.1	0.1
Tetrachloroethylene	0	0.005
Toluene	1	1
Toxaphene	0	0.003
2,4,5-TP (Silvex)	0.05	0.05
1,2,4 Trichlorobenzene	0.07	0.07
1,1,1-Trichloroethane	0.20	0.2
1,1,2-Trichloroethane	0.003	0.005
Trichloroethylene	0	0.005
Vinyl chloride	0	0.002
Xylenes	10	10
Inorganic Chemicals		
Antimony	0.006	0.006
Arsenic	0	0.010
Asbestos	7 MFL(7)	7 MFL(7)
Barium	2	2
Beryllium	0.004	0.004
Cadmium	0.005	0.005
Chromium	0.1	0.1
Copper	1.3	TT(6)
Cyanide	0.2	0.2
Fluoride	4.0	4.0
Lead	0	TT(6)
Mercury	0.002	0.002
Nitrate (as N)	10	10
Nitrite (as N)	1	1
Selenium	0.05	0.05
Thallium	0.0005	0.002
Radionuclides		
Uranium	0	30 µg/L
Ra-226 & Ra-228	0	5 pCi/L
Gross α particle activity	0	15 pCi/L
Gross ß particle activity	0	4 millirem/yr

Table WT.4 National Primary Drinking Water Standards Maximum Contaminant Levels
Water Technology Assessment Report
City of Surprise

Disinfectants	MRDLG(1) (mg/L(2))	MRDL(1) (mg/L(2))
Chloramines (as Cl_2)	4.0	4.0
Chlorine (as Cl_2)	4.0	4.0
Chlorine dioxide (as Cl_2)	0.8	0.8

Notes:

(1) Definitions:
Maximum Contaminant Level (MCL) – The highest level of a contaminant that is allowed in drinking water. MCLs are enforceable standards.
Maximum Contaminant Level Goal (MCLG) – The level of a contaminant in drinking water below which there is no known or expected risk to health. MCLGs allow for a margin of safety and are non-enforceable public health goals.
Maximum Residual Disinfectant level (MRDL) – The highest level of a disinfectant allowed in a drinking water.
Maximum Residual Disinfectant Level Goal (MRDLG) – The level of a drinking water disinfectant below which there is no known or expected risk to health.
Treatment Technique (TT) – A required process intended to reduce the level of a contaminant in drinking water.

(2) Units are in milligrams per liter (mg/L) unless otherwise noted.

(3) USEPA's SWTRs require systems using surface water or groundwater under the direct influence of surface water to (1) disinfect their water; and (2) filter their water or meet criteria for avoiding filtration so that the following contaminants are controlled at the following levels:
Cryptosporidium: 99% removal
Giardia lamblia: 99.9% removal/inactivation
Viruses: 99.99% removal/inactivation
Legionella: No limit, but USEPA believes that if *Giardia* and viruses are removed/inactivated, *Legionella* will also be controlled.
Turbidity: At no time can turbidity (cloudiness of water) go above 5 NTU; systems that filter must ensure that the turbidity go no higher than 1 NTU (0.5 NTU for conventional or direct filtration) in at least 95% of the daily samples in any month; turbidity may never exceed 1 NTU, and must not exceed 0.3 NTU in 95% of daily samples in any month.
HPC: No more than 500 bacterial colonies/mL.

4) More than 5.0% samples total coliform-positive in a month. For water systems that collect fewer than 40 routine samples/month, no more than 1 sample can be total coliform-positive per month. Every sample that has total coliform (TC) must be analyzed for either fecal coliforms or *Escherichia coli* if two consecutive TC-positive samples, and one is also positive for *E.col*i fecal coliforms system has an acute MCL violation.

(5) Each water system must certify, in writing, to the state (using third-party or manufacturer's certification) that when acrylamide and epichlorohydrin are used in drinking water systems, the combination (or product) of dose and monomer level does not exceed the levels specified, as follows:
- Acrylamide = 0.05% dosed at 1 mg/L (or equivalent)
- Epichlorohydrin = 0.01% dosed at 20 mg/L (or equivalent)

(6) Lead and copper are regulated by a Treatment Technique that requires systems to control the corrosiveness of their water. If more than 10% of tap water samples exceed the action level, water systems must take additional steps. For copper, the action level is 1.3 mg/L, and for lead is 0.015 mg/L.

(7) MFL = million fibers per liter, with fiber length >10 µm.

ADEQ Rules Update **-** Because the State of Arizona has primacy in drinking water regulations, public water systems must comply with ADEQ regulations, as well as USEPA regulations. ADEQ revised the state rules to incorporate the federal rules by reference and currently references the 40 Code of Federal Regulations (CFR) 141 July 1, 2007 version of the regulation.

ADEQ originally proposed this rulemaking for the purpose of maintaining primary enforcement authority of the Safe Drinking Water Act ("Act") for public water systems in Arizona, pursuant to Section 1413 of the Act and 40 CFR Part 142, Subpart B, the rules concerning state implementation. Arizona was initially granted primacy for the Act in 1978. Since that time, Arizona maintained primacy and periodically revised its drinking water rules in 18 A.A.C. 4 to keep its rules consistent with USEPA's National Primary Drinking Water Regulations in 40 CFR Part 141 until they were incorporated in 2005.

ADEQ believes that another benefit of the incorporation by reference is facilitated use of guidance documents USEPA creates for its drinking water rules, due to the parallel format of the state and federal rules.

This rulemaking also adopts a number of new federal drinking water rules into 18 A.A.C. 4, including the Radionuclides, Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring, Filter Backwash Recovery, Long Term 1 Enhanced Surface Water Treatment, Long Term 2 Enhanced Surface Water Treatment, Lead and Copper, Stage 1 Disinfection/Disinfection Byproducts, and Stage 2 Disinfection/Disinfection Byproducts Rules. The new rules were finalized near the end of 2005.

Applicability of MCLs to City of Surprise:

The City of Surprise existing and future water supply facilities must meet, at a minimum, all MCLs. The City's original intent was to adopt more stringent treatment standards on certain CoC to allow reasonable operational variations. The IWMP-Water Infrastructure Report listed a treatment goal of 70 percent of the MCLs as the City of Surprise's current standard for contaminants removal. Ultimately, the City and the developer representative achieved consensus on a revised level of water quality treatment standards. Refer to Section 4.0 for a summary of these standards and a description of the basis for establishing them.

3.1.1.2 Secondary Maximum Contaminant Levels

Under 40 CFR Part 143, National Secondary Drinking Water Standards have been developed to provide guidelines for contaminants that may affect the appearance or taste/odor of water, but do not have adverse health effects. Secondary standards are recommended for 15 contaminants to ensure the aesthetic quality of drinking water. While the standards are non-enforceable federal guidelines, several states have chosen to adopt them as enforceable standards. ADEQ has repealed all of the secondary standards from the state rules with the exception of fluoride and corrosivity-related parameters such as pH and copper. Table WT.5 outlines the secondary standards.

Table WT.5 National Secondary Drinking Water Regulations Water Technology Assessment Report City of Surprise	
Contaminant	**Federal Secondary Standards**
Aluminum	0.05 to 0.2 mg/L
Chloride	250 mg/L
Color	15 color units
Copper	1.0 mg/L
Corrosivity (aggressiveness index)	Non-corrosive
Fluoride	2.0 mg/L
Foaming Agents (MBAS)	0.5 mg/L
Iron	0.3 mg/L
Manganese	0.05 mg/L
Odor	3 threshold odor number (TON)
pH	6.5 - 8.5
Silver	0.10 mg/L
Sulfate	250 mg/L
Total Dissolved Solids (TDS)	500 mg/L
Zinc	5 mg/L

Applicability of SMCLs to City of Surprise:

It is not mandatory to deliver water with parameters meeting all of the secondary standards. ADEQ has only adopted fluoride and corrosivity-related parameters such as pH and copper. Secondary contaminants, including fluoride and potentially iron, manganese, chloride, sulfate, and TDS exist in elevated levels in some of the City's groundwater sources.

The City has particular concerns with fluoride levels in their current and future groundwater sources. Consequently, fluoride has been identified as a CoC. Public notification is required when fluoride levels exceed the SMCL. As established in Section 4.0, the City's final water quality standards require meeting the SMCL for fluoride. Fluoride treatment technologies were evaluated in Section 6.0.

3.1.1.3 Lead and Copper Rule (LCR)

The LCR was promulgated in June 1991 and became effective in December 1992. The rule requires a treatment technique when action levels are exceeded. The LCR provisions are:

- Action levels of 15 micrograms per liter (µg/L) for lead and 1.3 mg/L for copper, measured as the 90th percentile value collected in homeowners' taps in the distribution system;

- A treatment technique requirement for lead, which includes optimal corrosion control treatment, source water treatment, public education, and lead service line replacement;
- A treatment technique requirement for copper, which includes optimal corrosion control treatment and source water treatment; and
- Treatment technique requirements based on exceeding the action levels for lead and/or copper specified above.

Revisions to the LCR were promulgated in a final rule in January 2000, which became effective April 11, 2000. The revisions included clarification of rules with respect to optimal corrosion control demonstration, changes to the public education requirements, updated analytical methods for lead and copper, changes in monitoring requirements, and additional special primacy considerations for the determination of optimal compliance when multiple samples are collected daily. The action levels for lead and copper (15 µg/L and 1.3 mg/L, respectively) were maintained.

Revisions to public education requirements included a requirement that the utility must submit a letter to the state demonstrating that they met their public education requirements within 10 days after each period in which the tasks were required. Also, the requirement to resubmit a list of organizations and facilities to which the utility provided public education materials with each annual compliance letter to the state was eliminated if the utility certified that the list has not changed from previous lists. Additionally, minor revisions were made to mandatory public education language and distribution of public education materials requirements.

Demonstration of optimal corrosion control is accomplished by routine daily monitoring for water quality parameters (one sample per day per plant). If optimal water quality, with respect to corrosion control, is not met on more than a total of nine days (can be non-consecutive) during a 6-month period, the system is out of compliance with the LCR. Compliance determinations are always based on a 6-month period, regardless of the monitoring schedule for the utility or whether the sample is from an entry point or tap. Confirmation samples are not allowed. Monitoring requirements may be reduced if after two consecutive 6-month rounds, the 90th percentile lead level is less than or equal to 0.005 mg/L and the 90th percentile copper level is less than or equal to 0.65 mg/L (known as accelerated reduced monitoring). Daily corrosion control monitoring is only required if action levels are exceeded. If action levels are not exceeded, a reduced monitoring schedule for lead and copper is acceptable. For reduced monitoring requirements, a water system must demonstrate compliance with the optional water quality parameter monitoring requirements.

The Final Lead and Copper Rule (LCR) Short-Term Revisions and Clarifications (also known as the Lead and Copper Rule Minor Revisions, or LCRMR) was promulgated on October 10, 2007. The compliance date for all provisions of this Rule was April 7, 2008. The LCRMR does not change the action levels for lead or copper, nor does it affect the rule's basic requirements. The modified rule requires the following:

1. Consumer Awareness. All utilities must now provide a notification of tap water monitoring results for lead to owners and/or occupants of homes and buildings who consume water from the taps that are part of the utility's sampling program.

2. Lead Service Line Replacement. Some utilities must reconsider previously "tested-out" lines when resuming lead service line replacement programs. This provision applies to systems that had: 1) initiated a lead service line replacement program; 2) complied with the lead action level for two consecutive monitoring periods and discontinued the lead service line replacement program; and 3) were subsequently re-triggered into lead service line replacement. All previously "tested-out" lines would then have to be tested again or added back into the sampling pool and considered for replacement.

3. Public Education. The new rule changes the content of the message to be provided to consumers, changes how the materials are delivered to consumers, and the timeframe in which materials must be delivered. There are also changes to the delivery requirements which include additional organizations that systems must partner with to disseminate the message to at-risk populations as well as changes in the ways information is disseminated to ensure water systems reach consumers when there is an action level exceedance. The new rule also requires educational statements about lead in drinking water to be included in all Consumer Confidence Reports (CCRs).

An action level exceedance is not a violation but can trigger other requirements that include water quality parameter (WQP) monitoring, corrosion control treatment (CCT), source water monitoring/treatment, public education, and lead service line replacement (LSLR).

The LCR applies to all community water systems (CWSs) and non-transient, non-community water systems (NTNCWSs). Samples must be collected by all CWSs and NTNCWSs at cold water taps in homes/buildings that are at high risk of lead/copper contamination as identified in 40 CFR 141.86(a). The number of sample sites is based on system size. Systems serving >100,000 people must sample 100 sites for lead and 25 sites for copper every 6 months, unless they qualify for reduced monitoring (50 and 10 sites, respectively).

Applicability of LCR to City of Surprise:

The City of Surprise has not exceeded lead and copper action levels in recent rounds of sampling and is currently in a reduced monitoring schedule for lead and copper. It is recommended that the City complete and maintain the practice of optimizing water quality for corrosion control. A recommended practice is to maintain a finished water pH in the range of 7.6 to 8.1. In order to demonstrate that optimal corrosion controls are in place, routine monitoring for water quality parameters and continued tap sampling are recommended. Alkalinity and pH are equally important for corrosion control, particularly when determining corrosion control indices such as the Langelier Index and Calcium Carbonate Precipitation Potential or if membrane desalination is used. If reverse osmosis (RO) treatment is implemented in the future, the permeate corrosivity must be carefully addressed using post-treatment and closely monitored.

3.1.1.4 Total Coliform Rule (TCR)

The Total Coliform Rule was enacted on June 29, 1989. Total coliforms include both fecal coliforms and *E. coli*. The MCLG for total coliforms is set at zero. Compliance with the MCL is based on the presence or absence of total coliforms in a sample. To comply with the TCR, total coliforms must be absent in at least 95 percent of samples each month. Samples that are positive for total coliforms must be analyzed for fecal coliforms or *E. coli* bacteria, and at least three repeat samples (one upstream within five service connections, one downstream within five service connections, and at the point of first detection) must be collected and analyzed for total coliforms within 24 hours of a positive detection.

Secondary disinfection is required under the TCR in accordance with the following:

- A minimum disinfectant residual of 0.2 mg/L free chlorine or 0.5 mg/L chloramines measured as total chlorine must be present throughout the distribution system continually.
- A sample with heterotrophic plate counts (HPCs) less than 500 cfu/100 mL is assumed to carry the required minimum residual.

USEPA announced in July 2003 that the Total Coliform Rule would be revised to address monitoring requirements of the rule and also to regulate distribution systems. The TCR Revisions are discussed in the pending regulations portion of this section.

Applicability of TCR to City of Surprise:

The proposed Total Coliform Rule Revisions / Distribution System Rule will affect the City of Surprise. However, the potential impact of the regulation is unknown until more information about the proposed rule is available (anticipated in late 2010). A distribution system study will likely be required as part of the Total Coliform Rule Revisions / Distribution System Rule.

The TCR also has impacts on the Groundwater Rule, which are discussed in the Groundwater Quality Regulations in Section 3.2. When a total coliform positive sample is collected, a groundwater system must collect at least one groundwater source sample from each groundwater source used at the time of the positive sample collection. The samples must be collected within 24 hours of the positive sample. If a source water sample produces a positive fecal coliform sample, state notification must occur and a corrective action must be taken by the system which complies with the source water monitoring requirements outlined in the Groundwater Rule.

3.1.1.5 Radionuclides Rule

The Radionuclide Rule was proposed on July 18, 1991 and was finalized on December 7, 2000 (except for radon). The MCLs for radionuclides are summarized in Table WT.6. Initial monitoring for the Radionuclides Rule was required to begin by December 8, 2003. The Rule retained the existing MCLs for combined radium-226 and radium-228, gross alpha, beta, and photon radioactivity. The Rule also regulated uranium for the first time. The final Rule stipulates an enforceable MCL of 5 pCi/L for combined radium (radium-226 + radium-228), 4 mR/yr for beta particles and photon emitters, 30 µg/L for uranium, and 15 pCi/L for adjusted gross alpha. The MCLG for all of the regulated radionuclides is set at zero. Adjusted gross alpha refers to the gross alpha particle activity excluding the contributions from uranium. Compliance with the gross beta exposure standard is measured through three analytes: gross beta < 50 pCi/L, strontium < 8 pCi/L, and tritium < 20,000 pCi/L.

The uranium MCL is given as a mass concentration limit of 30 µg/L and not as an activity in pCi/L. In the final Rule, USEPA stated that the actual relationship between mass concentration (µg/L) and activity (pCi/L) varies somewhat in drinking water sources, since the relative amounts of the radioactive isotopes that make up naturally occurring uranium (U-238, U-235, and U-234) vary between drinking water sources. The typical conversion factors that are observed in drinking water range from 0.67 up to 1.5 pCi/µg. Based on data from the National Inorganics and Radionuclides Survey, the best estimate of a geometric average mass to activity ratio is 0.9 pCi/µg. All entry points and receiving waters must be tested to meet the MCL for radionuclides. Monitoring requirements are summarized in Table WT.6.

Table WT.6 Radionuclides Monitoring Requirements Water Technology Assessment Report City of Surprise		
Parameters	**Type**	**Frequency**
Gross alpha, combined radium 226/228 and uranium (Applicable to surface and groundwater systems)	Initial	Four consecutive quarters (Conducted 1999-2001)
	Reduced	Reduced sampling if average is below detection limit or 1/2 of MCL (Frequency – once every three years if initial results > 1/2 MCL but < MCL; once every six years if < 1/2 MCL; once every nine years if <detection limit)
	Increased	If entry point is above MCL, system must return to quarterly sampling until 4 consecutive samples are below MCL
Beta particles and photon radioactivity including strontium and tritium (Applicable to surface and GWUDISW systems)	Initial	No monitoring required for most groundwater systems. Surface water systems to sample for gross beta (quarterly), tritium (annually) and strontium-90 (annually)
	Reduced	One sample every 3 years if running average of gross beta minus naturally occurring potassium –40 activity ≤ 50 pCi/L
	Increased	Sample at initial monitoring frequency or speciate as required by state if gross beta activity minus potassium-40 activity exceeds 50 pCi/L

Applicability of Radionuclides Rule to City of Surprise:

Water quality data from existing wells does not indicate that radionuclides are a current concern for the City. The City should maintain monitoring programs for its existing and proposed wells to ensure compliance with the Radionuclides Monitoring Rule.

3.1.1.6 Unregulated Contaminant Monitoring Rule (UCMR)

The UCMR was published in the *Federal Register* in September 1999. This new UCMR supersedes the previous unregulated contaminant list included with the Phase II/V Rules and will operate on a five-year cycle. Unregulated contaminant monitoring provides a mechanism for USEPA to obtain occurrence data on contaminants that may be regulated in the future. By rule, unregulated contaminants have no associated MCLs but systems must meet monitoring requirements to maintain their compliance status.

The first cycle (UCMR 1) identified 36 contaminants that will be phased in with a three-tier process. Contaminants were classified into three separate lists according to analytical readiness and current contaminant occurrence data. List 1 is for Assessment Monitoring, List 2 is a Screening Survey, and List 3 is a Pre-Screening Test. Monitoring for these contaminants occurred in 2001 through 2005.

The second cycle (UCMR 2) of monitoring was signed on December 20, 2006 and includes different contaminants and other new requirements not included in UCMR 1. USEPA is requiring select public water systems (PWSs) to monitor for 25 chemicals using five different analytical methods.

All PWSs serving more than 10,000 people, and a representative sample of 800 PWSs serving 10,000 or fewer people, are required to conduct Assessment Monitoring (List 1) for 10 chemicals during a 12-month period during January 2008 - December 2010. List 1 contaminants include:

Dimethoate

Terbufos sulfone

Five Flame Retardants

2,2',4,4'-tetrabromodiphenyl ether (BDE-47)

2,2',4,4',5-pentabromodiphenyl ether (BDE-99)

2,2',4,4',5,5'-hexabromobiphenyl (HBB)

2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)

2,2',4,4',6-pentabromodiphenyl ether (BDE-100)

Three Explosives

1,3-dinitrobenzene

2,4,6-trinitrotoluene (TNT)

Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)

List 1 contaminants are monitored using testing methods that are more widely used.

All PWSs serving more than 100,000 people, 320 selected PWSs serving 10,001 to 100,000 people, and 480 selected PWSs serving 10,000 or fewer people are required to conduct the Screening Survey (List 2) for 15 contaminants during a 12-month period during January 2008-December 2010. List 2 contaminants include:

Three Parent Acetanilides

Acetochlor

Alachlor

Metolachlor

Six Acetanilide Degradates

Acetochlor ethane sulfonic acid (ESA)

Acetochlor oxanilic acid (OA)

Alachlor ethane sulfonic acid (ESA)

Alachlor oxanilic acid (OA)

Metolachlor ethane sulfonic acid (ESA)

Metolachlor oxanilic acid (OA)

Six Nitrosamines

N-nitroso-diethylamine (NDEA)

N-nitroso-dimethylamine (NDMA)

N-nitroso-di-n-butylamine (NDBA)

N-nitroso-di-n-propylamine (NDPA)

N-nitroso-methylethylamine (NMEA)

N-nitroso-pyrrolidine (NPYR)

List 2 contaminants are monitored using testing methods that are relatively new.

USEPA will use the collected information to determine which contaminants might need to be regulated in the future and further researched when listed on the Contaminant Candidate List (CCL). Additional rulemaking for these contaminants will only occur after the appropriate analytical method and monitoring requirements are specified. In most cases, analytical methods are in an early stage of development.

Contaminants on this list are emerging concerns and monitoring is only required for up to 200 large and small systems selected from states' nominees of vulnerable systems. However, almost 5,000 systems have elected to participate in UCMR 2.

Applicability of UCMR to City of Surprise:

UCMR identifies contaminates that could be regulated in the near future. The City should be aware of these contaminants and understand the impacts of possible future regulations when making decisions regarding future water sources and supply facilities. Future TAR updates should incorporate the UCMR changes.

3.1.1.7 Arsenic Rule

The 1996 Safe Drinking Water Act (SDWA) Amendments required USEPA to promulgate a new arsenic rule by January 2000, and to finalize that regulation by January 2001. A rule was issued on January 22, 2001, which reduced the arsenic standard from 50 µg/L to 10 µg/L. In March 2003, the USEPA published a rule clarification relating to rounding of the arsenic concentration. Monitoring results above 0.01 mg/L (i.e., 0.014 mg/L) cannot be

rounded down to 0.01 mg/L, as the rule states 10 µg/L (and 0.014 mg/L would be 14 µg/L). Therefore, the USEPA decided to revise the MCL to 0.010 mg/L rather than 10 µg/L. The rule also sets a non-enforceable MCLG at zero. The compliance date for the new standard was January 23, 2006.

Initial monitoring must be conducted at each entry point into the distribution system. Surface water systems must have collected initial samples by December 31, 2006. Groundwater systems must have collected initial samples by December 31, 2007. Systems whose initial sample is below the MCL can reduce monitoring frequency to once a year for surface water systems and once every 3 years for groundwater systems. For any system that exceeds the MCL, quarterly samples must be taken at that point until the concentration is consistently below the MCL.

Arsenic detection at all points of entry (POEs) above 0.005 mg/L and up to and including 0.010 mg/L must include an educational informational statement in the system's Consumer Confidence Report (CCR).

The arsenic rule for surface waters is directly applicable to groundwater sources as well. Wells impacted by the new 0.010 mg/L MCL will require treatment or blending with surface/distribution water with low levels of arsenic.

Applicability of Arsenic Rule to City of Surprise:

The City of Surprise groundwater sources have been found to contain levels of arsenic that exceed the arsenic rule requirements. Consequently, arsenic has been identified as a contaminant of concern by the City. The IWMP states that the City's current treatment goal is 70 percent of the MCL, or 7.0 µg/L. The City's final water quality standard / treatment goal for arsenic is 8.0 µg/L, based on the Maricopa County Environmental Services Department (MCESD) practices. See Section 4.0 for additional details.

Arsenic removal facilities have been installed at several City water supply facilities that have high arsenic levels. Arsenic treatment, along with blending, is utilized at these water supply facilities to reduce arsenic concentrations below the MCL. Various technologies that remove arsenic are investigated and evaluated further as part of this Water Technology Assessment Report.

3.2 Groundwater Quality Regulations

This section presents regulations related to groundwater supply and includes the following regulations:

- Current Regulations
  - Groundwater Rule (GWR)
  - Groundwater Under Direct Influence of Surface Water (GWUDISW)

- Pending Regulations
- Future Regulations

3.2.1 Current Regulations

The existing GWR specifically regulates groundwater supplies. MCLs included in the SDWA discussed above are also applicable to groundwater supplies (e.g., VOCs, SOCs under the Phase I, II and IIb, and V Rules). In addition, the GWUDISW subsection of the SWTR may also impact certain wells. The GWR and GWUDISW are discussed below. Other pending regulations aimed directly at groundwater supplies are discussed in the subsequent sections.

3.2.1.1 Groundwater Rule (GWR)

The GWR was proposed on May 10, 2000 and was published on November 8, 2006. Compliance was required by December 1, 2009. The main goal of the GWR is to provide increased protection against microbial pathogens, specifically bacterial and viral pathogens, in public water systems using groundwater. ADEQ has incorporated by reference the Groundwater Rule per 40 CRF 141, Subpart S. Some of the impacts of the GWR overlap with the requirements of the Arsenic Rule. Particularly, concentration times time (CT) required for viruses could potentially be achieved by injecting a disinfectant into pressure vessels or equalization tanks used for arsenic treatment. Therefore, it may be desirable to size equalization tanks following arsenic treatment to meet the requirements of the GWR, where practical and not cost prohibitive. The key elements of the GWR are summarized below.

The state must perform a sanitary survey every three years for CWS and every five years for NCWS. The sanitary survey includes an onsite review of eight elements:

- Source
- Treatment
- Distribution system integrity
- Finished water storage
- Pumps, pump facilities, and control
- Monitoring, reporting, and data verification
- Water system management and operations
- Water system operator compliance with state regulations

A groundwater system that has been identified as having significant deficiencies during the sanitary survey must do one or more of the following:

- Eliminate the source of contamination

- Correct the significant deficiency
- Provide an alternate source water
- Provide a treatment that reliably achieves 99.99 percent (4-log) inactivation or removal of viruses at or before the first customer
- Groundwater systems which provide 4-log inactivation or removal of viruses will be required to conduct compliance monitoring for continuous maintenance of the required residual disinfectant concentration to demonstrate treatment effectiveness. Details of implementation and reporting will be determined by the state

Groundwater systems must correct significant deficiencies within 120 days or seek a state-approved alternate compliance schedule.

USEPA states that wells that are situated in certain hydrogeologic settings are more likely to become contaminated. Groundwater from fractured bedrock or gravel hydrogeologic setting may be sensitive to fecal contamination unless the well is protected by a hydrogeologic barrier. The state may add additional sensitive hydrogeologic settings (e.g., volcanic aquifers) as necessary. A hydrogeologic barrier is defined as the physical, biological, and chemical factors that prevent the movement of viable pathogens from a contaminant source to a public supply well.

If groundwater systems not treating to 4-log inactivation of viruses are located in sensitive hydrogeologic settings, the state would consider the presence of any existing hydrogeologic barriers that may be present. If a hydrogeologic barrier is present, then the state can nullify the determination that a system is located in a sensitive hydrogeologic setting.

For these vulnerable systems described above, the GWR requires the system to conduct monthly fecal coliform (or indicator) source water monitoring for twelve months. Those systems where monitoring results are positive for the presence of fecal indicators may be required to eliminate the source of contamination, correct the significant deficiency, provide an alternate source water, or provide a treatment which reliably achieves at least 4-log inactivation or removal of viruses before or at the first customer.

Under the GWR, if a system detects no fecal indicator-positive samples after 12 monthly samples, the state would be permitted to reduce routine source water monitoring from monthly to quarterly. The state would also be permitted, after the first year of monthly samples, to waive source water monitoring altogether for a system if the state determines that fecal contamination of the well(s) is highly unlikely, based on sampling history, land use pattern, disposal practices in the recharge area, and proximity of septic tanks and other fecal contamination sources.

Additionally, USEPA detailed the following source water monitoring requirements for vulnerable systems where total coliforms are detected in the distribution system:

- Wells that do not treat for 4-log removal/inactivation of viruses and undisinfected groundwater systems must collect a source water sample within 24 hours of receiving notification of a total coliform-positive sample taken in compliance with the Total Coliform Rule and test for the presence of *E. coli*, *enterococci,* or *coliphage* in the source water sample.
- Hydrogeologically sensitive systems must conduct routine monthly monitoring during the months the system supplies water to the public and analyze for *enterococci*, *E. coli*, or *coliphage*.
- In either case, if any source water sample is fecal indicator-positive, the system would have to notify the state immediately and then must take corrective action.

Applicability of GWR to City of Surprise:

Under the GWR, the City is required to monitor its groundwater sources for fecal coliforms on a monthly basis. Wells that do not treat to 4-log removal/inactivation of viruses before the first customer are subject to monthly fecal coliform monitoring for 12 months. This monitoring should already be completed per the GWR implementation schedule. Any system defects identified as part of the monitoring should be corrected by installing a treatment technique to achieve 4-log removal/inactivation of viruses. Compliance requirements should have been in place by December 1, 2009.

3.2.1.2 Groundwater Under Direct Influent of Surface Water (GWUDISW)

According to Arizona Administrative Code (A.A.C.) R18-4-301.01, certain groundwater may be considered “under the direct influence of surface water,” and as such, is subject to the provisions of the SWTR associated with filtration and disinfection.

The A.A.C. interprets the following sources to be GWUDISW:

- Springs and infiltration galleries
- Radial, Rainey, and horizontal wells
- Wells less than 500 feet from a surface water (if ADEQ does not conclude, as part of a vulnerability study, that the source is not influenced by a surface water)
- Shallow wells with perforations or screens less than 50 feet below the surface
- Hand-dug or auger-bored wells without casings
- Groundwater sources with turbidities exceeding the interim MCL
- Groundwater sources where total coliform, fecal coliform, or *E. coli* are present

- Groundwater sources in which temperature fluctuates 15 to 20 percent from the mean groundwater temperature over one year, or where temperatures of the groundwater correlate to similar changes in surface waters

The state conducts sanitary surveys of systems suspected of using GWUDISW. Utilities may submit information to demonstrate that a groundwater is not under the influence of surface water, provided the information is prepared by a qualified professional such as a professional engineer, registered geologist, water system operator, or hydrogeologist. Within 90 days of receipt of this information, ADEQ may require Microscopic Particle Analysis (MPA) monitoring, or an alternate approved method, of the groundwater source if it continues to be suspected as GWUDISW. The procedures for the MPA are prescribed in the "Consensus Method for Determining Groundwater Under the Direct Influence of Surface Water Using Microscopic Particulate Analysis (MPA)" (USEPA 910/9-92-029). ADEQ uses the MPA risk rating to determine if the groundwater source is under the direct influence of surface water.

If ADEQ determines that the groundwater is under the direct influence of surface water, it will then establish a compliance schedule for the public water system to take corrective action to prevent direct surface water influence, if feasible. The corrective action must be completed no later than 18 months after receipt of the initial MPA results. The corrective action, when complete, is then subject to a second round of MPA monitoring. The alternative is to provide filtration and disinfection as per the SWTR within 18 months of the final determination that the groundwater is under direct influence of surface water.

Applicability of GWUDISW to City of Surprise:

The GWUDISW regulation is not anticipated to impact the City of Surprise's existing wells based on current available information. However, the City should carefully consider the applicability and potential impacts of the rule when siting and designing future groundwater wells and supply facilities.

3.2.2 Pending Regulations

Regulations reviewed in this section were pending at the time of this report and are subject to change before any rule is finalized. However, they may have a direct impact on the City's drinking water treatment standards in the near future, and therefore, should be carefully considered.

3.2.2.1 Sulfate Health Effect Study

Water containing high levels of sulfate, a naturally occurring contaminant, may result in diarrhea or other stomach ailments. An abrupt change in sulfate levels in drinking water may induce a laxative effect in a portion of the population.

The 1996 amendments of the SDWA directed the USEPA and the Centers for Disease Control and Prevention to conduct a study to identify the adverse health affects related to sulfate in drinking water. On March 2, 1998, sulfate was included on the Drinking Water Contaminant Candidate List to determine if sulfate should be regulated in drinking water. However, at this time USEPA has no plans to regulate sulfate.

Sulfate in drinking water currently has an SMCL of 250 milligrams per liter (mg/L), based on aesthetic effects (i.e., taste and odor). This regulation is not a federally enforceable standard, but is provided as a guideline for states and public water systems.

3.2.2.2 Radon Rule

The USEPA does not have a target date for finalizing the Radon Rule due to tight budgets and other priorities. The regulation, proposed in November 1999, stipulates an enforceable MCL of 300 pCi/L and a non-enforceable health goal of zero. For systems with multimedia mitigation (MMM) programs, an alternate MCL (AMCL) of 4,000 pCi/L is proposed to control indoor air. The SDWA of 1996 outlined the multimedia framework for the proposed radon regulation, which included two options. The first option is for states (or primacy agencies) to develop enhanced programs (known as MMM programs) to address the health risks from radon in indoor air while individual water systems reduce radon levels in drinking water to 4,000 pCi/L or lower.

The second option is for states that choose not to develop an MMM program. Individual water systems in such states would be required to either reduce radon in their system's drinking water to 300 pCi/L, or develop individual local MMM programs, while reducing radon levels in drinking water to 4,000 pCi/L. The MMM program is intended to provide a more cost-effective alternative to achieve radon reduction, by allowing states or water systems to address radon in indoor air from a soil source, while reducing the highest levels of radon in drinking water. However, the MMM is not likely to be implemented in the near future in Arizona due to logistics and costs.

Monitoring requirements are summarized in Table WT.7. Initial monitoring requirements are used to determine a routine, reduced, or increased monitoring program. State discretion may grant a waiver to these requirements based on previous analytical results and geological characteristics and require only one sample every nine years.

The status of the Radon Rule is uncertain at this time. The final rule could change the MCC to 1,000 pCi/L or the rule could be eliminated in its entirety. Depending on the final rule, a radon goal may be revised at a later date.

Table WT.7	Radon Monitoring Requirements Water Technology Assessment Report City of Surprise	
Type	**Frequency**	**Conditions**
Initial	Four quarters of monitoring for one year	At each entry point to the distribution system after treatment/storage
Routine	One sample per year	If RAA of quarterly samples is less than MCL or AMCL
Reduced	One sample every 3 years	If average from 4 quarterly samples is less than 1/2 the MCL or AMCL and no sample exceeds MCL or AMCL
Increased	Four consecutive quarters of monitoring	If MCL or AMCL is exceeded in single sample when monitoring annually
Increased	One sample per year	If radon level less than MCL or AMCL but above 1/2 MCL or AMCL in a single sample when monitoring every 3 years
Waivers	One sample every 9 years	Based on previous analytical results, geological characteristics and State discretion, and all analytical results are less than 1/2 the MCL or AMCL

3.2.2.3 TCR Revisions

The TCR was first published on June 29, 1989. Coliform bacteria are generally not harmful to humans, but the USEPA considers them a useful indicator of other pathogens. The rule requires all public water systems to monitor for the presence of total coliforms as an indicator of treatment efficacy and distribution system integrity.

Since the rule was first published, increased attention has been focused on how water quality changes in distribution systems. As part of the review of the Stage 2 DBP Rule and LT2ESWTR, the Federal Advisory Committee recommended that the USEPA revisit the TCR. In July of 2003, the USEPA announced its decision to revise the TCR. The Committee on Public Water Distribution Systems was created to study water quality in distribution systems, and has submitted a report that identifies priority issues for consideration in the pending revisions. It is anticipated that increased focus will be placed on the high priority issues from the report, which include:

- Cross connections and backflow events
- Pipe failures and maintenance activities
- Distribution system operations and storage facilities

In mid-2007, USEPA formed the Total Coliform Rule/Distribution System Federal Advisory Committee (TC R/DS FAC). Multiple meetings were held. Information on existing cross-connection control programs was presented. Problems with information and research gaps for several distribution system topics previously identified by the committee (contaminant

occurrence and associated public health risks in the distribution system) were also discussed. The FAC has requested its technical working group review the data so it can help the committee prioritize research and information-collection needs on these topics.

Potential options for the revising the TCR will be proposed and discussed as part of additional future meetings. The FAC finalized and approved their Agreement in Principal (AIP) in September 2008. The AIP includes elimination of the present MCL for Total Coliforms. Instead, it should be used as a trigger for assessment and corrective action, if needed. The established AIP also starts a collaborative effort between the FAC and the USEPA to turn the AIP outline into a proposed and final rule, and to develop tools to implement that rule. The proposal is anticipated to be completed in 2010 with a final rule completed in 2012. Compliance is anticipated to be required in 2015.

3.2.2.4 Pending Regulations on Distribution System Water Quality Changes

It is anticipated that pending regulations associated with water quality changes within the distribution system are imminent. Chronic changes affecting pH, corrosion, and turbidity and acute conditions caused by cross connections from backpressure, surface water infiltration, and sewage-contaminated soil will be subject to regulatory consideration. The efficacy of secondary disinfection will be a driving criterion. The likely form will be a BMP-based regulation.

3.2.3 Future Contaminant Regulations

The USEPA has many potential contaminants on their long-term "radar." These contaminants are currently being researched to identify their affects on human health and are being studied for their presence in drinking water supplies. Based on these findings, future regulations on these contaminants are possible. A brief discussion of significant contaminants being analyzed by the USEPA is included below.

3.2.3.1 Emerging Inorganic and Organic Contaminants

Endocrine Disrupting Compounds (EDCs), Pharmaceuticals, and Personal Care Products (PPCPs)

Endocrine disruptors (EDCs), pharmaceuticals, and personal care products (PPCPs) are chemicals that interfere with the normal function of the endocrine system consisting of a number of ductless glands in the human body. The 1996 SDWA Amendments and the Food Quality Protection Act require USEPA to develop a screening and testing program to determine which chemical substances have possible endocrine disrupting effects in humans. The Endocrine Disruptor Screening and Testing Advisory Committee (EDSTAC) defines endocrine disruptors as exogenous chemical substances, or mixtures, that alter the structure or function(s) of the endocrine system and cause adverse effects at the level of the organism, its progeny, populations, or subpopulations of organisms, based on scientific principles, data, weight-of-evidence, and the precautionary principle. The USEPA's EDSTAC estimated that there are approximately 87,000 chemicals that should be screened

for their endocrine disrupting activity. Approximately 25,000 are polymers with high molecular weights, making them incapable of penetrating the biologic membranes. Removing these chemicals resulted in approximately 62,000 chemicals to be screened. These compounds may include organohalides (chloroform, PCBs, dioxins, etc.), food antioxidants (BHA), pesticides (atrazine, chlordane, DDT and its metabolites), herbicides and insecticides (lindane), phthalates and plasticizers (bisphenol A), synthetic hormones and hormone blockers, natural hormones (phytoestrogens), surfactants, fire retardant chemicals, antibiotics, antacids, analgesics and other pharmaceuticals, and metals (arsenic, mercury, and lead). A number of these contaminants are already regulated in drinking water.

The sources for endocrine-disrupting chemicals in drinking water may include wastewater treatment plant effluent, land application of sludge, surface runoffs, industrial discharges, disposal in landfills, animal feeding operations, and intentional discharges. Generally, conventional water treatment processes are ineffective for control of these contaminants. Depending on the contaminant characteristics, the applicable treatment technologies may include powdered and granular activated carbon adsorption, aquifer recharge, chlorination, ozonation and advanced oxidation processes, UV irradiation, biologically enhanced water treatment, bank filtration, and high-pressure membranes.

A study by the Toxic Substances Hydrology Program of the U.S. Geological Survey (USGS) showed that a broad range of chemicals were found in residential, industrial, and agricultural wastewaters. The chemicals included human and veterinary drugs (including antibiotics), natural and synthetic hormones, detergent metabolites, plasticizers, insecticides, and fire retardants. One or more of these chemicals were found in 80 percent of the surveyed streams (139 streams in 30 states). Half of the streams contained 7 or more of these chemicals, and about one-third of the streams contained 10 or more of these chemicals. These observations indicate that occurrence of these chemicals is widespread, and a large number of these contaminants may be regulated in the future.

A number of endocrine-disrupting contaminants are already regulated and regulation for others may be only a few years away.

Hexavalent Chromium

Chromium exists in drinking water as trivalent Cr(III) and hexavalent Cr(VI). The current USEPA MCL for total chromium is 100 µg/L. There are no separate MCLs for the individual species. Cr(III) is not a carcinogen via ingestion and is considered non-toxic. Important aspects for consideration by utilities are the relative speciation, and the tendency for Cr(III) to be oxidized to Cr(VI) by treatment processes. Currently, California has a more stringent MCL on total chromium of 50 ppb, and a public health goal of 2.5 ppb for Cr(VI). No changes to the federal standard are anticipated at this time.

Perchlorate

Perchlorate is a chemical that occurs naturally, and is also man made. It is used as a primary ingredient of solid rocket propellant. Perchlorate is a highly stable and non-reactive anion when dissolved in water. Perchlorate currently has no primary standard. However, it is listed on the Contaminant Candidate List (CCL) in the category of "more research needed." The National Academy of Sciences (NAS) conducted a health review of perchlorate, which was released on January 10, 2005. In May 2007, the USEPA published a *Federal Register* notice that described the available health effects and occurrence information for perchlorate and stated that additional information was needed to more fully characterize perchlorate exposure and determine whether there was a meaningful opportunity for health risk reduction from a perchlorate regulation.

The USEPA conducted an extensive review of scientific data related to the health effects of exposure to perchlorate from drinking water and other sources and found that in over 99 percent of public drinking water systems, perchlorate was not at levels of public health concern. Therefore, based on the SDWA criteria, the Agency determined there is not a "meaningful opportunity for health risk reduction" through a national drinking water regulation. In July 2008, and after careful consideration of public comments, USEPA published its final determination that no regulatory action is appropriate or necessary for perchlorate.

In January 2009, USEPA issued an interim health advisory level of 15 µg/L to assist state and local officials in addressing local contamination of perchlorate in drinking water. The level is based on reference dose recommendations by the National Research Council of the National Academy of Sciences. The USEPA is continuing to monitor the research from the Academy before making a final regulatory determination on whether to issue a national regulation for perchlorate in drinking water. Arizona stipulates a 14 µg/L Health Based Guidance Level, and although no reporting is necessary, public notification is recommended if perchlorate is detected in the water supply.

Methyl Tertiary Butyl Ether (MTBE)

MTBE is a synthetic gasoline additive that is a persistent groundwater contaminant. It is classified as a possible human carcinogen and is detectable by humans at very low concentrations in water because of its turpentine taste and odor. No National Primary Drinking Water Regulation exists for MTBE, but USEPA has established a Drinking Water Advisory limit of 0.020 to 0.040 mg/L. California DHS currently maintains a public health goal and primary standard of 13 µg/L, as well as a secondary standard of 5 µg/L for taste and odor considerations. The State of Arizona has established an MTBE Health-Based Guidance Level of 35 mg/L. Future regulation of MTBE has begun to emerge with the advance notice of proposed rulemaking for MTBE issued by USEPA in March 2000 under the authority of the Toxic Substances Control Act. A federal MCL for MTBE is not anticipated for several years.

3.2.3.2 Contaminant Candidate List (CCL)

The USEPA uses the Contaminant Candidate List (CCL) to prioritize research and data collection efforts for future regulation of emerging microbial, inorganic, organic, and radioactive contaminants. The contaminants on the list are known or anticipated to occur in public water systems, but are currently unregulated. From each list, the USEPA decides whether to regulate at least five or more contaminants on the list called Regulatory Determinations.

CCL 1 was published in 1998 and contained 60 contaminants. The review determinations were published in 2003 and the Agency announced its final determination that no regulatory action is appropriate or necessary for the nine contaminants identified by the regulatory determination.

CCL 2 was published in 2005 containing 51 contaminants. The review determinations were published in 2008 where the Agency announced its final determination that no regulatory action is appropriate or necessary for the eleven contaminants identified by the regulatory determination.

The most recent list, CCL 3, was published in October 2009 containing 116 contaminants. The list contains 104 chemicals or chemical groups and 12 microbiological contaminants. In developing this list, USEPA employed a new classification process based on National Drinking Water Advisory Council (NDWAC) recommendations. The process began with the identification of 7,500 potential chemical and microbial contaminants in the “CCL 3 Universe.” For this review, USEPA considered all drinking water regulations promulgated through 2003, except for the Stage 2 Microbial and Disinfection Byproduct Rules. This list was narrowed to 560 potential contaminants on the preliminary CCL (PCCL) based on the potential to occur in public water systems and the potential for public health concern. The PCCL was then pared down to a final list. USEPA is using this list of unregulated contaminants to prioritize research and data collection efforts to help determine whether specific contaminants should be regulated. The Regulatory Determinations 3 is anticipated to be published in 2013.

3.2.3.3 Emerging Pathogens (Microspiridium, Cyclospora, etc.)

Emerging pathogens are disease-causing microorganisms that have recently appeared in the population or have begun to rapidly expand their range, with a corresponding increase in disease. These organisms are the result of natural microbial adaptation and developed resistance to anti-microbial agents. Several parasites, bacteria, and viruses have been included on the drinking water CCL for eventual USEPA regulatory determination. These emerging pathogens are listed in Table WT.8.

Table WT.8 Contaminant Candidate List Emerging Pathogens Water Technology Assessment Report City of Surprise		
Parasites	**Bacteria**	**Viruses**
Microsporidia Enterocytozoan	*Mycobacterium avum*	*Coxsackie virus*
Microsporidia Septata	*Aeromonas hydrophila*	*Adenovirus*
	Helicobacter pylori	*Calciviruses* (Norwalk)
	Cyanobacteria, toxigenic	*Echovirus*

As these pathogens are regulated, USEPA will provide removal and inactivation criteria for water systems. Regulated levels for these pathogens are not available at this time.

Pathogens enter the drinking water system through four primary pathways:

- Failure to remove in the WTP
- Failure to inactivate during treatment
- Regrowth within the distribution system
- Contamination within the distribution system

Contamination within the distribution system may occur because of pressure transients within the system. Pressure transients are hydraulic surges that can travel through the distribution system and can cause negative pressures within the system. Negative pressure can potentially introduce untreated water, or other substances, into the distribution system through pipe breaks and other openings. Pressure transients have several potential causes including startup and shutdown of pumps, sudden opening and closing of valves, and sudden changes in system demand. Operation and maintenance strategies to reduce pressure transients may protect the distribution system from some pathogen contamination. Pressure transients and distribution system contamination from emerging pathogens may be addressed as part of the proposed Total Coliform Rule Revisions/Distribution System Rule.

Naegleria fowleri (also known as “the brain-eating amoeba”) is a free-living excavate form of protist typically found in warm fresh water, in an amoeboid or temporary flagellate stage. It belongs to a group called the Percolozoa or Heterolobosea. It has occurred across the nation in both surface water and groundwater sources.

N. fowleri can invade and attack the human nervous system. Although this occurs rarely, such an infection will nearly always result in the death of the victim. Symptoms of Naegleria Fowleri include headache, nausea, vomiting, high fever, lethargy, coma, and seizures.

Annual sampling for N. fowleri is recommended for wells with water temperature greater than 25 degrees Celsius. These wells shall be sampled and disinfected once every three years, after a positive total coliform sample, after being idle for more than 6 months, or after a bore hole maintenance.

Filtration and disinfection using chlorine or chloramines can achieve 4-log removal of N. fowleri. It is recommended that reservoirs and water storage tanks be inspected every two years prior to summer operations. Tanks shall be washed and disinfected if visible sediment and/or biofilms are present.

Annual distribution system sampling at the bacteria monitoring points is recommended. A minimum chlorine residual of 0.5 mg/L shall be maintained. Unidirectional flushing of the distribution system shall be performed once every three years, especially for the dead-end or low flow areas in the system. Water mains with lower chlorine residual should be flushed more frequently.

3.2.4 Aesthetic Requirements

3.2.4.1 Taste and Odor

In Central Arizona, earthy-musty to moldy taste and odor problems in drinking water are largely attributed to 2-methylisoborneol (MIB) and Geosmin in the source water. Levels of these compounds are perceptible by some individuals at 5 nanograms per liter (ng/L), and customers' perceptions of water safety are typically affected above 10 ng/L (Suffet et. al., 1995). Although not regulated by USEPA, taste and odor problems can have health and economic impacts. For example, reduced water consumption due to less than optimal palatability may lead to acute health consequences such as heat exhaustion and sunstroke, and chronic conditions such as kidney stones and aggravated arthritis. Economically, customers may resort to purchasing bottled water or in-home treatment devices ($0.30 to over $1.00 per gallon).

3.2.4.2 Hardness

Hardness is defined as the sum of polyvalent cations (primarily calcium and magnesium) present in water expressed as an equivalent quantity of calcium carbonate. Generally, water with hardness less than 50 mg/L as $CaCO_3$ is termed soft water and water with hardness greater than 150 mg/L as $CaCO_3$ is termed hard water. Aesthetic effects associated with hardness may include its reaction with soaps to form unsightly precipitates and internal scaling in pipes, water heaters, and plumbing fixtures. There is no evidence that hardness, at the level it is present in drinking water, has any adverse effect on human health.

3.2.4.3 Total Dissolved Solids (TDS)

TDS is the total quantity of salts dissolved in water and is comprised of anions such as bicarbonate, carbonate, chloride, sulfate, and silica and cations such as sodium, calcium, and magnesium. TDS originates in natural geologic formations and is concentrated in processes such as irrigation return and field run-off, water reclamation, and membrane technologies. A secondary standard of 500 mg/L of TDS is recommended by the USEPA.

Drinking water containing high TDS levels may taste bitter, salty, or metallic and may have unpleasant odors. High TDS water is less thirst quenching and makes food and beverages less desirable to consume. Some of the individual mineral salts that make up TDS pose a variety of health hazards, causing stiffness in the joints, hardening of the arteries, kidney stones, gall stones, and blockages of arteries.

Salt buildup in the Phoenix metropolitan area is a growing concern. TDS concentrations in the City of Surprise's groundwater sources range from 200 to 400 mg/L. Salt levels become more concentrated as water is used and reclaimed. Because the potential for reuse opportunities of reclaimed water diminishes (especially for irrigation uses) as salt concentrations rise, the Cities in the Phoenix metropolitan area need to understand the importance of controlling salt buildup in the future. Due to the importance of establishing and maintaining reclaimed water as a viable future water supply, the City must be aware of the affects of increasing TDS. TDS removal and concentrate disposal alternatives may need to be examined in the future. As more efficient and practical methods of TDS removal and concentrate disposal evolve, the City should consider establishment of numerical TDS goals and implementation of control measures, as appropriate.

3.2.4.4 Color

The presence of natural metallic ions (iron and manganese), humic and fulvic acids, plankton, dissolved plant components, bacteria, suspended solids, and industrial wastes can impart color to water. For consumer acceptance, an acceptable color range is 3 to 15 color units. Control of color in water depends on the contributing factor and may include technologies such as oxidation, conventional water treatment, ion exchange, adsorption onto GAC and high-pressure membranes.

Applicability of Aesthetic Requirements to City of Surprise:

Although none of the aesthetic parameters is required, it is recommended that the City deliver water with parameters meeting all of the secondary and aesthetic standards. Pending and future regulations should be monitored closely and considered when siting and designing new water supply facilities.

3.3 Surface Water Quality Regulations

The City of Surprise is not currently using surface water sources, and does not intend to utilize surface water as a source of drinking water in the near future. However, in an effort to provide a complete regulatory review, and equip the City with adequate information for future decision making, this section presents the regulations that are related to surface water supplies. Some of these regulations (such as filter backwash recycling rules and DBP rules) may be referenced when evaluating residuals, reuse, and recharge options. This section includes the following regulations:

- Current Regulations
  - Surface Water Treatment Rule (SWTR)
  - Interim Enhanced Surface Water Treatment Rule (IESWTR)
  - Stage 1 Disinfectant/Disinfectant Byproduct (D/DBP) Rule (Stage 1 D/DBP)
  - Stage 2 Disinfectant/Disinfectant Byproduct (D/DBP) Rule (Stage 2 D/DBP)
  - Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)
  - Filter Backwash Recycling Rule (FBRR)
- Pending Regulations
- Future Regulations
  - NDMA
  - Perchlorate

3.3.1 Current Regulations

3.3.1.1 Surface Water Treatment Rule (SWTR)

The SWTR was published in the *Federal Register* on June 29, 1989, and became effective December 31, 1990. The objective of the rule is to prevent waterborne illness caused by viruses and *Giardia lamblia*. Most surface waters are likely to contain these disease-causing organisms to some degree. The health goal for these contaminants is zero because any exposure constitutes some health risk. Because monitoring for these contaminants is infeasible, USEPA has implemented requirements for treatment technique instead of setting MCLs for each microbe. Under the rule, systems are required to filter and disinfect water from surface sources to reduce the occurrence of these microorganisms.

The rule specifies that all systems must filter and disinfect water to achieve a 99.9 percent (3-log reduction) combined removal and inactivation of *Giardia*, and 99.99 percent (4-log reduction) for viruses. The effectiveness of filtration is established by measuring turbidity in the treated water. Conventional and direct filtration plants must achieve filtered water turbidity levels of 0.5 NTU or less in at least 95 percent of the measurements taken each month. Further, the turbidity of the filtered water can never exceed 5 NTU. Surface water systems must also take a grab sample and measure the turbidity of the filtered water at least

once every four hours while the plant is operating. The rule also requires that the secondary or residual disinfectant entering the distribution system cannot be less than 0.2 mg/L for more than four consecutive hours and that 95 percent of monthly distribution system residual measurements are above detection.

Direct filtration plants are required to achieve inactivation of 1-log *Giardia* and 3-log viruses through primary disinfection, assuming that the plant can consistently achieve filtered water turbidity levels of 0.5 NTU. Conventional filtration plants are required to achieve 0.5-log *Giardia* inactivation through primary disinfection, allowing for a 0.5-log credit by physical removal processes (e.g., flocculation, sedimentation, and filtration). In addition, the residual or secondary disinfectant entering the distribution system cannot be less than 0.2 mg/L for more than four consecutive hours. Disinfection must be continuous and a detectable level must be maintained within the distribution system.

Applicability of SWTR to City of Surprise:

The City of Surprise is not currently using surface water sources and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system.

3.3.1.2 Interim Enhanced Surface Water Treatment Rule (IESWTR)

The IESWTR was proposed in December 1998, and became effective for large public water systems serving more than 10,000 persons in January 2002. Final revisions to the IESWTR and the Stage 1 D/DBPR (see below) were published on January 16, 2001. The IESWTR supersedes the turbidity removal requirements of the SWTR with the inclusion of protection against *Cryptosporidium*. The *Giardia* inactivation requirements in the original SWTR are still maintained. The key components of this rule are:

- A MCLG of zero for *Cryptosporidium*.
- 2-log *Cryptosporidium* physical removal requirement for systems that filter (assumed to be met if the turbidity standard is met).
- Combined filter effluent from conventional or direct filtration plants must be less than or equal to 0.3 NTU in 95 percent of measurements each month, and combined filter effluent must always be less than 1 NTU.
- A self-assessment must be performed on individual filters if there are two consecutive results greater than 1 NTU, taken 15 minutes apart, for 3 consecutive months or turbidities greater than 0.5 NTU in two consecutive measurements 15 minutes apart at the end of the first four hours of operation following backwashing or off-line.
- A self-assessment on individual filters including development of a filter profile, identification and prioritization of factors limiting performance, assessment of

corrective actions, and preparation of a filter self-assessment report. The approach specified in USEPA's Composite Correction Program Manual can be followed when performing a self-assessment.

- Disinfection profiling and benchmarking are required for systems exceeding 80 percent of the proposed MCLs for total trihalomethanes (TTHMs) and haloacetic acids (HAAs) (64 ppb and 48 ppb, respectively) during the ICR monitoring period. Disinfection profiling is used to establish "disinfection benchmarks" for each WTP. The benchmark is based on one year of daily CT (disinfectant residual x contact time) data for *Giardia* inactivation. The month where the ratio of CT achieved (in the WTP) to CT required (by regulation) is lowest represents the disinfection benchmark for a particular WTP. The WTP should aim to meet the benchmark level of disinfection during all operational periods. The purpose of the benchmark is to verify that water systems do not sacrifice disinfection efficiency to meet the reduced TTHM and new HAA5 standards.

Applicability of IESWTR to City of Surprise:

The City of Surprise is not currently using surface water source, and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system.

3.3.1.3 Stage 1 Disinfectant / Disinfectant Byproduct (D/DBP) Rule (Stage 1 D/DBPR)

The Stage 1 D/DBP Rule was proposed along with the IESWTR and became effective on January 2002 for large systems. The Stage 1 D/DBP Rule applies to all community and non-transient, non-community water systems that treat their water with a chemical disinfectant for either primary or residual treatment. This rule updates and supersedes the 1979 regulation that regulated TTHMs, a group of the chlorinated byproducts of concern in drinking water treatment. The rule also sets MCLGs, MCLs, maximum residual disinfectant level goals (MRDLGs), maximum residual disinfectant levels (MRDLs), and treatment technique requirements for removal of DBP precursors (measured as total organic carbon) in conventional surface WTPs. The final Stage 1 D/DBPR includes the following key provisions:

- MRDLGs for chlorine (4 mg/L), chloramines (4 mg/L), and chlorine dioxide (0.8 mg/L)
- MRDLs, computed quarterly, based on running annual averages (RAA) of all distribution system samples, of 4.0 mg/L for chlorine and chloramines and 0.8 mg/L for chlorine dioxide
- MCLGs for bromodichloromethane (zero), dibromochloromethane (0.06 mg/L), bromoform (zero), dichloroacetic acid (zero), trichloroacetic acid (0.3 mg/L), bromate (zero), and chlorite (0.8 mg/L)

- MCLs (computed quarterly based on RAAs) of all samples collected in the system, of 0.080 mg/L for the sum of four trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform), 0.060 mg/L for the sum of five haloacetic acids (monochloroacetic acid, dichloroacetic acid, trichloroacetic acid, monobromoacetic acid, and dibromoacetic acid), 1.0 mg/L for chlorite (applicable only to systems using chlorine dioxide), and 0.010 mg/L for bromate (applicable only to systems using ozone)

The Stage 1 DBP Rule also established minimum requirements for systems to remove naturally occurring organic precursors in water sources, which upon disinfection contribute to the formation of the DBPs. These standards, called the Enhanced Coagulation guidelines, require that all water systems that use surface water or groundwater under the direct influence of a surface water *and* use conventional treatment (coagulation / sedimentation / filtration), must remove specified percentages of total organic carbon (TOC) as listed in Table WT.9.

Table WT.9 Enhanced Coagulation Guidelines
Water Technology Assessment Report
City of Surprise

Source Water TOC (mg/L)	Source Water Alkalinity (mg/L as $CaCO_3$)		
	≤ 60	**> 60 and ≤ 120**	**> 120**
>2.0 and ≤ 4.0	35%	25%	15%
>4.0 and ≤ 8.0	45%	35%	25%
>8.0	50%	40%	30%

Alternate Compliance Criteria

All conventional surface WTPs will be required to achieve Step 1 TOC removal levels within the treatment plant to minimize DBP formation, unless the water system meets one of the alternate criteria listed below, or satisfies alternate Step 2 TOC removal requirements. To be fully exempt from TOC removal requirements, a water system must meet one of the following criteria:

- Raw or treated water TOC level less than or equal to 2.0 mg/L.
- Raw water TOC less than 4.0 mg/L, alkalinity greater than 60 mg/L, and running annual averages for THMs and HAAs less than 40 µg/L and 30 µg/L, respectively.
- Running annual averages for THMs and HAAs less than 40 µg/L and 30 µg/L, respectively, with chlorine used as the primary and the secondary disinfectant.
- Ten percent magnesium hardness removal or use of ion exchange.
- Raw water SUVA, measured monthly, less than or equal to 2.0 L/mg-m, calculated quarterly as a running annual average. SUVA is the specific UV absorbance at 254 nanometers (in meters-1) divided by the TOC content (in mg/L).

- Finished water SUVA, sampled prior to the addition of any oxidant and measured monthly, less than or equal to 2.0 L/mg-m, calculated quarterly as a running annual average.

Step 2 TOC Removal Criteria

Step 2 requirements are based on an alum dose which produces an incremental TOC removal rate of less than or equal to 0.3 mg TOC/L per 10 mg/L alum added. The alternate TOC removal (in percent) is that which corresponds to this alum dose on the TOC versus alum dose curve. Alternate removal requirements can also be based on addition of ferric chloride that produces an incremental TOC removal rate of less than or equal to 0.55 mg/L per 10 mg/L ferric chloride added.

As identified in 40 CFR Part 141.135(b)(4)(v), "if the TOC removal is consistently less than 0.3 mg/L of TOC per 10 mg/L of incremental alum dose at all dosages of alum (or equivalent addition of iron coagulant), the water is deemed to contain TOC not amenable to enhanced coagulation. The system may then apply to the state for a waiver of enhanced coagulation requirements."

Applicability of Stage 1 D/DBP Rules to City of Surprise:

The Stage 1 D/DBP Rule is a distribution system regulation. The City of Surprise must comply with the MCLs, and maximum residual disinfectant levels throughout the distribution system. However, the City is only required to meet the treatment technique requirements for removal of DBP precursors for groundwater under the direct influence of surface water when using conventional treatment techniques. Consequently, the treatment techniques are not applicable for the City at this time.

The City of Surprise is not currently using surface water sources and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system. The City would be required to meet the minimum requirements for organic precursors contributing to the formation of DBPs if surface water sources are utilized for drinking water.

3.3.1.4 Stage 2 Disinfectant / Disinfectant Byproduct Rule (Stage 2 D/DBPR)

The purpose of this Rule is to strengthen the Stage 1 D/DBP Rule requirements and reduce occurrences of disinfection byproducts concentration spikes in distribution systems. The MCLs for TTHMs and HAAs remain the same as those in the Stage 1 D/DBP Rule (80 and 60 µg/L, respectively); but the manner in which compliance is calculated has changed. The Stage 2 D/DBP Rule was proposed in August 2003 and was finalized in December 2005. The Stage 1 D/DBP Rule will remain in effect until compliance monitoring for the Stage 2 Rule begins in 2012 to 2014, depending on system size. The intent of this rule is to ensure that customers in all locations of the distribution system receive water that complies

with DBP standards. The Stage 2 D/DBP Rule and the LT2ESWTR (discussed subsequently) will be addressed simultaneously in order to protect public health and optimize technology selection.

New compliance monitoring sites will be selected based on an Initial Distribution System Evaluation (IDSE). All public water systems which supply water that has been disinfected with a primary or residual disinfectant (other than UV) must conduct an IDSE. Public water systems exempted from conducting IDSE include:

- Systems serving less than 500 persons
- Systems with TTHM/HAA5 less than 40/30 ppb

There are two approaches to conduct an IDSE. The Standard Monitoring Program (SMP) is the default option and requires one year of monitoring based on system size and type of residual disinfectant. The other option is to conduct a System Specific Study (SSS), which consists of identifying equivalent or superior monitoring sites based on:

- Calibrated hydraulic model plus at least one round of sampling during the month of peak historical TTHMs
- Historical data (within last 10 years)
- Historical data combined with new data
- Historical data and tracer study
- New TTHM and HAA5 data, distribution system modeling, and a tracer study

Under the SMP approach, samples must include the peak historical DBP month and sampling locations are in addition to Stage 1 D/DBPR compliance monitoring sites. The location of the eight IDSE sites will depend on the type of residual disinfectant. For systems using chloramines for residual disinfection, these sites should include:

- Two sites located near the distribution system entry point
- Two sites at average residence time locations
- Four sites at points representative of the highest THM and HAA5 concentrations

For systems using free chlorine for residual disinfection:

- One site located near the distribution system entry point
- Two sites at average residence time locations
- Five sites at points representative of the highest THM and HAA5 concentrations

All IDSE samples will be paired (TTHM and HAA5 samples collected at each site). IDSE samples will not be used for compliance purposes during the monitoring period. The results of the IDSE will be used to select the long-term compliance sites, where systems will

monitor quarterly on a regular schedule at four distribution sites per plant. The four locations will be determined as follows:

- One site representative of average DBP levels from among current Stage 1 locations. This may be either the highest TTHM or HAA5 RAA from among the three compliance monitoring locations representative of average residence time.
- One location representative of the highest HAA5 identified during the IDSE.
- Two sites at the highest TTHM locations identified under the IDSE.

Compliance with the Stage 2 D/DBP Rule is based on Locational Running Annual Average (LRAA) DBP concentrations. This means that RAA DBP concentrations must be calculated for each sampling location, rather than averaging system-wide as in the Stage 1 D/DBP Rule. Systems comply with the Stage 2 D/DBP Rule in two phases:

- 2009 - 2010, depending on system size, all systems must comply with MCLs of 120 µg/L for TTHMs and 100 µg/L for HAA5, based on LRAA at Stage 1 D/DBP Rule monitoring sites. Systems must continue to comply with Stage 1 D/DBP Rule 80 µg/L TTHM and 60 µg/L HAA running annual averages during this period.
- 2012 - 2013, depending on system size, systems must comply with 80 µg/L and 60 µg/L for THMs and HAAs, respectively, based on LRAA at the four new sampling sites identified under the IDSE.

Both phases described above may be extended by two years for systems requiring capital improvements. All wholesale/retail water systems must conduct the IDSE and comply with the Stage 2 D/DBP requirements simultaneously.

Applicability of Stage 2 D/DBP rules to City of Surprise:

Similar to the Stage 1 D/DBP Rule, the City must comply with the MCLs, and maximum residual disinfectant levels throughout the distribution system. However, the City is only required to meet the treatment technique requirements for removal of DBP precursors for groundwater under the direct influence of surface water when using conventional treatment techniques. Consequently, the treatment techniques are not applicable to the City at this time.

The City of Surprise is not currently using surface water sources and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system. The City would be required to meet the minimum requirements for organic precursors contributing to the formation of DBPs if surface water sources are utilized for drinking water.

3.3.1.5 Long Term 2 Enhanced Surface Water Treatment Rule (LT2ESWTR)

The LT2ESWTR is focused on providing additional protection against *Cryptosporidium*. Although the 1996 SDWA Amendments did not require the LT2ESWTR to be finalized along with Stage 2 D/DBP Rule, USEPA has taken the concurrent approach to balance the risks between microbial and DBP contaminants. A LT2ESWTR proposed rule was published on August 11, 2003, and the final rule was published in December 2005.

The LT2ESWTR assigns systems into "bins" based on source water *Cryptosporidium* monitoring results. Additional treatment may be required based on the bin classification. A "toolbox" of options is available for systems to choose technologies to comply with additional treatment requirements.

The initial assessment monitoring for LT2ESWTR requires monthly *Cryptosporidium*, *E. coli*, and turbidity source water sampling for 24 months. A system may elect to sample twice per month for a total of 48 samples over the 24-month period. *Cryptosporidium* monitoring using USEPA Method 1622/23 and no less than 10 L samples must be conducted using USEPA certified laboratories. Bin classification is based on the highest 12-month running annual average if samples are taken monthly, or a two-year mean may be used if samples are taken twice per month. *Cryptosporidium* concentrations defining bin assignments are shown in Table WT.10.

Table WT.10 *Cryptosporidium* Inactivation Requirements[(1)]
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Bin Number	Average Source Water *Cryptosporidium* Concentration (oocysts/L)	Additional Treatment Requirements [(1)]	
		Conventional Filtration, Diatomaceous Earth Filtration, or Slow Sand Filtration	Direct Filtration
1	<0.075	No Action	No Action
2	0.075 to <1.0	1-log	1.5-log
		Using any or all of the microbial toolbox technologies	
3	1.0 to <3.0	2-log	2.5-log
		With at least 1-log of credit earned using any of: • Bag/cartridge filters • Bank filtration • Chlorine dioxide • Membranes • Ozone • UV	

Table WT.10 *Cryptosporidium* Inactivation Requirements[1] Water Technology Assessment Report City of Surprise			
Bin Number	**Average Source Water *Cryptosporidium* Concentration (oocysts/L)**	**Additional Treatment Requirements [1]**	
		Conventional Filtration, Diatomaceous Earth Filtration, or Slow Sand Filtration	**Direct Filtration**
4	≥ 3.0	2.5-log	3.0-log
		With at least 1-log of treatment accomplished using any of: • Bag/cartridge filters • Bank filtration • Chlorine dioxide • Membranes • Ozone • UV	

Systems have three years following bin classification to meet the treatment requirements associated with the assigned bin. An additional two years may be granted where capital improvements are necessary. For bin classification purposes, it is assumed that conventional treatment plants are in full compliance with IESWTR and achieve a 3-log physical removal of *Cryptosporidium*. Direct filtration plants complying with IESWTR receive 2.5-log *Cryptosporidium* physical removal credit. One or more actions may be selected from an array of management strategies, which include watershed control (potential for 0.5-log credit), alternative sources (potential for assignment to a lower bin), pretreatment (potential for 0.5 – 1.0-log credit), improved treatment (potential for 0.5 – 2.0-log credit), improved disinfection (log credit based on demonstration of compliance with CT values), and peer review or other demonstration of system performance (potential for 1.0-log credit). Table WT.11 summarizes the "Toolbox" options available as part of the rule.

Table WT.11 Microbial Toolbox Options (CFR 71(3), pp. 684-685) Water Technology Assessment Report City of Surprise	
Toolbox Option	**Maximum *Cryptosporidium* Treatment Credit Possible**
Source Protection and Management	
Watershed control program	0.5-log
Alternative source/intake management.	No prescribed credit
Prefiltration	
Presedimentation basin with coagulation	
Two-stage lime softening	0.5-log
Bank filtration	

Table WT.11 Microbial Toolbox Options (CFR 71(3), pp. 684-685) Water Technology Assessment Report City of Surprise	
Toolbox Option	**Maximum *Cryptosporidium* Treatment Credit Possible**
Treatment Performance	
Combined filter performance	0.5-log
Individual filter performance	0.5-log credit (in addition to 0.5-log combined performance filter credit)
Demonstration of performance	Credit at discretion of the state
Additional Filtration	
Bag and cartridge filters	Up to 2- to 2.5-log
Membrane filtration	Credit at discretion of the state
Second stage filtration	0.5-log
Slow sand filters	2.5-log
Inactivation	
Chlorine dioxide	Log credit based on measured CT in relation to CT table
Ozone	Log credit based on measured CT in relation to CT table
UV	Log credit based on validated UV dose in relation to UV dose table; reactor validation testing required to establish UV dose and associated operating conditions.

Additional requirements of the LT2ESWTR are summarized below:

- Systems that provide a total of 2.5 logs of treatment (equivalent to Bin 4 including inactivation) for *Cryptosporidium* in addition to conventional treatment meeting IEWSTR requirements are exempt from reassessment and future monitoring.
- Four years after initial bin characterization, a stakeholder process will be conducted to determine the appropriate analytical method, monitoring frequency, monitoring location, etc., for the second round of national assessment monitoring.
- Six years after completion of the initial bin characterization, systems will conduct a second round of monitoring, equivalent or superior to the initial round from a statistical perspective, as part of a national reassessment.
- As part of the three-year sanitary survey process, the Primacy Agency will assess any significant changes in the watershed and source water and will determine with the systems what follow-up action is appropriate.

Applicability of LT2ESWTR to City of Surprise:

The City of Surprise is not currently using surface water sources and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system.

3.3.1.6 Filter Backwash Recycling Rule (FBRR)

USEPA promulgated the final FBRR on June 8, 2001. This rule requires that conventional and direct filtration plants return recycled water to a point in the main treatment process such that all processes of a plant's treatment train are utilized. Recycled water consists of spent filter backwash water, sludge thickener supernatant, and any liquids from dewatering processes. The rule also requires that any system performing recycle report to the state that it does so, and provide:

- A plant schematic, showing origin of all recycle flows
- Treatment/equalization facilities for recycle flows
- Location of return point
- Recycle flow rate, plant flow rate and capacity data

Additionally, the systems must keep on record the following information:

- Copy of the recycle notification
- List of all recycle flows and frequencies
- Backwash flow rates and durations
- Typical filter run length and description of backwash initiation triggers
- Type of treatment provided to recycle flows
- Recycle treatment process design data

Requirements for conventional and direct filtration plants are equivalent. Furthermore, there are no limitations or reporting requirements based on the magnitude of recycle streams (i.e., 10 percent of total plant flow). However, in the language of the final rule, USEPA clearly indicates that hydraulic surges in treatment plants have been identified in many studies as causing deteriorated finished water quality due to upsetting the filtration process. However, instead of putting a general limit on recycled water flow rates, USEPA felt it would be more efficient to have systems report their general configuration and flows to the state, and let the individual states decide which systems may be at a greater risk. If the state identifies an "at-risk" system, it can then ask the system to forward the data it is required to be keeping onsite. While there is currently no requirement that limits the maximum return flows a plant can have, USEPA has indicated a 10 percent value as guidance for the states to use in

determining what systems to investigate more closely. Systems were required to comply with the FBRR reporting requirements by December 8, 2003 (30 months) and with recycle return location requirements by June 8, 2004 (36 months). If capital improvements are required, then the compliance date is June 8, 2006 (60 months).

Applicability of FBRR to City of Surprise:

The City of Surprise is not currently using surface water sources and does not intend to utilize surface water as a source of drinking water in the near future. However, should the City ever consider using surface water as a drinking water source, the City must be aware of the regulations that are required for a surface water system and the impacts of using surface water sources on the overall water distribution system.

3.3.2 Future Contaminant Regulations

3.3.2.1 N-Nitrosodimethylamine (NDMA)

N-Nitrosodimethylamine (NDMA) is not currently regulated by USEPA and its future regulation will depend on its occurrence in public water systems. It is a highly toxic and carcinogenic member of the nitrosamine family of nitrogen-containing organic compounds. California has an action level for NDMA at 20 ng/L. NDMA can be introduced into water by leaching from ion exchange resins, chloramination, chlorination of water treated with polymers, and other precursors such as nitrite, and in biologically active distribution systems with chloraminated water. Industrial spills (for example, fish, dyes, leather, etc.) can also add NDMA to a source water.

3.3.2.2 Perchlorate

As discussed in Section 3.2.3.1 *Future Groundwater Emerging Inorganic and Organic Contaminants*, perchlorate is a chemical that is both naturally occurring and is also man made. Perchlorate can be found in both groundwater and surface water. Most perchlorate contamination in Arizona is in the Colorado River watershed and was first detected in the Lower Colorado River in 1997. Perchlorate contamination has been found to be moving through the Las Vegas Wash into Lake Mead, and then into the Colorado River. One main source of the perchlorate contamination in both groundwater and surface water has been identified as generating from a manufacturing facility located outside of Las Vegas. Since identifying this contamination source, the manufacturing facility is extracting groundwater at three locations and treating it to remove more than one ton of perchlorate per day before it reaches Las Vegas Wash. The captured groundwater and surface water is treated in fluidized bed reactors (biologically based wastewater treatment systems) to remove more than 99.99 percent of the perchlorate.

Currently, there is no federal drinking water standard for perchlorate. However, as of April 2005, Arizona established a Health Based Guidance Level of 14 ppb. Perchlorate has been proven to be successfully removed from water using biological treatment methods and ion

exchange and can also be removed by means of RO, nanofiltration, granular activated carbon (GAC), and chemical reduction processes. If, in the future, the City of Surprise elects to use a groundwater or surface water source that contains high levels of perchlorate, then a proper treatment technique will need to be evaluated.

3.4 Drinking Water Best Available Technologies

The best available technologies (BAT), treatment techniques (TT) or other means are identified in the Safe Drinking Water Act, Title 40 - Protection of Environment, Chapter I - Environmental Protection Agency, Subchapter D - Water Programs, Part 142 - National Primary Drinking Water Regulations Implementation, Subpart G - Identification of Best Technology, Treatment Techniques or Other Means Generally Available. The following summarizes USEPA's official responses on BATs regarding the critical CoC for the City of Surprise groundwater supply (nitrate, arsenic, and fluoride).

A designer is entitled to consult the engineering review program at the ADEQ and MCESD for site-specific approval when considering technologies for a treatment facility. If a system can demonstrate that an alternate technology is viable through comprehensive engineering assessments, which may include pilot plant studies, the state or county may approve additional treatment technologies.

3.4.1 BAT for Nitrate

The Administrator, pursuant to Section 1412 of the Act, hereby identifies the following as the best technology, treatment technique, or other means available for achieving compliance with the maximum contaminant levels for inorganic contaminants identified in paragraph (b) of this section, except fluoride: (40 CFR 141.62(c))

- Ion Exchange
- Reverse Osmosis
- Electrodialysis

3.4.2 BAT for Arsenic

The Administrator, pursuant to Section 1412 of the Act, hereby identifies the following as the best technology, treatment technique, or other means available for achieving compliance with the maximum contaminant levels for inorganic contaminants identified in paragraph (b) of this section, except fluoride: (BATs for Arsenic V. Pre-oxidation may be required to convert Arsenic III to Arsenic V.) (40 CFR 141.62(c))

- Activated Alumina
- Coagulation/Filtration (not BAT for systems < 500 service connections)
- Ion Exchange
- Lime Softening (not BAT for systems <500 service connections)

- Reverse Osmosis
- Electrodialysis
- Oxidation/Filtration (To obtain high removals, iron to arsenic ratio must be at least 20:1)

3.4.3 BAT for Fluoride

The Administrator, pursuant to Section 1415(a)(1)(A) of the Act, hereby identifies the following as the best technology, treatment techniques or other means generally available for achieving compliance with the Maximum Contaminant Level for fluoride: (40 CFR 142.61(a))

- Activated Alumina Absorption, centrally applied
- Reverse Osmosis, centrally applied

Pursuant to §142.43 (c)–(g) or corresponding state regulations, the Administrator or primacy state that issues variances shall issue a schedule of compliance that may require the system being granted the variance to examine the following treatment methods (1) to determine the probability that any of these methods will significantly reduce the level of fluoride for that system; and (2) if such probability exists, to determine whether any of these methods are technically feasible and economically reasonable, and that the fluoride reductions obtained will be commensurate with the costs incurred with the installation and use of such treatment methods for that system:

- Modification of lime softening;
- Alum coagulation;
- Electrodialysis;
- Anion exchange resins;
- Well field management;
- Alternate source; and
- Regionalization.

3.4.4 BAT for Total Trihalomethanes (TTHM)

The Administrator, pursuant to Section 1415(a)(1)(A) of the Act, hereby identifies the following as the best technology, treatment techniques, or other means generally available for achieving compliance with the maximum contaminant level for total trihalomethanes (§141.12(c)):

(1) Use of chloramines as an alternate or supplemental disinfectant or oxidant.

(2) Use of chlorine dioxide as an alternate or supplemental disinfectant or oxidant.

(3) Improved existing clarification for THM precursor reduction.

(4) Moving the point of chlorination to reduce TTHM formation and, where necessary, substituting for the use of chlorine as a pre-oxidant chloramines, chlorine dioxide, or potassium permanganate.

(5) Use of powdered activated carbon for THM precursor or TTHM reduction seasonally or intermittently at dosages not to exceed 10 mg/L on an annual average basis.

Pursuant to §142.43 (c) through (g) or corresponding state regulations, the Administrator or primacy state that issues variances shall issue a schedule of compliance that may require the system being granted the variance to examine the following treatment methods (1) to determine the probability that any of these methods will significantly reduce the level of TTHM for that system; and (2) if such probability exists, to determine whether any of these methods are technically feasible and economically reasonable, and that the TTHM reductions obtained will be commensurate with the costs incurred with the installation and use of such treatment methods for that system:

- Introduction of off-line water storage for THM precursor reduction.
- Aeration for TTHM reduction, where geographically and environmentally appropriate.
- Introduction of clarification where not currently practiced.
- Consideration of alternative sources of raw water.
- Use of ozone as an alternate or supplemental disinfectant or oxidant.

If the Administrator or primacy state that issues variances determines that a treatment method identified in §142.60(c) is technically feasible, economically reasonable, and will achieve TTHM reductions commensurate with the costs incurred with the installation and/or use of such treatment method for the system, the Administrator or primacy state shall require the system to install and/or use that treatment method in connection with a compliance schedule issued under the provisions of Section 1415(a)(1)(A) of the Act. The Administrator's or primacy state's determination shall be based upon studies by the system and other relevant information. In no event shall the Administrator require a system to install and/or use a treatment method not described in §142.60 (a) or (c) to obtain or maintain a variance from the TTHM Rule or in connection with any variance compliance schedule.

3.4.5 BAT Summary

Table WT.12 summarizes the best technologies for removing the City's primary CoC - nitrate, arsenic, and fluoride.

Table WT.12 Best Available Treatment Technologies for Nitrate, Arsenic and Fluoride Water Technology Assessment Report City of Surprise			
	Nitrate Removal	**Arsenic Removal**	**Fluoride Removal**
Best Available Technologies		***Activated Alumina Absorption***	***Activated Alumina Absorption***
	Reverse Osmosis	**Reverse Osmosis**	**Reverse Osmosis**
	Electrodialysis	**Electrodialysis**	**Electrodialysis**
	Ion Exchange	**Ion Exchange**	
		Coagulation/Filtration (not BAT for systems < 500 service connections)	
		Lime Softening (not BAT for systems <500 service connections)	
		Oxidation/Filtration (To obtain high removals, iron to arsenic ratio must be at least 20:1.)	
Other Technologies	Drinking Water Biological Filtration		***Coagulation / Filtration***
			Ion Exchange

Note:
(1) Bolded technologies are common for all three critical CoC. Technologies shown in Bold and Italic are common for two critical CoC.

3.5 Residual Disposal Regulations

As part of Section 6.0, the technology assessment accounts for the volume of residuals each technology alternative produces, the handling and disposal of the residuals, and the residuals handling costs. Moreover, residuals handling and disposal associated with the implementation of each recommended technology alternative are discussed in Section 6.11. This section briefly reviews the regulatory basis for residual disposal.

Residuals from the City's WSFs could potentially include wastes in both solids form (dewatered backwash wastes, exhausted adsorption medias, replaced ion exchange resins, etc.) and liquid form (filter spent water, rinse water, resin regeneration waste, brines, etc.). Liquid form residuals may be treated to recover more water, separate solids from water, and reduce the residual volume. Solids residuals are typically disposed of in a municipal landfill or monofilled.

To be disposed of in a solid waste landfill, the waste must pass a paint filter test, be non-hazardous, and contain less than 50 parts per million of polychlorinated biphenyls. Resource Conservation Recovery Act (RCRA) and the state's solid waste regulations will govern the final disposal for a sanitary landfill. Under current RCRA guidelines, the water plant residuals must be classified as non-hazardous by passing the Toxicity Characteristics Leaching Procedure (TCLP) test. The TCLP test sets maximum concentration limits on contaminants that are considered toxic. Included in the list is arsenic < 5.0 mg/L and lead < 5 mg/L. The presence of any of the listed contaminants at or above the regulatory level deems the substance hazardous and prohibits disposal in a solid waste landfill. Conventional WTP residuals typically pass the TCLP test.

Federal waste regulations would also prevent sanitary landfills from receiving any wastes that contain free-flowing liquids as determined by Paint Filter Solids Tests. Water treatment plant residuals generally must have a solids concentration of 18 to 25 percent to pass this test.

4.0 DRINKING WATER TREATMENT STANDARDS

To ensure the provision of safe drinking water to its customers, the City of Surprise has set uniform water quality treatment standards for all water supply facilities within the City limits. All future water supply facilities shall be designed to achieve these water quality requirements. This section establishes these standards and provides policy justifications and regulatory basis for each.

4.1 Existing City of Surprise Water Quality Standards

Prior to this project, the City of Surprise had adopted a specific set of drinking water quality standards, as documented in the City of Surprise Water Guidelines and Standards (Revised June 2006). Per these standards, any new drinking water source should not exceed any of the following:

- Seventy (70) percent of the most current State of Arizona Drinking Water MCLs
- Seventy (70) percent of the most current Federal Primary Drinking Water MCLs
- City of Surprise Supplemental Drinking water MCLs (Table WT.13)

Table WT.13 City of Surprise Supplemental Drinking Water Maximum Contaminant Levels Water Technology Assessment Report City of Surprise		
Contaminant Name	**Arizona Department of Environmental Quality Contaminant Code**	**Maximum Contaminant Level (MCL)**
Alkalinity	1927	150 mg/L
Arsenic	1005	7.0 μg/L
Copper	1022	1.0 mg/L
Escherichia *Coli*	3013	0 CFU/100 mL
Fluoride	1025	2.0 mg/L
Hardness, Calcium (as $CaCO_3$)	1918	100 mg/L
Lead	1030	0.010 mg/L
Nitrate (as N)	1040	7.0 mg/L
Nitrite (as N)	1041	0.70 mg/L
PH	1925	6.5 – 8.5
Sodium	1052	120 mg/L
Sulfate	1055	90 mg/L
Temperature	1996	33 °C
Total Coliform	3000	0 CFU/100 mL
Total Dissolved Solids	1930	450 mg/L

Note:
(1) Data adapted from Table 1 in the City of Surprise Water Guidelines and Standards (Revised 2006).

4.2 Basis for Establishing New Water Quality Standards

As part of the technology assessment, the City's original water quality standards were revised to incorporate updated regulatory information, current City direction, and input from participating developer's representatives. These revisions established a new set of water quality standards, which balance protection of water quality for City residents and the treatment costs (both capital and O&M) required to achieve the desired quality. The standards help the City to attract development and investment within the City limits and strengthen the partnership with the developers without compromising customer's confidence in the City's drinking water. The following list summarizes several potential regulatory bases for establishing the City's new water quality standards. The team reviewed each in detail to assist in determining the most appropriate standards for the City

1. The City's standards must be set to comply with the current federal or state primary MCLs requirements.
2. The City's standards should avoid public notification/action levels triggered by federal or state regulations.

3. The City's standards should avoid more intensive monitoring triggered by federal or state regulations.
4. The City's standards should allow a reasonable operational safety factor based on fair engineering determination and the state and Maricopa County Environmental Services Department (MCESD) practices.
5. The City's standards should be consistent other utilities' current water quality goals and industry standards (e.g., "AWWA standards").
6. The City's standards should consider future federal or state regulations that are reasonably expected to become effective within the next five to ten years (also defined as the "Study Period" for the Water Technology Assessment).
7. The City's standards should be set with consideration for contaminant specific or technology specific economic implications and environmental responsibility, if such implications can be demonstrated with reasonable effort.

Each of the basis for establishing new water quality standards is discussed in the following sections.

4.2.1 Primary MCL Requirements

The City's standards must be set to comply with the current federal or state primary MCL requirements, Therefore, all primary MCLs have been adopted as the City's water quality standards (Basis No. 1).

4.2.2 Drinking Water Regulations and Public Notifications

To understand the implications associated with setting standards to avoid public notification/action levels triggered by federal or state regulations, the team consulted federal and state regulatory representatives.

The USEPA 816-R-07-003 Revised Public Notice Handbook (March 2007) established the framework for public notification. It provides guidelines on when, how, and to whom public notices must be given. A quick reference guide of the Public Notification Rule can be found on USEPA website
at http://www.epa.gov/safewater/publicnotification/pdfs/qrg_publicnotification.pdf

In general, public notice is required for any of the following violations:

- Exceedances of MCLs or maximum residual disinfectant levels;
- Violation of treatment techniques;
- Monitoring and testing procedure violations; and
- Failure to comply with the schedule of a variance or exemption.

Other situations (not violations), which require notice include:

- Operation under a variance or exemption;
- Occurrence of a waterborne disease outbreak or other waterborne emergency;
- Exceedance of the secondary maximum contaminant level for fluoride;
- Availability of unregulated contaminant monitoring results; and
- Exceedance of the nitrate MCL in non-community systems that have been granted permission by the primacy agency to continue to exceed the nitrate MCL of 10 mg/L (although they must not exceed 20 mg/L).

ADEQ, the primacy agency, adopted the federal public notification framework without significant additional/more stringent requirements. The state generally required that public notification be given when the MCLs or the secondary MCL for fluoride is exceeded.

No public notification is required when the contaminant levels in the drinking water are approaching a percentage of the MCL. The water quality data should be recorded in the annual water quality monitoring report and published in the CCR. Health information language about the contaminants should also be included in the CCR.

In summary, public notification is required when the MCL for any contaminant or the SMCL for fluoride is exceeded. To avoid public notification, which can undermine customer's confidence in the City's drinking water quality, the City determined that all WSFs must treat water to meet all MCLs and the SMCL for fluoride.

4.2.3 Monitoring Frequency

The USEPA document titled "Standardized Monitoring Framework (SMF): A Quick Reference Guide" provides an overview of the monitoring framework. This document defines the monitoring frequency after the start-up and initial compliance of a facility.

The start-up and initial compliance refers to the equipment testing and monitoring, the seven-day testing, and subsequent weekly, monthly, and the quarterly monitoring. After the facility passes the initial compliance, the standardized monitoring framework defines how often a contaminant must be monitored and reported to the state.

The monitoring frequency depends on contaminant categories (inorganic compound, synthetic organic compound, volatile organic compound, nitrate, etc.) and the source water contaminant levels. This document can also be used to determine the change in monitoring frequency when the source water contaminant levels change.

For the inorganic category (including arsenic and fluoride), there is no percentage of the MCL that triggers a monitoring frequency change. The SMF requires one annual sample at each entry point to the distribution system, taken during the quarter, which previously resulted in the highest analytical results, if:

1. The source is surface water and all 4 quarters of results are less than 50 percent MCL; or
2. The source is groundwater and the water quality is reliably and consistently less than the MCL.

If the result is greater than or equal to 1/2 MCL (for surface water), four quarterly samples at each entry point to the distribution system are required. As the City's primary water supply is groundwater, this modification would only apply if the sample was 100 percent of the MCL. In general, there is no specific percentage of the MCL (or levels more stringent than the MCL) defined in the federal or state regulations that would trigger a change in monitoring frequency. Therefore, this regulatory basis does not support the justification of any standards that are more stringent than the MCL.

Note:

The term "report level" or "reporting level" is not used in the drinking water regulations. Regardless of the contaminant level, all monitoring results must be reported to the state at the frequency defined by the Standardized Monitoring Framework.

Similarly, the term "alert level" is not used in the drinking water regulations, except for the Aquifer Protection Permit (APP). See the subsequent section of this document associated with the Aquifer Protection Permit and aquifer water quality standards for additional information.

4.2.4 Targeting Value for Design and Operational Safety Factor

To understand the implications associated with establishing standards to allow a reasonable operational safety factor based on fair engineering determination and the state and MCESD practices, Carollo consulted the various federal, state, and county regulatory representatives.

Federal regulations do not define a percentage of the MCL or water quality standards as a trigger to any action or recommended target value for design and operational purposes. However, it is common practice for the engineering review programs at the state (or in the case of the City, MCESD) to consider 80 percent of the MCL for critical contaminants (e.g., 8 µg/L of arsenic, 8 mg/L nitrate, and 80 percent of the TTHMs and HAAs) as a target design value to provide a safety factor, considering operational variations. While agencies recommend this reduced target design level, their policy is generally not to adopt any fixed percentage as a universal design guideline, as all engineering design must be approved on case-by-case basis.

If a system can demonstrate compliance through comprehensive engineering assessments, which may include pilot-scale testing studies, the state or county engineering review may approve a design that is based on a different safety factor. The engineering review program at MCESD should be consulted for site-specific approval of various treatment technology design guidelines, if the City or the developer wishes to conduct a demonstration study. This approach provides flexibility for innovative technologies that can provide significant cost or operational savings or water quality benefits.

In summary, MCESD's recommended design target values provide justification for the establishment of standards more stringent than the MCLs. While the team agreed that a broad application of reduced standards may be cost prohibitive and unnecessary, it is reasonable for the City to adopt reduced standards specifically for the City's identified constituents of concern, as outlined below.

- 80 percent of the MCL for arsenic;
- 80 percent of the MCL for nitrate;
- 80 percent of the MCL for TTHMs and HAAs (based on LRAA).

Note:

Engineers and designers often apply safety factors to the design to assist in ensuring compliance with water quality standards. The engineers/designers of the treatment facilities should be made aware of the consequences of exceeding the City's reduced "Standards" to assist in developing and incorporating sufficient safety factors into the design. (Noted in Section 4.3.)

4.2.4.1 Health Advisory Level

Drinking water and health advisory summary tables are prepared periodically. They can be downloaded at http://www.epa.gov/waterscience/criteria/drinking/. These tables contain drinking water standards in the form of non-enforceable concentrations of drinking water contaminants, MCLGs, or enforceable MCLs. Health advisories provide information on contaminants that can cause human health effects and are known or anticipated to occur in drinking water. Health advisories are guidance values based on non-cancer health effects for different durations of exposure (e.g., one day, ten day, and lifetime). They provide technical guidance to USEPA's regional offices, state governments, and other public health officials on health effects, analytical methodologies, and treatment technologies associated with drinking water contamination.

In summary, health advisory levels represent an estimate of acceptable drinking water contaminant levels for a chemical substance based on health effects information. They are not legally enforceable federal standards, but serve as technical guidance to assist federal, state, and local officials. The health advisory level water quality standards are provided as

guidance levels only and would be difficult to justify as an indiscriminate basis for establishing the City's water quality.

4.2.5 Comparison to Other Cities' Water Quality Goals

Carollo reviewed the water quality goals of other cities throughout the valley/state to serve as a baseline and point of comparison for establishing the City's water quality standards. These reviewed standards are summarized in Table WT.14.

Table WT.14 List of Other Cities used in Comparison of Water Quality Goals
Water Technology Assessment Report
City of Surprise

City/Standard	Date
Existing City of Surprise Water Guidelines and Standards	Revised June 2006
City of Phoenix Lake Pleasant WTP Water Quality Sampling and Testing Study	2001
City of Phoenix Water Quality Master Plan Update Amendment	2008
Town of Gilbert Surface Water Treatment Plant Expansion Study	1999
Town of Gilbert South Water Treatment Plant Pre-Design Report	2005
City of Tempe Johnny G. Martinez WTP 30 mgd Expansion Study Report	2002
City of Yuma Water Quality Management Plan	2005
City of Mesa Water Master Plan	2004
City of Scottsdale 2008 Scottsdale Integrated Water Master Plan	2008
Chandler Integrated Master Plan Update	2008

The City of Phoenix Water Quality Goals were originally recommended as the basis for the City of Surprise's water quality standards. The Phoenix goals were developed and recently validated by water quality focus groups including leading water industry experts such as Phil Singer, Gary Amy, Stuart Krasner, Mike McGuire, Paul Westerhoff, Fred Cannon, Larry Baker, David Cornwell, Charles Gerba, Bill Knocke, Mel Suffet, David Walker, etc. The Phoenix water quality goals were based on an extremely extensive review of current and future regulations, industry trends, emerging contaminants, issues and technologies, and adopted numerical values for a wide range of contaminants.

The City of Tempe and Town of Gilbert took a similar (although somewhat less extensive) approach and have also developed a wide-ranging list of water quality goals. However, other cities, such as the City of Mesa and City of Yuma, have developed goals that focus only on the critical water quality issues for their specific systems. For example, the City of Mesa's Water Master Plan adopted goals for only five parameters including disinfection byproducts, taste and odor, arsenic, nitrate, and temperature.

For most of the cities referenced above, the water quality goals are not intended to be a comprehensive list of regulated standards. Instead, the listed goals are a guideline of

parameters, which require routine monitoring and control measures. More importantly, these “reference” standards often vary significantly. For example, the arsenic goals for these cities range from 0.005 to 0.008 mg/L, the nitrate goals range from 5 to 10 mg/L, and the fluoride goals range from 0.8 to 2 mg/L. A summary of the water quality goals for each reference city is included in Table WT.15 for the City of Surprise identified CoC.

Table WT.15 Other Cities Within the Phoenix Metropolitan Area Water Quality Goals Water Technology Assessment Report City of Surprise

	MCL (SMCL)	Phoenix (2008)	Gilbert (2005)	Tempe (2002)	Mesa (2004)	Scottsdale (2008)	Existing Surprise Standards	Range
Nitrate	10	8	-	10	5	-	7	5 -10
Arsenic	0.010	0.005	0.005	0.01 (when MCL was 0.05)	0.008	0.008	0.007	0.005 -0.008
Fluoride	4 (2)	2	0.8	2	-	-	2	0.8 - 2

While these existing water quality goals serve as a reasonable reference point, they do not necessarily assist in achieving a consensus as they provide potential justification for a wide range of standards.

4.2.5.1 AWWA Standards

The term “AWWA Water Quality Standards” is a misnomer. AWWA Water Quality Standards did exist in the past and were widely referenced in many early studies in the 1970 to 1980s. Their origin can be traced to the early editions of two AWWA publications: the Water Treatment Plant Design Handbook (ASCE and AWWA) and Water Quality and Treatment - A Handbook of Community Water Supplies (AWWA). Before USEPA was established in 1970, AWWA and other trade organizations adopted water quality goals based on U.S. Department of Health standards. These goals, published in the 2nd Edition of the Water Treatment Plant Design Handbook, were referred to as AWWA goals. After USEPA was established, the newer version of the Handbook (e.g., 4th and 5th Editions) referred to these goals as USEPA standards.

4.2.6 Future Expected Federal and State Drinking Water Regulations in the Near Term

The team researched and evaluated future federal or state regulations that are reasonably expected to become effective within the next five to ten years, to understand their potential impact on establishing water quality standards for the City of Surprise. As described throughout this document, the study period considered for the Water Technology Assessment is approximately five to ten years. It is not anticipated that the City’s groundwater sources will be impacted by any future regulations during the study timeframe.

Consequently, no provisions were made in the established City standards to account for future regulations.

4.2.7 Contaminant Specific or Technology Specific Economic Implications

The team also evaluated water quality standards with consideration for contaminant specific or technology specific economic implications and environmental responsibility, if such implications can be demonstrated with reasonable effort. Although no intense economic analysis was included in this study, the criteria used for ranking technology alternatives included capital and O&M cost components. In addition to these criteria, the analysis also included planning level capital, O&M, and life cycle costs for each technology alternative being evaluated. No "triple-bottom-line" studies were performed to fully address the economic, environmental, and social aspects related with the water treatment facilities. However, specific criteria evaluated/included in the technology assessment (e.g., air quality impacts, energy usage) generally represent environmental and social aspects. Consequently, while specific or technology specific economic implications and environmental responsibility do not necessarily directly impact establishment of the City's water quality standards, since the criteria and the weighting factors included in the evaluation reflect the City's current values and priorities, the implications are indirectly addressed in the technology selection and assessment.

4.3 City of Surprise Water Quality Standards

Based on the above discussion, the following water quality standards were established for the City of Surprise:

- 100 percent of the MCL for all regulated contaminants, unless otherwise noted
- Secondary MCL for fluoride
- 80 percent MCL for arsenic and nitrate
- 80 percent MCL for TTHMs and HAA5 (based on LRAA)
- No standards on non-regulated contaminants, unless specific evidence exists to indicate a goal will be established in the next five to ten years

Note: Variances from the above "standards" will be considered only if the design engineer can adequately demonstrate the acceptability of the proposed variance to the City and the County's satisfaction (e.g., through pilot testing, etc.).

Table WT.16 provides a summary of the policy justifications and regulatory basis for the City's water quality standards.

Table WT.16 Justification of City of Surprise Water Quality Standards Water Technology Assessment Report City of Surprise	
Water Quality Standards	**Justifications**
100% MCL	Required to comply with the current federal or state primary MCLs requirements.
Secondary MCL for Fluoride	Required to avoid public notification triggered by current alert levels.
80% MCL for Arsenic and Nitrate 80% MCL for TTHM and HAA5 (based on LRAA)	Recommended standards "below" the MCLs are focused specifically on the City's identified constituents of concern. The City's standards for these constituents are set to allow a reasonable process control buffer considering technology specific and operational variations. The standards are consistent with typical engineering and the State and MCESD practices.
No standards on non-regulated contaminants	Standards for non-regulated contaminants are not required. It is not anticipated that the City's groundwater sources will be impacted by any future regulations during the 5-10 study timeframe.

5.0 GROUNDWATER QUALITY

5.1 Historical Groundwater Quality Data

Available water quality data for several of the City's existing wells was summarized in the IWMP-Water Infrastructure Report. Table WT.17 includes the water quality data presented in the IWMP.

Because the data represent only one sampling event for each well, the values may not be representative of long-term trends in the wells and the associated groundwater. However, the data provide a reasonable indication of potential water quality problems. For example, arsenic in all samples exceeded the City's goal of 8 micrograms per liter (µg/L) and the federal MCL of 10 µg/L. Fluoride in one well (Litchfield Manor) was equal to the secondary MCL, but was below the primary MCL of 4 mg/L. All other parameters were below their respective MCLs.

Table WT.17 Water Quality Data from the IWMP - Water Infrastructure Report
Water Technology Assessment Report
City of Surprise

Parameters (Units)	Arsenic (µg/L)	Fluoride (mg/L)	Nitrate (mg/L)	Sulfate (mg/L)	pH (SU)	Alkalinity (mg/L)	Calcium Hardness (mg/L)	TDS (mg/L)
Maximum Contaminant Level	10	4	10	-	-	-	-	-
Secondary Maximum Contaminant Level	-	2	-	250	6.5 - 8.5	-	-	500
SPA 1								
Mountain Vista Ranch WSF								
Mountain Vista Ranch	-	-	-	-	-	-	-	-
Ashton Ranch WSF								
Ashton Ranch 1	-	-	-	-	-	-	-	-
Orchards	***14***	0.8	1					290
City of Surprise Well	-	-	-	-	-	-	-	-
Royal Ranch	**8**	0.5	7.1	84	8.1	120	59	390
Sierra Verde	***12***	1.2	1.6	77	8.1	120	51	360
Roseview WSF								
Roseview	***12***	1.7	1.1	31	8.1	148	49	350
Litchfield Manor	***48***	**2.0**	1.1	33	8.1	140	10	250
Rancho Gabriela WSF								
Rancho Gabriela 1	-	-	-	-	-	-	-	-
Rancho Gabriela 2	***12***	1.7	3.1	80	7.9	94	35	400
Marley Park 1	***11***	1.1	4.4	81	7.5	100	53	400
SPA 2								
Desert Oasis WSF								
Desert Oasis W1	-	-	-	-	-	-	-	-
Desert Oasis W2	***27***	0.9	0.6	20	8.3	110	27	260

Notes:
(1) Data adapted from Table 3-2 of the IWMP-Water Infrastructure (FINAL 2009). Table modified to include MCL.
(2) ***X.XXX*** (Bold and Underlined) Values Exceeding MCL
(3) **X.XXX** (Bold) Values Exceeding City of Surprise WQ Standards

As part of the Water Technology Assessment, additional water quality information, including 2009 water quality data along with well completion reports from many of the existing wells within the City limits, was evaluated. Table WT.18 summarizes 2009 water quality data including fluoride, nitrate, nitrite, and arsenic data for wells throughout the City, including the count, average, minimum, and maximum values. Only a few data points were available at each sampling location. Based on the 2009 water quality data set, arsenic exceeds the City's water quality standard in eight of the fifteen locations provided, nitrate exceeds the City's water quality standard in two of the locations, and fluoride is approaching the City's water quality standard in two of the locations. While these data provide further insight into the City's potential water quality concerns, the data still represent only a "snapshot" in time and may not indicate the long-term water quality.

Table WT.19 summarizes the water quality from the well completion reports for wells located throughout the City. Parameters listed in the table are contaminants that may require treatment or parameters that may impact the effectiveness of treatment. Based on evaluation of the well completion reports and other miscellaneous water quality data, three major CoC were identified and confirmed - nitrate, arsenic, and fluoride. No other CoC were identified based on the data review and subsequent conversations with City staff.

Arsenic is considered a CoC for the City of Surprise groundwater supply because historic water quality data indicated that arsenic levels in multiple wells exceed the primary drinking water standard of 10 µg/L. Arsenic was also identified in the IWMP as a CoC for the City. To date, the City's has five arsenic treatment facilities.

Nitrate is considered a CoC for the City of Surprise groundwater supply because historic water quality data indicated that nitrate levels in multiple wells are close to exceeding the City's current Water Quality Standard of 8 mg/L. Nitrate was also identified in the IWMP as a CoC for the City. To date, none of the City's existing water supply facilities are equipped with nitrate treatment. However, nitrate levels at many facilities are nearing levels which would require treatment.

Fluoride is considered a CoC for the City of Surprise groundwater supply because historic water quality data indicates that fluoride levels in a small number of wells have reached the City's current Water Quality Standard and SMCL of 2 mg/L and multiple wells are approaching fluoride levels of 2 mg/L. Fluoride was also identified in the IWMP as a CoC for the City. To date, none of the City's existing water supply facilities is equipped with fluoride removal systems. However, fluoride levels at many facilities are nearing levels which would require treatment.

Table WT.18 2009 City of Surprise Water Quality Data
Water Technology Assessment Report
City of Surprise

Parameters (units) MCL	Arsenic (mg/L) 0.010				Fluoride (mg/L) 4.0				Nitrate (mg/L) 10.0				Nitrite (mg/L) 1.0			
	Count	Average	Maximum	Minimum	Count	Average	Maximum	Minimum	Count	Average	Maximum	Minimum	Count	Average	Maximum	Minimum
SPA 1																
Mountain Vista Ranch WSF	2	0.0058	0.0059	0.0056	1	0.57	0.57	0.57	2	4.76	4.89	4.62	1	< 0.1	< 0.1	< 0.1
Mountain Vista Ranch	1	0.0059	0.0059	0.0059	1	0.59	0.59	0.59	1	4.55	4.55	4.55	1	< 0.1	< 0.1	< 0.1
Ashton Ranch WSF	2	0.0057	0.0057	0.0056	1	0.92	0.92	0.92	2	3.27	3.36	3.17	2	< 0.1	< 0.1	< 0.1
Ashton Ranch 1	2	0.0077	0.0078	0.0075	1	0.69	0.69	0.69	2	3.34	3.53	3.14	2	< 0.1	< 0.1	< 0.1
Orchards	2	***0.0165***	***0.0168***	***0.0162***	1	0.89	0.89	0.89	1	1.11	1.11	1.11	1	< 0.1	< 0.1	< 0.1
City of Surprise Well	1	**0.0083**	**0.0083**	**0.0083**	1	0.95	0.95	0.95	1	1.06	1.06	1.06	1	< 0.1	< 0.1	< 0.1
Royal Ranch	2	0.0049	0.0065	0.0032	1	0.61	0.61	0.61	2	5.11	**8.39**	1.83	2	0.12	0.14	< 0.1
Sierra Verde	1	***0.0122***	***0.0122***	***0.0122***	1	1.42	1.42	1.42	1	1.15	1.15	1.15	1	< 0.1	< 0.1	< 0.1
Roseview WSF																
Roseview	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Litchfield Manor	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Rancho Gabriela WSF	4	0.0052	0.0088	0.0037	1	0.89	0.89	0.89	2	5.64	6.04	5.23	2	< 0.1	< 0.1	< 0.1
Rancho Gabriela 1	2	**0.0095**	**0.0109**	**0.0081**	1	0.82	0.82	0.82	2	7.05	**8.15**	5.95	2	< 0.1	< 0.1	< 0.1
Rancho Gabriela 2	1	***0.0114***	***0.0114***	***0.0114***	1	0.99	0.99	0.99	1	4.00	4.00	4.00	1	< 0.1	< 0.1	< 0.1
Marley Park 1	5	***0.0103***	***0.0146***	0.0040	1	1.48	1.48	1.48	5	3.92	6.08	2.44	5	< 0.1	< 0.1	< 0.1
SPA 2																
Desert Oasis WSF	1	0.0071	0.0071	0.0071	1	0.73	0.73	0.73	1	0.62	0.62	0.62	1	< 0.1	< 0.1	< 0.1
Desert Oasis W1	1	***0.0164***	***0.0164***	***0.0164***	1	0.74	0.74	0.74	1	0.63	0.63	0.63	1	< 0.1	< 0.1	< 0.1
Desert Oasis W2	1	***0.0264***	***0.0264***	***0.0264***	1	0.94	0.94	0.94	1	0.65	0.65	0.65	1	< 0.1	< 0.1	< 0.1

Notes:
(1) Data from 2009 Water Quality Data provided in spreadsheet titled "WQ No2,No3,F,As @ WSF WELLS 2009"
(2) ***X.XXX*** Values Exceeding MCL
(3) **X.XXX** Values Exceeding City of Surprise WQ Standards

Table WT.19 City of Surprise Well Completion Report Water Quality Summary
Water Technology Assessment Report
City of Surprise

Well	Date of Well Completion Report	Parameter															
		Arsenic (mg/L)	Sodium (mg/L)	Fluoride (mg/L)	Nitrate (mg/L as N)	Sulfate (mg/L)	Chloride (mg/L)	Iron (mg/L)	Manganese (mg/L)	TOC (mg/L)	TDS (mg/L)	pH (pH units)	Alkalinity (mg/L as CaCO3)	Calcium (mg/L)	Magnesium (mg/L)	Silica (mg/L)	Phosphorous (mg/L)
Desert Oasis Well 1 & 2	May-03	**0.027**	<0.50	0.92	0.63	20	-	-	-	-	260	8.28	110	11	1.5	-	-
Litchfield Manor Well 1	Nov-03	**0.048**	86	**2.0**	1.1	33	28	-	-	-	250	8.1	140	4.2	<1.0	-	0.056
Rancho Gabriela Well 2	Feb-03	**0.012**	110	1.7	3.1	80	-	-	-	-	400	7.9	94	-	-	-	-
Roseview Well 1	Apr-99	**0.012**	94	1.7	1.1	31	-	-	-	-	250	8.1	148	15	3	-	-
Sierra Verde Well 1	Feb-04	**0.012**	82	1.2	1.6	77	55	-	-	-	360	8.11	120	20	-	-	-
Summit Business Park Well 2	Mar-08	**0.040**	120	**2.4**	6.3	45	-	0.074	ND		330	8.25	120	15	5.1	25	ND
Surprise Pointe	Sep-07	**0.016**	88	0.98	1.5	32	-	-	-	-	240	8.2	120	-	-	-	-
Royal Ranch Well 1	May-02	**0.0084**	-	0.52	7.1	84	-	-	-	-	390	8.14	120	24	-	-	-
Marley Park Well 1	Jan-04	**0.011**	88	1.1	4.4	81	73	-	-	-	400	7.49	100	21	-	-	-
Surprise Center Well 1	Oct-06	**0.018**	100	0.95	0.89	75.3	-	-	-	-	281	8.5	136	12	7	-	-
Fox Trails Well 1	Feb-02	**0.0084**	48	0.70	1.0	15	-	-	-	-	170	8.24	110	-	-	-	-
Beardsley Water Company(1)	2008	0.0031	42	0.62	1.4	-	-	-	-	-	-	-	-	-	-	-	-
Average		**0.018**	86	1.23	2.5	52	52	0.074	-	-	303	8.1	120	15	4	25	0
Minimum		0.0031	42	0.52	0.6	15	28	0.074	-	-	170	7.5	94	4.2	1.5	25	0.056
10th Percentile		**0.008**	47	0.63	0.9	20	33	0.074	-	-	240	7.9	100	9	2.0	25	0.056
50th Percentile		**0.012**	88	1.04	1.5	45	55	0.074	-	-	281	8.1	120	15	4.1	25	0.056
90th Percentile		**0.039**	111	1.97	6.1	81	69	0.074	-	-	400	8.3	140	22	6.4	25	0.056
Maximum		**0.048**	120	**2.40**	7.1	84	73	0.074	-	-	400	8.5	148	24	7	25	0.056
MCL		0.010		4.0	10												

Notes:
(1) Data collected for the Beardsley Water Company is from the 2008 Consumer Confidence Report average water quality. Well is located in City of Surprise SPA 3.
(2) ND = Non-Detect
(2) ***X.XXX*** Values Exceeding MCL
(3) **X.XXX** Values Exceeding City of Surprise WQ Standards

As noted previously, the City does not currently treat for fluoride or nitrate. However, several wells in the City have fluoride and nitrate levels approaching or slightly above the City and state fluoride MCL. For those wells that exceed the MCL, the City uses blending as a means of treatment. In addition, the City has recently completed the construction of a 6,000-gpm conventional coagulation/filtration arsenic treatment plant, and an arsenic adsorption treatment plant.

5.2 THM Studies

The City's existing groundwater supplies have a relatively low TOC. As a result, disinfection byproduct (DBP) formation is not expected to be a concern as long as the City continues to use groundwater as its primary source of drinking water. Table WT.20 includes a sample of DBP information from various locations throughout the existing distribution system. As indicated in the table, no DBP values exceed the MCLs for TTHM or HAA of 80 µg/L and 60 µg/L, respectively.

5.3 Future Groundwater Quality and Sustainability

The City's current groundwater supply is sufficient to meet present demands. However, alternative options may need to be explored if the groundwater supply is not sufficient/sustainable to meet future demands, if the groundwater quality changes significantly, or if social, economic, or political drivers develop. The IWMP documented the potential to utilize CAP water to help replenish the groundwater supply in the future. The recharge of CAP water may have an impact on the groundwater quality over time.

Groundwater quality is continuously changing. Previous studies (such as the Central Arizona Salinity Study and the Appraisal Level Study of a Brackish Water Treatment Plant, City of Goodyear, 2005) have identified the potential change in groundwater flow and quality. Such changes may impact the City's groundwater quality over time, including increasing TDS. Current TDS concentrations in the City's groundwater sources range from 200 to 400 mg/L in data collected from well completion reports. While these concentrations are below typical levels of concern, changes in groundwater flow direction could introduce higher TDS concentrations to the City's groundwater supplies. Consequently, it is recommended that the City embark on a groundwater modeling and sampling study to address critical unknowns in the future groundwater supply and assist in better preparing the City for future water treatment requirements.

This report will briefly describe various desalination technologies in general terms. While technologies such as RO may be evaluated for the purpose of arsenic / fluoride / nitrate treatment, desalination treatment will not be specifically evaluated in detail as the City is not likely to experience high levels of TDS (consistently above 750 mg/L) over the study period (i.e., five to ten years).

Table WT.20 Disinfection Byproduct Formation within the Distribution System
Water Technology Assessment Report
City of Surprise

Address	TTHM				HAA			
	Average (µg/L)	Minimum (µg/L)	Maximum (µg/L)	Count	Average (µg/L)	Minimum (µg/L)	Maximum (µg/L)	Count
14676 154th Lane	3.8	1.9	8.6	11	0.4	0	3.8	10
14414 Mandalay	2.1	0.7	3.4	11	0.1	0	1.4	10
15451 Desert Mirage	11.8	5.3	18.4	11	1.0	0	4.3	10
13105 Calavar Rd	5.0	2.5	14.2	11	0.2	0	1.3	10

Notes:
(1) Data provided by Water Parameter History MV PWS spreadsheet provided by the City.
(2) Data collected from March 2005 to September 2007.

5.4 Water Quality Constituents of Concern

The following summarizes the critical and potential water quality CoC for the City of Surprise water supply system.

5.4.1 Critical Constituents of Concern

Based on previously identified CoC in the IWMP and a review of existing water quality data (highlighted data in Tables WT.17 through 19), three critical CoC were identified. For these parameters, the source water contaminant levels exceeded or approached the MCLs or the City's established water quality standards (See Section 4.0). The City's water treatment facilities shall be designed to sufficiently remove these constituents. Table WT.21 summarizes these CoC and their treatment standards. The Water Technology Assessment focuses on the treatment processes of these critical CoC.

Table WT.21 City of Surprise Drinking Water Quality Constituents of Concern
Water Technology Assessment Report
City of Surprise

Water Quality Parameters	USEPA MCL	USEPA SMCL	City of Surprise WTP WQ Standards	Occurrences in City's Existing Water Supply Wells(1)
Critical Constituents of Concern				
Arsenic	0.010 mg/L	NS	0.008 mg/L	9 out of 12 wells exceeded the MCL for arsenic and 11 out of 12 wells exceeded the City's Water Quality Standard.
Fluoride	4.0 mg/L	2.0 mg/L	2.0 mg/L	2 out of 12 wells exceeded the SMCL for fluoride and 2 out of 12 wells exceeded the City's Water Quality Standard.
Nitrate As Nitrogen	10 mg/L	NS	8 mg/L	0 out of 12 wells exceeded the MCL or the City's Water Quality Standard for nitrate. However, nitrate levels at many facilities are nearing levels which would require treatment.

Notes:

(1) Data from Well Completion Reports summarized in Table WT.19.

Abbreviations:

MCL = Maximum Contaminant Level. The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to MCLGs as feasible using the best available treatment technology and taking cost into consideration. MCLs are enforceable standards.

NS = No Numerical Standards

WQ = Water Quality

5.4.2 Other Constituents of Concern

Other CoC, such as turbidity, total coliforms, and virus can be concerns for groundwater supply systems. These parameters are not necessarily directly tied to numerical standards for groundwater supplies, but are a critical indicator of the treatment effectiveness relative to other contaminants or pathogens.

For instance, turbidity is not a primary or secondary drinking water standard. However, USEPA's surface water treatment rules require systems using surface water or groundwater under the direct influence of surface water to filter water such that at no time turbidity levels exceed 5 NTU. The Surface Water Treatment Rule (SWTR) requires that combined filter effluent from conventional or direct filtration plants must be less than or equal to 0.3 NTU in 95 percent of measurements each month, and combined filter effluent must always be less than 1 NTU. This criteria is also often accepted as the treatment goal for groundwater supply wells.

Other parameters, such as TTHMs, HAAs, total coliform, and virus are of critical importance to public safety. Although they are most commonly concerns for surface water supply systems and are not typically major issues for the City's groundwater supply, they do drive the treatment technology assessment for disinfection.

5.4.3 Potential Constituents of Concern

Other contaminants such as salinity (TDS, chloride, sodium, iron, and manganese) may potentially become a concern for the City's future water supply. Drinking water containing high TDS levels (> 700 mg/L) may taste bitter, salty, or metallic and may have unpleasant odors. High TDS water is less thirst quenching and makes food and beverages less desirable to consume. Some of the individual mineral salts that make up TDS pose a variety of health hazards, causing stiffness in the joints, hardening of the arteries, kidney stones, gallstones, and blockages of arteries. Elevated levels of chloride increases infrastructure corrosion issues. When water is being consumed and reused, the chloride concentrate in the reclaimed water can result in Whole Effluent Toxicity concerns and limit the reclaimed water disposal and reuse potential. High sodium levels in drinking water are often blamed for causing cardiac disease. If the tap water or reclaimed water is used for irrigation, the high sodium content, or a high sodium adsorption ratio (SAR), results in yield reduction and deterioration of physical soil conditions.

Iron and manganese is present in many wells in the Valley. High levels of iron and manganese deteriorate the drinking water quality and interfere with many treatment processes (e.g., fouling adsorption media, ion exchange resins, and membranes). Even though iron and manganese have not been an issue for the City's current production wells, they cannot be neglected from the potential CoC list for the City's future wells, given their sporadic and unpredictable occurrence.

N-Nitrosodimethylamine (NDMA) is not currently regulated by USEPA and its future regulation will depend on its occurrence in public water systems. Most common NDMA issues are introduced to water by chloramination. Although it is not anticipated that the City will implement chloramination to meet its THM and HAA requirements, the City still considers NDMA as a potential future CoC, given its strong toxicity and carcinogenicity.

While not anticipated to be an issue in the near term, as the City grows and demands increases, the impacts of these parameters may become more severe. In addition, drilling wells in new, previously undeveloped areas may yield new water quality concerns not apparent in the City's current water supply system. Consequently, it is recommended that the City embark on and maintain a source water sampling program to routinely monitor these parameters. The list of potential CoC should be revisited when updating the IWMP and the Water Technology Assessment Report in the future.

6.0 TREATMENT PROCESS EVALUATION

This section evaluates potential groundwater treatment processes for treating the CoC in the City's water sources to achieve the established drinking water quality standards.

6.1 Categories of Treatment Technologies

The groundwater CoC and the treatment standards were identified and established in Section 5.0. These CoC include:

- Critical CoC: Arsenic, fluoride, and nitrate.
- Other CoC: Turbidity, total coliform, virus, and TTHMs.
- Potential Future CoC: TDS, chloride, sodium, iron, manganese, and NDMA.

Table WT.22 summarizes the treatment categories that are anticipated for the City's WSFs. More than one treatment step is required to remove or control all the above CoC. For a given WSF, several categories, including pre-oxidation, coagulation and flocculation, filtration, advanced treatment (e.g., adsorption, ion exchange, desalination) and disinfection, may be required to treat the identified critical, other and potential CoC in the City's groundwater source and achieve the established finished water standards.

As illustrated in Table WT.22, different treatment categories target different CoC. For example, pre-oxidation can help improve the removal of arsenic, iron, and manganese. Adsorption is effective in removing arsenic and fluoride and can also reduce turbidity. Disinfectants protect water from microbial contamination (total coliform, virus, etc.) and protect against contamination in the distribution system. Strictly speaking, while DBPs are not the target CoC (rather byproducts) for the disinfection treatment category, their control is closely related with this treatment category.

Table WT.22 Categories of Treatment for Groundwater and the identified Constituents of Concern
Water Technology Assessment Report
City of Surprise

	Target CoC or Related Issues								
Treatment Categories	**Arsenic**	**Fluoride**	**Nitrate**	**Virus**	**Total Coliform**	**TDS**	**Turbidity**	**Iron and Manganese**	**DBPs**
Pre-oxidation	X							X	
Chemical Pretreatment	X	X					X	X	
Filtration	X	X	X	X	X		X	X	
Adsorption	X	X					X	X	
Ion Exchange	X	X	X			X		X	
Desalination	X	X	X	X		X	X	X(1)	
Disinfection				X	X				X(2)

Notes:
(1) Desalination technologies can remove iron and manganese. However, high levels of iron and manganese can cause severe membrane fouling.
(2) Strictly speaking, DBPs are not the target CoC (rather byproducts) for the disinfection treatment category. DBP control is closely related with this treatment category.

Generally speaking, mitigation strategies to reduce the formation of DBPs include reducing TOC concentrations in the water prior to chlorine addition, delaying chlorine addition, and reducing the applied chlorine dose (while still maintaining required levels for disinfection). Strategies for reducing DBP concentrations in the distribution system include minimizing water age and the storage reservoirs and optimizing chlorine residuals in the system (while still maintaining required residual concentrations).Given the low TOC levels in the current City water supply, it is not expected that DBPs compliance will be a challenge for the City's WSFs. Therefore, the technology assessment will not focus on DBP mitigation. It is not anticipated that the City will need to implement additional DBP mitigation strategies for the treatment systems or the distribution system.

Many of the proposed treatment categories (such as chemical pretreatment, adsorption, ion exchange, desalination, etc.) produce residuals that must be handled/disposed of. Residuals handling is a critical consideration in technology selection. Residuals treatment technologies associated with primary treatment categories are discussed in Section 6.11.

6.2 Treatment Technology Prescreening

In order to determine the most applicable and beneficial water treatment technologies for the City of Surprise, four principals were used to prescreen each of the treatment technology alternatives:

1. Technology alternatives must be capable of achieving the established treatment standards for the City.
2. Technology alternatives must be established, proven technologies that can be reliably implemented at full-scale without significant additional testing.
3. In general, technology alternatives were evaluated based on the contaminant removal mechanism. Individual manufacturers/equipment/commercial names were referenced, but generally not evaluated individually.
4. Technology alternatives that have specific local experience/application or which the City has indicated specific interest in were generally included in the evaluation.

Table WT.23 summarizes the prescreened treatment technology alternatives for each treatment category discussed above. Input from the City and the developer representatives are incorporated into the table. Each of the noted technology alternatives was considered a potentially viable option for the City's groundwater treatment and was recommended for further evaluation.

Table WT.23 Prescreened Treatment Technology Alternatives Water Technology Assessment Report City of Surprise		
Treatment Categories	**Prescreened Treatment Technology Alternatives**	**Functions**
Pre-oxidation	• Aeration Pre-oxidation / Stripping • Chlorine Pre-oxidation • Chlorine Dioxide Pre-oxidation • Ozone and Advanced Pre-oxidation • Potassium Permanganate Pre-oxidation	Oxidation can improve arsenic treatment, control of taste and odor and DBP formation.
Chemical Pretreatment	• Coagulation • Enhanced Coagulation • Enhanced Lime Softening	Pretreatment is critical for particulate matter (turbidity) removal, TOC and DBP reduction, and arsenic and fluoride removal. It enhances the removal of various CoC during downstream filtration processes.
Filtration	• Granular Media Filters • Microfiltration / Ultrafiltration (MF/UF) • Oxidizing Filters (Green Sand Filters) • Drinking Water Biological Filtration	Filtration removes particulate matter (colloidal material, pathogens, etc.). Aided by pretreatment steps, filtration can significantly reduce turbidity, arsenic, fluoride, TOC, etc. Drinking water biological filtration can remove nitrate, perchlorate, and other inorganic contaminants.
Advanced Treatment Operations (Adsorption, Ion Exchange, Desalination)	• Granular Iron Media Adsorption • Activated Alumina and Iron Modified Activated Alumina • Granular Activated Carbon (GAC) • Ion Exchange • Nanofiltration / Reverse Osmosis (NF/RO) • Electrodialysis / Electrodialysis Reverse (ED/EDR)	Advanced treatment, such as adsorption and ion exchange processes, remove critical CoC (arsenic, nitrate, and fluoride). Membrane processes remove dissolved inorganic and organic contaminants.
Disinfection	• Gaseous Chlorine Disinfection • Sodium Hypochlorite Onsite Generation Disinfection • Sodium Hypochlorite Bulk Disinfection • Chloramines Disinfection • Ozonation	Disinfection processes protect public safety by killing and inactivating pathogens (i.e., bacteria, viruses, *Cryptosporidium*, *Giardia)* in finished water. Selection of disinfection technologies must also consider impacts on DBP formation.

6.3 Three-Tier Technology Assessment

Sections 6.4 through 6.10 provide a detailed description for each of the prescreened treatment technology alternatives listed in Table WT.23. The sections include a general description of each technology, why it is applicable for the City's WSFs, how it works, and what critical implementation considerations may impact its applicability. Additional details associated with each technology can be found in the presentation material developed for Workshop TA2 (see Appendix B).

Based on the detailed evaluation in Sections 6.4 through 6.10 and input from the City and developer representatives, the original alternatives were further narrowed to a list of recommended alternatives for potential implementation. These recommended treatment technology alternatives were further evaluated using the SurpriseTree™ Water Model (see Section 7.0) by comparing the treatment processes using a three-tier evaluation consisting of performance based criteria evaluation, implementation based criteria evaluation, and financial evaluation criteria.

The performance based criteria evaluation utilizes a set of criteria established to identify the effectiveness of a treatment process in removing target CoC. As defined in Table WT.24, these criteria include particle removal, arsenic removal, nitrate removal, fluoride removal, iron and manganese removal, DBP control, and pathogen inactivation.

Table WT.24 Performance Based Criteria
Water Technology Assessment Report
City of Surprise

Performance Criteria	Definition / Description
Particle Removal	Does this option remove or help to improve the removal efficiency of particles? Is it subject to fouling by particles?
Arsenic Removal	Does this option remove or help to improve the removal efficiency of arsenic? What is the expected removal efficiency?
Nitrate Removal	Does this option remove or help to improve the removal efficiency of nitrate?
Fluoride Removal	Does this option remove or help to improve the removal efficiency of fluoride?
Iron and Manganese Removal	Does this option remove or help to improve the removal efficiency of iron and manganese? Is this option subject to iron and manganese fouling?
DBP Control	Does this option reduce the formation of chlorinated DBPs? Does this option produce other non-chlorinated DBPs (e.g., bromated) and emerging (non-regulated) DBPs?
Pathogens	Does this option provide log-removal credits for pathogens? Does this process help to improve the pathogen kill by other processes?

A table summarizing the performance of each treatment alternative relative to each of these criteria is included at the end of the each section.

The implementation based criteria evaluation focuses on the ability to effectively implement each treatment technology. The City and the developer representatives participated in the development of these criteria. Compared to the performance-based criteria, these criteria are more comprehensive, covering technical, environmental, economical, and social aspects. As defined in Table WT.25, this set of criteria includes O&M Costs, Capital Costs, Process Robustness, Maturity of Technology, City of Surprise Familiarity, Maintenance Intensity, Operation Flexibility, System Complexity, Process Footprint, Regulatory Requirements, Risks and Safety, Residuals Impacts/Handling, Versatility, Expandability and Air Quality Impacts.

Table WT.25 Treatment Process Implementation Based Criteria
Water Technology Assessment Report
City of Surprise

Water Process Screening Criteria	Definition / Description
O&M Costs	What are the annual operation and maintenance cost for the alternative?
Capital Costs	What are the equipment costs, initial installation costs, and construction costs for the alternative?
Process Robustness	Does the alternative provide sufficient treatment stability with expected source water quality variations? Is it more reliable than the other alternatives?
Maturity of Technology	Is the alternative mature in design and operation?
City of Surprise Familiarity	Does the City of Surprise have operational experience with this alternative? Is the City's operations staff familiar with the process associated with this alternative?
Maintenance Intensity	What are the maintenance requirements associated with the alternative?
Operation Flexibility	Does the alternative allow flexible operation to meet process control goals?
System Complexity	How complex is the equipment and required operation of the alternative?
Process Footprint	How much land area is required for the alternative?
Regulatory Requirements	What are the regulatory coordination efforts associated with implementation and operation of the alternative?
Risks and Safety	Does the alternative present concerns associated with process safety such as hazardous materials handling and process risk management?

Table WT.25 Treatment Process Implementation Based Criteria Water Technology Assessment Report City of Surprise	
Water Process Screening Criteria	**Definition / Description**
Residuals	What volume/type of residuals are produced by the alternative? How can the residuals generated by this alternative be treated/handled compared to other alternatives?
Versatility	Is the alternative versatile in removing multiple contaminants, including emerging concerns?
Expandability/Ultimate Capacity	Does the alternative provide a configuration that allows easy future expansion using a module design concept (to accommodate the ultimate treatment capacity on the site)?
Air Quality Impacts	What volume/type of air pollutants/emissions does the alternative generate?

A table summarizing the applicability of each treatment alternative relative to each of these criteria is included at the end of each section.

The financial based criteria evaluation focuses on the financial impacts of each treatment technology. Treatment technologies are compared to each other based on a dollar per gallon of water treated basis. The cost comparison is an order of magnitude comparison based on preliminary design assumptions. As defined in Table WT.26, this set of criteria includes Capital Costs, O&M Costs, and Life Cycle Costs.

Table WT.26 Treatment Process Financial Based Criteria Water Technology Assessment Report City of Surprise	
Financial Criteria	**Definition / Description**
Capital Cost	What are the equipment costs, initial installation costs, and construction costs for the alternative?
Operation and Maintenance Cost	What are the annual operation and maintenance cost for the alternative?
Life Cycle Cost	What are the capital costs plus O&M costs over a 20-year period for the alternative?

6.4 Pre-oxidation Technologies

In addition to disinfection, oxidants are used to accomplish a wide range of treatment objectives including taste and odor control, removal of iron, manganese, and color, and oxidation of organic chemicals to lessen subsequent chlorine or disinfection demand. Oxidation can also improve flocculation, sedimentation, and filtration by aiding in the destabilization of colloidal material or changing the form of a contaminant (e.g., arsenate versus arsenite). The improvement of settlability through oxidation is well documented for strong oxidants such as ozone. However, the mechanisms for improving destabilization are

not well characterized. One potential mechanism is that oxidation improves the removal of colloidal material through the conversion of organics into more polar forms, causing them to desorb from and thus destabilize clay particles (American Water Works Association (AWWA) 1990).

Nuisance inorganics present in the City of Surprise local groundwater, such as dissolved iron and manganese, could interfere with subsequent treatment processes if not removed. Although they are not toxic, iron and manganese, if not removed, could precipitate on adsorbents, resins, membranes and/or stripping tower packing material, interfere with process performance, and diminish the effectiveness and efficiency of the treatment. They can also pass through the treatment processes and precipitate in finished water reservoirs and the distribution piping, resulting in taste, odor, and color complaints. Oxidation can be accomplished for ferrous iron (II) and manganese (II) removal using simple, available equipment and reagents. After oxidation, the insoluble ferric iron (III) and manganese (IV) can be removed easily by filtration or adsorption processes designed for iron and manganese removal.

Similar to iron and manganese, arsenic removal can be enhanced using oxidation and filtration. Inorganic arsenic occurs in two valence states, arsenite (As III) and arsenate (As V). As (III) species consist primarily of arsenious acid (H_3AsO_3) in natural waters. As (V) species consist primarily of H_2AsO^{4-} and $HAsO_4{}^{2}$- in natural waters (Clifford and Lin, 1995). Removal efficiencies for As (V) are much better than removal efficiencies for As (III) because the arsenate species carry a negative charge and arsenite is neutral under these pH conditions. As (III) may be converted through pre-oxidation to As (V) using one of several oxidants.

Data on oxidants indicate that chlorine, potassium permanganate, and ozone are effective in oxidizing As (III) to As (V). Oxidation/filtration is a best available technology (BAT) for arsenic treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4). Pre-oxidation with chlorine may create undesirable concentrations of disinfection byproducts and may increase membrane fouling of subsequent treatments such as reverse osmosis. Most groundwater in the Phoenix Metropolitan area contains primarily As (V) and very little As (III). Consequently, oxidation may not be necessary to convert As (III) to As (V) for removal. However, it is recommended that the City's WSF designs include the flexibility to use the selected disinfection chemical for the facility as pre-oxidant. This practice enhances the treatment effectiveness and reliability with minimal additional capital costs.

Oxidation processes do not assist in the removal of nitrate or fluoride. While oxidants can be used in groundwater remediation for oxidation of organic compounds, this application is not anticipated to be required for the City's near term water supplies. In summary, the primary benefit of oxidation processes for the City's groundwater sources is to enhance arsenic, iron and manganese removal by adsorption, chemical pretreatment, sedimentation, and filtration.

The oxidation methods reviewed in this section include aeration / stripping pre-oxidation, free chlorine (gaseous chlorine or sodium hypochlorite) pre-oxidation, chlorine dioxide pre-oxidation, ozone (and advanced oxidants such as ozone coupled with hydrogen peroxide) pre-oxidation, and potassium permanganate pre-oxidation. Each technology is reviewed primarily based on their ability to aid in the removal of CoC. Because of the similarity in the chemicals used for oxidation and disinfection, a review of delivery methods including bulk delivery of chlorine and sodium hypochlorite, and on-site generation of sodium hypochlorite, is provided in Section 6.10.

6.4.1 Aeration Pre-Oxidation / Stripping

	• Aeration is effective for oxidizing iron and manganese. • Aeration is not effective for oxidizing arsenic. • Aeration has a low reliability and low efficiency for oxidation.

Atmospheric air (oxygen) is the most cost-effective method of oxidizing the iron and manganese present in groundwater.

6.4.1.1 Anticipated Arsenic Removal

Oxidation using aeration is not effective for oxidizing arsenic.

6.4.1.2 Anticipated Fluoride Removal

Oxidation using aeration is not effective for fluoride removal.

6.4.1.3 Anticipated Nitrate Removal

Oxidation using aeration is not effective for nitrate removal.

6.4.1.4 Anticipated Iron and Manganese Removal

Iron is easily oxidized by atmospheric oxygen. Manganese can also be oxidized by air but the reaction is slow. Aeration provides the dissolved oxygen needed to convert the iron and manganese from their ferrous and manganous forms to their insoluble oxidized ferric and manganic forms. It takes 0.14 ppm of dissolved oxygen to oxidize 1 ppm of iron, while it takes 0.27 ppm of dissolved oxygen to oxidize 1 ppm of manganese.

Operation of the aeration process requires careful control of both the air and groundwater flow. If the groundwater flow becomes too great, not enough air is applied to oxidize the iron and manganese. If the groundwater flow is too low and the aeration is not cut back, the water can become saturated with dissolved oxygen and, consequently, become corrosive to the conveyance piping or distribution system. Corrosive water may lead to increased lead and copper levels at customers' taps.

After the oxidation of the iron and manganese is complete, the water must be filtered to remove the precipitated material and prevent deposition on piping and equipment surfaces. The filtration process is discussed in Section 6.6.

Due to the low oxidation potential of the atmospheric oxygen, oxidation with aeration requires a long detention time (at least 20 minutes or more) to allow the reaction to proceed to completion. This typically requires a large reaction basin. The pH of the water influences how much time is needed for the reaction to be completed. If the reaction basin is separate from the filters, the basin must, on a regular schedule, be cleaned and monitored for iron and manganese sludge accumulation.

The oxidation of iron and manganese with air is considered the most cost-effective oxidation method since there are no chemical costs. However, it is not recommended because of its many disadvantages. Due to its low efficiency in manganese oxidation, the required reaction time can be fairly long and requires a large reaction tank. In addition, small changes in the water quality, such as pH and temperature, may affect the oxidation rate and result in a decrease in iron and manganese precipitation and subsequent removal, and nuisance iron and manganese precipitation in basins, equipment, and piping.

Aeration also promotes the growth of slime growths on the aeration equipment. If these growths are not controlled, they could produce taste and odor problems in the water. The growth of slime can be controlled by the addition of chlorine at the head of the treatment plant. The process should be inspected regularly to identify and address the problems early.

6.4.1.5 Anticipated Organic Compound Removal

Oxidation using aeration is not effective in oxidizing organic compounds.

6.4.1.6 Pilot Testing Requirement

No pilot testing is necessary since the process is not recommended.

6.4.1.7 Residuals Requirement

Aeration could strip VOCs (a gaseous phase residual). The oxidized iron and manganese precipitate in the filter and / or clarification processes and can be disposed of through a variety of mechanisms including air-drying followed by landfill or monofill.

Applicability to City of Surprise

Oxidation using aeration is **not recommended** for the City of Surprise due to its low reliability, low efficiency, and inability to assist in the removal of arsenic.

6.4.2 Chlorine Pre-oxidation

- Available in both liquid and gaseous forms.
- Chlorine is a strong oxidizing agent capable of oxidizing iron, manganese, and arsenic.
- Using chlorine in water containing NOM forms DBPs.

Chlorine is a strong oxidizing agent that is economical and widely used in the water treatment industry. For oxidation in groundwater treatment, chlorine is used to oxidize iron, manganese, and arsenic, improve filtration, and oxidize filter media for improved manganese adsorption. Chlorine is available as both chlorine gas and liquid sodium hypochlorite. In water, gaseous chlorine or sodium hypochlorite forms hypochlorite acid and hypochlorite ions. Refer to Section 6.10 for more details.

6.4.2.1 Anticipated Arsenic Removal

Chlorine can be used to improve the removal of arsenic (As) in groundwater treatment systems that employ filtration, by oxidizing As (III) to As (V), promoting adsorption to insoluble precipitates such as manganese hydroxide or ferric hydroxide. The precipitates are then removed from the water supply in the subsequent clarification and filtration processes.

6.4.2.2 Anticipated Fluoride Removal

Oxidation is not effective for fluoride removal.

6.4.2.3 Anticipated Nitrate Removal

Oxidation is not effective for nitrate removal.

6.4.2.4 Anticipated Iron and Manganese Removal

Iron and manganese in water can be oxidized by chlorine and converted into ferric hydroxide and manganese dioxide. These flocculated materials can then be removed by filtration. The more chlorine that is fed, the more rapid the reaction. Some plants have been

designed for initial chlorine residuals of 5 to 10 ppm. After filtration, the chlorine can be removed by the addition of sodium bisulfite or sulfur dioxide, if necessary. When dechlorinating, the operator must be careful not to overdose the chemical used for dechlorination. This could result in inadequate disinfection in the system as dechlorination chemical left in the water could also remove the required chlorine in the distribution lines.

At pHs between 7.0 and 7.5, ferrous iron is easily oxidized to insoluble ferric iron. Manganese is more difficult to oxidize than iron. Consequently, if the treatment process effectively oxidizes and removes manganese, it will also effectively oxidize and remove iron. While manganese can be oxidized by chlorine, this reaction may proceed slowly and may not occur until after filtration – resulting in potential precipitation in the distribution system.

6.4.2.5 Anticipated Organic Compound Removal

Although occasionally used for oxidizing and masking some taste and odor causing organic compounds in surface water, chlorine cannot effectively oxidize the trace organic compounds (VOCs and SOCs) contained in groundwater.

Free chlorine reacts with natural organic matter in water to form THMs, HAAs, and other DBPs. When using chlorine to oxidize groundwater containing high organic material, the likelihood of generating DBPs is greatly increased. In this case, other oxidants should be considered in lieu of chlorine.

6.4.2.6 Improved Filtration

Chlorine oxidation during treatment has been shown to improve filterability of some source waters. No data is available to confirm if the City's groundwater supplies would experience improved filterability from chlorine addition.

6.4.2.7 Pilot Testing Requirement

No pilot testing is necessary, as chlorine is a widely used and well-documented oxidizing agent.

6.4.2.8 Residuals Requirement

This process does not generate residuals.

Anticipated Performance for the City of Surprise

The use of chlorine as a pre-oxidant is a **recommended** alternative for City of Surprise groundwater treatment systems. It is recommended that the City's WSF designs include the flexibility to use the selected disinfection chemical for the facility as pre-oxidant. This practice enhances the treatment effectiveness and reliability with minimal additional capital costs.

6.4.3 Chlorine Dioxide Pre-oxidation

	• Chlorine dioxide must be generated onsite. • Taste and odor compounds along with arsenic, iron, and manganese can be oxidized by chlorine dioxide. • The DBP chlorite can be formed when chlorine dioxide reacts with natural organic matter.

ClO_2 is a very effective disinfectant. More than 500 water utilities use chlorine dioxide either full-time or seasonally to control tastes and odors, oxidize iron and manganese, and reduce the levels of DBPs in the finished water. Most often, it is used as a substitute for chlorine as a pre-oxidant and is applied to the raw water, in an effort to reduce THM levels in the finished water. Chlorine dioxide is not as sensitive to pH as free chlorine and its disinfection strength works over a broader range, which can reduce required concentration times time (CT) requirement for a given pH.

Chorine dioxide is considered a more aggressive oxidant than free chlorine. It is used to oxidize certain taste and odor causing compounds as well as iron and manganese. It is effective in destroying phenols, but does not form THMs or HAAs in significant amounts (compared to other forms of chlorine).

6.4.3.1 Chlorine Dioxide Generation

Chlorine dioxide gas cannot be stored once it is generated. The pure gas is unstable and can explode if subjected to an increase in temperature, exposure to light, changes in pressure, and exposure to organic compounds. Chlorine dioxide generation equipment is usually simple and relatively inexpensive. Sodium chlorite and chlorine are reacted in a generator. The resultant gas is added to the raw water either as a gas or as a concentrated solution. There are several potential methods of generating chlorine dioxide, each of which has advantages and disadvantages.

Scale-up problems associated with ClO_2 use are generally not a problem as long as the generator is sized correctly. However, many utilities attempt to use generators that are too large for their particular level of production. An over-sized generator necessitates operation at the low end of its efficiency. Eductor flow rates, proper vacuum, and chemical flow rates are difficult to maintain when the generator is operated at low output levels.

A major problem associated with ClO_2 use in full-scale operation is that the oxidant is a gas at temperatures greater than 11 degrees Celsius and is easily volatilized if the generator effluent is added to the rapid mixer and exposed to the atmosphere during the contact period. Furthermore, ClO_2 is oxidized to chlorate ion by photolysis in sunlight (and even under fluorescent lighting). Therefore, maximum benefit from ClO_2 treatment is achieved only if the contact basin is covered or if the reactions take place in a pipeline.

Monitoring the ClO_2 residual in water immediately after dosing is difficult because reliable aqueous ClO_2 detectors are not currently available. Proper ClO_2 generator operation cannot be ensured unless all components are properly maintained. Removing scale in the reaction column and chemical feed lines is essential when 25 percent solutions of sodium chlorite are used for generation. Ensuring that rotameters used to regulate reactant feed rates are properly sized and maintained is another essential component of a reliable operation.

The chemical analyses of ClO_2 and chlorite ion (ClO_2^-) pose other problems at the treatment plant. Operators have to be properly trained in analytical methods because daily analyses of ClO_2 in the water leaving the plant by amperometric titration is specified in the D/DBP Rule. While many operators are well versed in chlorine analyses by amperometric titration, accurate analysis of ClO_2 is considerably more difficult. If ClO_2 levels are to be monitored, the plant laboratory must be equipped with an ion chromatograph. Generally, the method is too expensive and complicated for routine use, and utilities find it better to control the distribution-system ClO_2 levels by maintaining the ClO_2 dose below 1.0 to 1.2 mg/L.

Because ClO_2 solubility decreases with increased temperature, a utility can expect that losses of the gas from uncovered basins at the treatment plant will be greater during warmer weather. Odor complaints from plant personnel and neighboring customers usually increase when the water temperature is warm because the ClO_2 solubility decreases markedly with increased temperature.

6.4.3.2 Anticipated Arsenic Removal

Chlorine dioxide is a stronger oxidant than chlorine and is effective in improving the removal of arsenic in groundwater treatment systems that employ filtration by oxidizing As (III)to As (V).

6.4.3.3 Anticipated Fluoride Removal

Oxidation is not effective for fluoride removal.

6.4.3.4 Anticipated Nitrate Removal

Oxidation is not effective for nitrate removal.

6.4.3.5 Anticipated Iron and Manganese Removal

Chlorine dioxide can effectively oxidize iron and manganese. However, the byproducts of chlorine dioxide oxidation (chlorite and chlorate) must be closely monitored to avoid exceeding the chlorite MCL (MCL for chlorite is 1.0 mg/L).

6.4.3.6 Anticipated Organic Compound Removal

In surface water treatment, chlorine dioxide is recognized as a taste and odor treatment chemical and can be used to destroy phenolic compounds that produce medicinal odors when chlorinated, and algae-related odors. At the limited dosage as mentioned above, the effectiveness of chlorine dioxide in oxidizing the trace organic compounds (VOCs and SOCs) contained in the local groundwater are expected to be minimal. The removal of these organic compounds could be achieved more effectively through air stripping, GAC adsorption, and/or high-pressure membranes.

A major problem associated with the use of ClO_2 is a distribution system odor problem that occurs only in systems that use ClO_2 during treatment and maintain free chlorine residuals in the distribution system. Chlorine will react with ClO_2^-, which is the major byproduct of ClO_2 generation, and cause low-level ClO_2 reformation in the distribution system. The ClO_2 is released into the air in the customers' home or places of business and can react with airborne organic compounds (especially from new carpeting) to produce highly odorous compounds described most commonly as kerosene-like or cat urine odors.

6.4.3.7 Pilot Testing Requirement

If the City is interested in using chlorine dioxide, pilot testing is recommended to address the treatability and chlorite / chlorate formation concerns.

6.4.3.8 Residuals Requirement

This process does not generate residuals.

6.4.3.9 Improved Filtration

Chlorine dioxide is a strong oxidant that should improve filterability, similar to free chlorine.

6.4.3.10 DBP Formation

Chlorine dioxide's usefulness is due in part to the fact that it is an oxidizing agent rather than a chlorinating agent. As such, it does not add chlorine to organic compounds except under conditions that are uncommon in water supplies (it does not dissociate, as do chlorine compounds under normal drinking water pH ranges). The fact that ClO_2 is not a chlorinating agent accounts for its popularity as an aid in minimizing DBP concentrations in finished water, without eliminating pre-oxidation from the treatment train. THMs are not formed by the reaction between chlorine dioxide and natural organic matter (NOM).

However, chlorine dioxide use can produce chlorate and chlorite, which are inorganic DBPs. The MCL for the chlorite ion is 1 mg/L. The chlorate ion does not yet have an MCL.

Chlorite is the primary end product of chlorine dioxide reactions. Because chlorite formation is typically about 70 percent of the chlorine dioxide dosage, the maximum chlorine dioxide dosage is limited to approximately 1.4 mg/L and the maximum residual for chlorine dioxide is limited to 0.80 mg/L unless a chlorite quenching process is implemented. It is also possible that chlorate may be regulated in the future and may limit the dosage of chlorine dioxide that can be applied.

Chlorate, as well as chlorite, is also produced during improperly managed chloride dioxide generation. Chlorate can also be formed during reactions between: 1) chlorite and free chlorine; and 2) chlorine dioxide and free chlorine. Other known sources of chlorate include the disproportion of chlorine dioxide at high pH and in sunlight.

6.4.3.11 Reduction of Oxidant Demand

The addition of chlorine dioxide as an oxidant not only allows delay of chlorination until a large fraction of the natural organic compounds in raw water can be removed during treatment, but can also chemically alter DBP precursor compounds by partially oxidizing them and forming products that do not halogenate when chlorine is finally applied.

Anticipated Performance at the City of Surprise

Chlorine dioxide may be a viable pre-oxidant for the City of Surprise, especially if emerging contaminants such as trace organic compounds become a CoC. Chorine dioxide is considered a more aggressive oxidant than free chlorine. It is used to oxidize certain taste and odor causing compounds and iron and manganese. It is effective in destroying phenols, but does not form THMs or HAAs in significant amounts. However, the byproducts of chlorine dioxide oxidation (chlorite and chlorate) must be closely monitored, which limits the maximum chlorine dioxide dosage. Based on the current low TOC levels of the City's groundwater sources, implementation of chlorine dioxide on the short term is **not recommended** nor required/warranted.

6.4.4 Ozone and Advanced Pre-oxidation

- Ozone must be generated at the treatment facility.
- Taste and odor compounds, trace organic compounds, EDCs and PPCPs, along with arsenic, iron, and manganese can be oxidized by ozone.
- The DBP bromate can be formed when ozone reacts with bromide.

Ozone is a very strong oxidizing agent of metals such as iron and manganese, organics, and taste and odor causing compounds. Ozone produces fewer known byproducts than free chlorine with regard to DBP formation. Ozone is also effective for reducing the chlorine demand of water, and for oxidizing organic compounds including those that are associated with taste and odor. However, it is not recommended for groundwater pre-oxidation due to the potential for ozone to react with bromide and produce bromate concentrations in excess of the MCL of 0.010 mg/L.

6.4.4.1 Anticipated Arsenic Removal

Ozone can oxidize arsenic effectively.

6.4.4.2 Anticipated Iron and Manganese Removal

Ozone can oxidize iron and manganese effectively.

6.4.4.3 Anticipated Fluoride Removal

Oxidation is not effective for fluoride removal.

6.4.4.4 Anticipated Nitrate Removal

Oxidation is not effective for nitrate removal.

6.4.4.5 Advanced Oxidation

Advanced oxidation, a relatively new technology, destroys hydrocarbon contaminants by converting them to carbon dioxide and water. The emerging advanced oxidation processes include high intensity UV oxidation via photolysis and coupling UV with hydrogen peroxide or ozone, and sometimes a catalyst. Most systems consist of several reaction chambers with UV lamps and oxidant injectors. Retention times are around 40 minutes. These systems have been installed in remediation systems at groundwater wellheads for oxidizing organic compounds including tetrachloroethene and MTBE. However, limited data is available for full-scale treatment plant installations.

These systems are generally complicated, energy intensive, and operation and maintenance intensive. In addition, the organic compounds present in the local groundwater are at trace levels and can be removed at relatively low cost through air stripping, GAC adsorption or high-pressure membranes, which is required for removing other contaminants. The capital costs and the associated operation and maintenance requirements do not merit the recommendation of the advanced oxidation processes.

6.4.4.6 Pilot Testing Requirement

If ozone is selected for the City of Surprise water supply facilities, pilot testing is recommended to address the treatability and bromate formation concerns.

6.4.4.7 Residuals Requirement

This process does not generate residuals other than ozone off-gas, which requires catalytic destruction.

6.4.4.8 Improved Filterability

Pre-ozonation can improve filtered water turbidities, including removal of color, lower finished water particle counts, and longer filter runs. The oxidation during pre-ozonation of organic carbon compounds changes the chemical structures, often making them more amenable to removal in the settling and filtration processes. In addition, particle counts in filtered water treated with pre-ozone have been reported to be lower than particle counts in filtered water treated with pre-chlorination.

6.4.4.9 Reduction of Disinfectant Demand

In some cases, ozone can be used to oxidize DBP precursors, thereby reducing subsequent DBP formation during chlorination. However, for other waters, ozone reacts with organics and makes them more prone to THM formation during subsequent chlorination. This was observed during ozone treatment evaluations of CAP water in Tucson, AZ. THM formation was greater at the highest dosages of ozone tested (i.e., 10 mg/L), than at lower ozone dosages (i.e., less than 3 mg/L).

6.4.4.10 DBP Formation

Ozonation of waters containing organic material can produce hydrogen peroxide, bromate, bromoform, aldehydes, glyoxal, methyl glyoxal, and biodegradable matter. In waters with low bromide concentrations, ozone does not react to form halogenated DBPs. When bromide concentrations are substantial, ozone reacts to form brominated organic and inorganic DBPs, such as bromoform and bromate, respectively. Bromate is an inorganic byproduct of ozonation of waters containing bromide. Ozonation of the City's groundwater has the potential to form concentrations of bromate.

Methods of reducing bromate formation during ozonation include: 1) using lower ozone dosages; 2) lowering the pH; and 3) ammonia addition. Regulated organic brominated DBPs, such as bromoform, cyanogen bromide, and dibromoacetic acid, can also be formed during ozonation.

Anticipated Performance at the City of Surprise

Ozone is a very strong oxidizing agent of metals such as iron and manganese, organics, and taste and odor causing compounds. Ozone can still be used as an oxidant at a dosage low enough to avoid bromate violations. However, the capital costs of ozone generation and the associated risk likely do not merit the recommendation of ozone. Considering its effectiveness in addressing emerging contaminants such as certain trace organic compounds, ozone is included in the SurpriseTree™ Water Model, but is not ranked favorably given the City's current needs and interests. Based on the City's current needs, ozone is **not recommended**.

6.4.5 Potassium Permanganate Pre-oxidation

- Potassium permanganate is a moderately strong oxidant able to oxidize iron, manganese, and arsenic.
- Potassium permanganate has a relatively simple feed system to operate and maintain. It is a relatively safe chemical to store and feed.
- Potassium permanganate does not contribute to THM formation.

Potassium permanganate is a moderately strong oxidant, which is relatively economical and simple to feed to a water system. Its addition does not result in THM formation. Potassium permanganate in water produces a pink solution. If added in excess and not fully reduced by reacting with reduced compounds in the water supply, the resulting water will remain pink. This is undesirable because manganese could then travel into and through the filters. This condition should be avoided because soluble manganese entering the distribution system will be converted to colloidal and particulate manganese with extended contact time with the secondary disinfectant. This leads not only to customer complaints regarding staining, but also to a potential exceedance of the turbidity standard due to the formation of manganese oxide particles.

Potassium permanganate is a viable pre-oxidant for City of Surprise. It is not as effective an oxidant as ozone or chlorine dioxide for improving filterability or for removal of taste and odor; however, its feed system is much simpler to operate and maintain, and it is a relatively safe chemical to store and feed. It is more effective at oxidizing manganese than aeration or chlorination.

6.4.5.1 Anticipated Arsenic Removal

Potassium permanganate can also be used to improve the removal of arsenic (As) in groundwater treatment systems that employ filtration, by oxidizing As (III)to As (V) promoting adsorption to insoluble precipitates such as manganese hydroxide or ferric hydroxide. The precipitates are then removed from the water supply in the subsequent clarification and filtration processes.

6.4.5.2 Anticipated Fluoride Removal

Oxidation is not effective for fluoride removal.

6.4.5.3 Anticipated Nitrate Removal

Oxidation is not effective for nitrate removal.

6.4.5.4 Anticipated Iron and Manganese Removal

Potassium permanganate is used in the iron (Fe) and manganese (Mn) removal processes in both surface water and groundwater systems that employ filtration. Permanganate oxidizes soluble iron and manganese to insoluble precipitates. The precipitates are removed from the water supply in the clarification and filtration processes.

The dose of potassium permanganate must be great enough to oxidize all of the manganese, but not too great to produce a pink water color in the distribution system. Observing water being treated will indicate if any adjustments of the feeders are needed.

Factors that affect iron and manganese removal efficiency include water chemistry, pH, temperature, and application point. Reaction times are rapid under normal conditions of temperature and pH. Generally, temperatures <35 degrees Fahrenheit, and pH values <5.5 require reaction times longer than two minutes for manganese removal. In most cases, 5 to 10 minutes of reaction time is sufficient.

Sufficient time (approximately 30 minutes) is required for coagulation of the oxidation byproducts (manganese dioxide and ferric hydroxide). The preferred location for feeding potassium permanganate is the point that gives the longest contact time ahead of coagulation (usually at the intake of the plant).

Oxidized precipitates are removed more easily in hard water than soft water. Alkalinity and hardness > 50 mg/L are recommended for proper coagulation of these precipitants.

6.4.5.5 Pilot Testing Requirement

No pilot testing is necessary since the process is widely used and easy to implement.

6.4.5.6 Residuals Requirement

This process does not generate residuals.

6.4.5.7 DBP Formation

Potassium permanganate does not contribute to THM formation. However, it does not generally oxidize THM precursors completely.

Anticipated Performance at City of Surprise

Potassium permanganate is a viable pre-oxidant for the City of Surprise and was included for further evaluation using the SurpriseTree™ Water Model. Its feed system is much simpler to operate and maintain, and it is a relatively safe chemical to store and feed. Potassium permanganate is a **recommended** alternative for the City of Surprise.

6.4.6 Pre-oxidants Summary

Table WT.27 summarizes the performance based criteria evaluation for the pre-oxidation technology alternatives and their applicability to the City of Surprise groundwater sources. Table WT.28 summarizes the implementation based criteria evaluation for the pre-oxidation technology alternatives. Chlorine, chlorine dioxide, ozone, and potassium permanganate were all included in the SurpriseTree™ Water Model for the City of Surprise groundwater sources. Aeration / stripping is not included due to its ineffectiveness at oxidizing arsenic.

The use of gaseous chlorine is not recommended due to safety concerns. Liquid chlorine is a practical choice as it can be used as both the pre-oxidant at the front of the treatment process and as a disinfectant at the end of the treatment process.

Table WT.27 Pre-Oxidation Unit Operations – Performance-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal
Aeration / Stripping	Not Included	N/A	Good. No DBP formation. Aeration may even reduce volatile DBPs if present.	N/A	Okay for iron. Slow reaction for manganese. Not reliable.	Not effective.	N/A	N/A
Chlorine	Included	N/A	Fair. May form chlorinated DBPs. Also chlorate may be formed when bulk sodium hypochlorite decays.	Very good. See also Table WT.40.	Very good. Effective oxidant for iron and manganese removal.	Very good. Effective oxidant for arsenic removal.	N/A	N/A
Potassium Permanganate	Included	N/A	Very good. Does not form chlorinated DBPs.	Weak as a disinfectant. See also Table WT.40.	Good. Acceptable	Very good. Effective oxidant for arsenic removal.	N/A	N/A
Chlorine Dioxide	Included	N/A	Good. Forms less chlorinated DBPs but does form chlorate.	Very good. See also Table WT.40.	Very good. Effective oxidant for iron and manganese removal.	Very good. Effective oxidant for arsenic removal.	N/A	N/A
Ozone	Included	N/A	Good. Forms less chlorinated DBPs but does form bromate.	Very good. See also Table WT.40.	Very good. Effective oxidant for iron and manganese removal.	Very good. Effective oxidant for arsenic removal.	N/A	N/A

Note:
(1) The effectiveness of the pre-oxidation unit operations ultimately depends on the main treatment process it is paired with.

Table WT.28 Pre-Oxidation Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Aeration / Stripping	Not Included	No significant difference. Potential to release volatile contaminants if groundwater contains VOCs.	Good. Requires minimal O&M.	Good. Little additional costs.	Good. Simple and reliable.	Good. Mature technology.	Familiar.	Good. Simple system.	Weak. May require other strong oxidant depending on water quality.	Very good. Simple.	Good. Compact footprint.	Very good. No major regulatory issue expected.	Excellent. Safer compared to other options.	Good. Does not generate residuals or byproducts other than off-gas.	Weak. May require other strong oxidant depending on water quality.	Good. Can be easily expanded.
Chlorine(3)	Included	No significant difference. Minor potential for chlorine leaks if gaseous form is used.	Excellent. Essentially no additional costs if used as primary disinfectant.	Excellent. Essentially no additional costs if used primary disinfectant.	Very good. Simple and reliable.	Very good. Long history.	Good. Very familiar.	Good. Simple but may require more safety equipment if gaseous chlorine is used.	Excellent. Use as primary disinfectant or oxidant.	Good. Relatively simple.	Good. Compact footprint.	Good, if assuming liquid chlorine.	Good, if assuming liquid chlorine use. Fair for gaseous chlorine.	Good. No significant differences.	Good. Same chemical can be used for both primary disinfectant and oxidant.	Good. Easy to expand.
Potassium Permanganate	Included	No significant difference. No major impacts on air quality.	Good. Minimal costs.	Good. Little additional costs.	Good. Weak oxidant.	Very good.	Good.	Good. Simple.	Good. Easy to operate.	Very good. Simple.	Good. Compact footprint.	Good. Simple chemical solution.	Very good. Safer compared to other chemical options.	Good. May result in MnO_2 precipitation	Requires an additional chemical for primary disinfectant.	Very good. Simple system and easy to expand.
Chlorine Dioxide	Included	No significant difference. Minor potential of leaking chlorine gas.	Fair. Complex system results in more O&M.	Fair. Complex system.	Good.	Good.	Fair. The City has limited experience.	Fair. Complex system. On-site generation uses multiple chemicals.	Very good.	Good. Complex system. Must be generated on site.	Good. Compact footprint.	Good. Requires handling additional chemical systems.	Good. Requires handling additional chemical systems.	Good. Chlorate formation is a concerned DBP.	Very good for NDMA control, EDCs and PCPPs control.	Good expandability. More components to be expanded.
Ozone	Included	Good. Minor potential of leaking liquid oxygen.	Poor. Complex system results in more O&M.	Poor. Complex system.	Very good. Strongest oxidant.	Good.	Fair. The City has no ozone facilities currently.	Fair. Complex system.	Very good. Ozone can assist in biological filtration and improve finished water quality.	Fair. Complex system. Must be generated on-site.	Fair. More components, thus larger footprint.	Good. Requires handling additional chemical systems (LOX).	Fair. LOX and additional chemical systems required.	Fair. Potential for Bromate formation. Require ozone destruction.	Very good for NDMA control, EDCs and PCPPs control.	Good expandability. More components to be expanded.

Notes:
(1) The effectiveness of the pre-oxidation unit operations ultimately depends on the main treatment process paired with (i.e., microfiltration/ultrafiltration, or granular media filtration).
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.
(3) Chlorine can be either gaseous form or liquid form. See also Table WT.40. It is assumed that if chlorine (gaseous or liquid) is selected as the selected primary disinfectant, the same form of chlorine will be used as the oxidant.

6.5 Chemical Pretreatment Technologies

Chemical pretreatment technologies refer to the chemical precipitative and clarification processes using coagulation, flocculation or softening to aid in the removal of CoC (turbidity, iron, manganese, arsenic, fluoride, virus, etc.). The effectiveness of the chemical pretreatment upstream of a filtration step directly influences the performance of the filtration process.

The chemical pretreatment processes reviewed in this section include coagulation, enhanced coagulation, and enhanced lime softening.

6.5.1 Coagulation

- Coagulation involves the addition of chemicals by rapid mixing to initiate the formation of floc.
- Coagulated particles are removed through either direct filtration or conventional treatment processes (i.e., sedimentation and filtration).

Coagulation involves the addition of chemicals by rapid mixing to initiate the formation of floc. The process of coagulation is an established technology that can be a cost-effective way to remove multiple contaminants including iron, manganese, arsenic, and fluoride - particularly in larger sized treatment facilities. Depending on the water quality, a large quantity of chemical may be required to achieve the desired contaminant removal. Chemicals typically used for coagulation processes include aluminum salts, iron salts, polymer or PACL. A coagulation process can be used as part of direct filtration treatment or conventional treatment.

6.5.1.1 Coagulation using Direction Filtration

Direct filtration is a treatment process that includes coagulation, possibly followed by flocculation, and filtration, but excludes a separate sedimentation process. Filtration technologies will be discussed in detail in Section 6.6. With direct filtration, all suspended solids are removed by the filters. Direct filtration with granular media filters has been used successfully on source waters of relatively high quality (i.e., average turbidity approximately 5 NTU or less), and can provide some advantages over a conventional treatment plant process. These advantages include lower capital (no sedimentation structures) and annual O&M costs (less residuals generated and lower chemical usage on a dollars per gallon treated basis) when compared to conventional treatment.

6.5.1.2 Conventional Treatment

Conventional treatment includes coagulation, flocculation, and sedimentation (clarification) in horizontal flow type basins, and granular media filtration. Sedimentation is the separation of settleable solids by gravity.

In a conventional treatment train, the unit processes upstream of the filters are designed to remove a significant portion of turbidity in order to improve the filtration process. A typical surface loading rate or overflow rate of up to approximately 0.5 gpm/ft^2 is used for conventional sedimentation, with flocculation detention times ranging from approximately 10 to 30 minutes, and coagulant mixing energies dependant on the coagulant used and the method of mixing. Rapid mixing is needed to thoroughly distribute chemicals into the raw water. Flocculation is the process of gentle mixing to promote the agglomeration of smaller floc into larger, more settleable floc. Flocculation facilities must provide adequate time for development, provide tapered energy input, and produce uniform floc particle size. During sedimentation or clarification, the particles are removed by gravity settling.

High-rate precipitative and clarification process technologies such as ballasted flocculation or dissolved air flotation can be used to reduce the footprint required, compared to conventional treatment processes. These technologies, as well as conventional treatment processes, are typically used for treating high turbidity and high TOC sources, such as surface water. These technologies are not necessary for the City's groundwater source.

6.5.1.3 Arsenic Removal

Coagulation and flocculation processes using alum or ferric are effective in removing arsenic from groundwater. Ferric salts have been found to be more effective in removing arsenic than alum on a weight basis and effective over a wider range of pH (6.0 to 8.5). In alum coagulation, the removal is most effective in the pH range 7.2 to 7.5.

As (V) can be more effectively removed than As (III). During the flocculation process, various micro-particles and negatively charged ions are attached to the flocs by electrostatic attachment. Arsenic is also adsorbed onto coagulated flocs. As As (III) occurs in non-ionized form, it is not subject to significant removal. As mentioned in Section 6.3, oxidation of As (III) to As (V) using chlorine or potassium permanganate will enhance the arsenic removal. Coagulation/filtration is a best available technology (BAT) for arsenic treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.5.1.4 Fluoride Removal

Coagulation and flocculation processes assist in high removal efficiencies of fluoride when present at high concentrations (15 ppm feed down to 5 ppm). However, coagulation and flocculation it will likely not reduce fluoride concentrations to less than 2 ppm - the SMCL for fluoride. Although the City's groundwater source is not likely to contain levels of fluoride above 15 ppm, coagulation and filtration followed by a polishing process such as adsorption or ion exchange could offer an economic treatment strategy should high fluoride water sources be developed in the future. Coagulation/filtration is a best available technology (BAT) for fluoride treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.5.1.5 Nitrate Removal

This technology does not remove nitrate.

6.5.1.6 Turbidity and Pathogen Removal

The coagulation and flocculation processes involve addition of coagulants such as alum, ferric chloride, or organic polymers, in some cases pH adjustment, rapid mixing to initiate the formation of flocs, and "gentle mixing" (flocculation) to promote floc growth. For groundwater treatment systems, lime softening is also widely used in lieu of ferric and alum coagulation. By forming flocs, coagulation and flocculation enhance the removal of fine solids by filtration and/or adsorption.

6.5.1.7 Iron and Manganese Removal

Coagulation and flocculation can enhance the iron and manganese removal by filtration. As mentioned previously, even without applying oxidants, iron and manganese can be slowly oxidized into flocculated materials (ferric hydroxide and manganese dioxide) by atmospheric oxygen when the groundwater is in contact with air. Coagulation and flocculation promotes the formation of these flocculated materials.

Systems that have a lime-soda ash softening system do not need a separate iron and manganese removal system. The high pH generated during softening allows rapid oxidation and precipitation of the iron and manganese as well as incorporation in the calcium and magnesium precipitates.

6.5.1.8 TOC Removal

TOC removal in surface water is generally moderate (< 30 percent) in a conventional treatment process or direct filtration process, unless using enhanced coagulation. For groundwater, the removal is even lower (< 10 percent) due to the low TOC concentration. Enhanced coagulation (discussed below) can increase TOC removal.

6.5.1.9 Taste and Odor Removal

Neither conventional treatment nor direct filtration treatment by themselves will substantially reduce taste and odor causing compounds (Geosmin and MIB). However, taste and odor compounds are not expected to be a significant issue for the City's water supply.

6.5.1.10 Pilot Testing Requirements

Simple bench scale jar testing can be used to address the coagulant selection and dosing for groundwater treatment. Jar testing will also assist in determining the effectiveness of arsenic, fluoride, iron and manganese removal through coagulation and flocculation. For complicated applications and/or critical facilities, a pilot study is recommended.

6.5.1.11 Residuals Handling Requirements

Flocs formed in the coagulation and flocculation process will be removed in the subsequent filtration or adsorption processes. The residuals generated through these processes are relatively easy to treat compared to other contaminant treatment technologies. For coagulation using alum, approximately 0.26 pounds of solids are produced for every pound of alum added. For coagulation using ferric chloride, approximately 0.54 pounds of solids are produced for each pound of ferric chloride added. However, depending on water quality, large quantities of residuals can be produced. Residuals produced by coagulation processes are further discussed in Section 6.11.

Anticipated Performance at the City of Surprise

Coagulation and flocculation is a **recommended** pretreatment process alternative for assisting in the removal of turbidity, arsenic, fluoride, iron and manganese at the City of Surprise water supply facilities. The optimum coagulation system is included for further evaluation using the SurpriseTree™ Water Model.

6.5.2 Enhanced Coagulation

- Enhanced coagulation is an operating strategy to enhance the removal of contaminants.
- The coagulation process is optimized to enhance the removal of TOC or other target contaminants.

Enhanced coagulation is an operating strategy (as defined by the USEPA). Enhanced coagulation can be used in some conventional treatment plants as a compliance strategy for the Disinfectants and Disinfectants Byproducts Rules for which the coagulation process is operated to optimize the removal of TOC. Enhanced coagulation is achieved in most cases by either increasing coagulant doses and/or adjusting the pH during the coagulation reaction. Coagulants typically used for treating drinking water include metal salts coagulants (i.e., alum, ferric chloride), polymerized metal-salt coagulants (i.e., poly-aluminum chloride [PACL]), and organic polymers that may be cationic, anionic, and non-ionic. These coagulants and polymer flocculation aids not only destabilize particles, but also remove a fraction of dissolved natural organic matter present in raw waters. Coagulation using iron or aluminum salts in the pH range of 5.5 to 6.5 generally corresponds to maximum precursor removal. However, the optimum pH for iron salts is typically 0.5 to 1.0 pH unit higher than for alum.

6.5.2.1 Arsenic Removal

Enhanced coagulation with metal salt coagulants will increase the removal of arsenic compared to conventional treatment.

6.5.2.2 Fluoride Removal

Enhanced coagulation with metal salt coagulants will increase the removal of fluoride compared to conventional treatment.

6.5.2.3 Nitrate Removal

This technology does not remove nitrate.

6.5.2.4 Turbidity and Pathogen Removal

Enhanced coagulation will provide excellent pretreatment for filtration operations to produce filtered water with a turbidity of 0.10 NTU or less - especially compared to conventional treatment. Enhanced coagulation generally provides a lower finished water turbidity than does conventional filtration under similar raw water conditions, with a turbidity goal of < 0.15 NTU readily achievable.

6.5.2.5 TOC Removal

TOC removal with enhanced coagulation widely varies depending on the raw water alkalinity, initial TOC concentrations, coagulant chemicals, specific UV absorbance (SUVA), and other parameters. However, TOC removal is likely not a challenge for the City's current or newer-term groundwater supply.

6.5.2.6 Taste and Odor Removal

Enhanced coagulation is equally as effective as conventional treatment for controlling taste and odor causing compounds (Geosmin and MIB). However, taste and odor control is not expected to be an issue for the City's water supply.

6.5.2.7 Residuals Handling Requirements

Similar to the conventional coagulation processes, flocs formed in the enhanced coagulation process will be removed in the subsequent filtration, adsorption, and/or clarification processes. The residuals generated through these processes are relatively easy to treat compared to other contaminant treatment technologies. However, enhanced coagulation generates more residuals due to the use of elevated coagulant doses compared to conventional treatment. Residuals produced by coagulation processes are further discussed in Section 6.11.

Anticipated Performance at the City of Surprise

The enhanced coagulation process is typically not necessary for groundwater applications due to relatively low TOC in the water. However, for a coagulation flocculation facility, enhanced coagulation can be implemented easily with minimal additional capital investment. Enhanced coagulation is considered a viable treatment option for the City of Surprise and was included in the SurpriseTree™ Water Model. Enhanced coagulation is a **recommended** alternative for the City of Surprise.

6.5.3 Enhanced Softening (Lime)

- Lime softening is a chemical precipitation process that converts hardness into insoluble solids
- Solids are removed from solution by settling and filtration.
- Removing hardness prevents scale formation in plumbing fixtures.
- Arsenic is efficiently removed through co-precipitation.

Lime softening is a chemical precipitation process that converts hardness into insoluble solids that are then removed from solution by subsequent settling and filtration. "Hard" water requires more soap to develop soapsuds or lather because anionic detergents chelate divalent cations present in water, thus leaving less soap available for removing dirt/residue. Another reason to remove hardness is to prevent scale formation in plumbing fixtures. Besides hardness removal, other advantages of lime softening include removal of

other potential CoC including pathogens and arsenic as well as some heavy metals. Softening processes serve as a good pretreatment alternative for ion exchange and RO processes because interference contaminants can be removed. Lime soda softening involves either soda ash or caustic soda addition when non-carbonate hardness is removed. Lime softening will not significantly decrease overall TDS concentrations. Enhanced lime softening in particular improves chemical precipitation at a high pH (pH = 10.5).

Lime softening is similar to the typical coagulation process in that it is an established technology that can be a cost-effective way to remove multiple contaminants - particularly for larger sized treatment facilities. However, the effluent arsenic and fluoride concentrations are not as low as ion exchange and adsorption treatment processes. Also, a large amount of chemical is required to raise the pH to the high optimum range and to adjust the pH back down to a neutral range after softening.

Softening can also occur through a pellet softening process. This process involves a fluidized bed using sand and lime combined with a high filtration rate. Residuals produced through pellet softening can be easily dewatered by gravity.

6.5.3.1 Arsenic Removal

Lime softening processes operated within the optimum pH range of greater than 10.5 can provide a high percentage of arsenic removal. At pH levels below 10.5, the efficiency of arsenic removal may be diminished. Lime softening is a best available technology (BAT) for arsenic treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.5.3.2 Fluoride Removal

Coagulation and flocculation processes assist in high removal efficiencies of fluoride when present at high concentrations (15 ppm feed down to 5 ppm). However, the process will likely not reduce fluoride concentrations to less than 2 ppm - the SMCL for fluoride. Although the City's groundwater source is not likely to contain levels of fluoride above 15 ppm, coagulation and filtration followed by a polishing process such as adsorption or ion exchange could offer an economic treatment strategy should high fluoride water sources be developed in the future. Lime softening is a best available technology (BAT) for fluoride treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.5.3.3 Nitrate Removal

This technology does not remove nitrate.

6.5.3.4 Residuals

Softening generates a large quantity of residuals, especially compared to conventional coagulation processes. Approximately 3.5 pounds of calcium carbonate are precipitated for every 1 pound of quick lime added to hard water. However, the residuals are relatively easy

to treat compared to residuals produced from other removal methods. A sedimentation process is typically integral to the softening process. Many of the precipitants formed will settle out and be removed during this process. A filtration process will remove additional flocs formed in the enhanced softening process. A typical solids content of 1 to 4 percent can be expected from the softening blowdown process.

Softening residuals are typically processed using a dewatering method. Residual equalization storage is recommended to store residuals during the intermittent operation of the dewatering process. Gravity thickening may be used to increase the solids content of the residuals prior to handling by other dewatering methods. Mechanical dewatering methods such as filter press dewatering are capable of achieving a solids content of 40 to 70 percent and centrifuge dewatering methods are capable of achieving a solids content of 65 to 70 percent for softening residuals. Evaporation ponds and storage lagoons are also viable softening residual handling options for small treatment plants, However, since both options are land intensive, they are prohibitive for large treatment plants. Refer to Section 6.11 for descriptions of residual handling alternatives.

Anticipated Performance at the City of Surprise

Softening is widely practiced in the Midwest U.S. The economics of precipitative softening in the Southwest U.S. make it not as favorable due to increased chemical feed and residuals disposal costs. The City's groundwater sources are considered to be "soft" water. "Soft" water is typically defined as water with hardness < 50 mg/L as $CaCO_3$ (AWWA/ASCE 2005). Although the City may not require softening to address hard water, softening is a viable treatment process for removing arsenic, high concentrations of fluoride, turbidity, iron, and manganese. Consequently, softening was included for further evaluation using the SurpriseTree™ Water Model. Lime softening is a **recommended** alternative for the City of Surprise.

6.5.4 Chemical Pretreatment Summary

Table WT.29 summarizes the performance based criteria evaluation for the chemical pretreatment technologies. Table WT.30 summarizes the evaluation results using the implementation-based criteria. Coagulation, enhanced coagulation, and enhanced lime softening were all recommended for further evaluation using the SurpriseTree™ Water Model. It is worthwhile to note the dependencies on water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size (as noted by the shaded cells in the tables).

Table WT.29 Chemical Pretreatment Unit Operations – Performance-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal
Coagulation	Included	Good.	Good. Assists in removal of DBP precursors.	N/A	Very good. Effective in removing iron and manganese.	Good. Effective in removing arsenic - especially with oxidation.	N/A	Fair. Some removal is achieved at high F concentrations. May require polishing.
Enhanced Coagulation	Included (as an operational strategy)	Excellent	Better than conventional coagulation. High removal of DBP precursors.	N/A	Very good, Effective in removing iron and manganese.	Good. Effective in removing arsenic - especially with oxidation.	N/A	Good. Some removal is achieved at high F concentrations. May require polishing.
Lime Softening	Included	Good	Good, Assists in removal of DBP precursors.	N/A	Good. Effective in removing iron and manganese.	Good. Effective in removing arsenic.	N/A	Fair. Some removal is achieved at high F concentrations. May require polishing.

Notes:
(1) The effectiveness of the chemical pretreatment unit operations ultimately depends on the main treatment process it is paired with (i.e., microfiltration/ultrafiltration, or granular media filtration).
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.30 Chemical Pretreatment Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Coagulation	Included	No significant impacts.	Especially good for large facilities.	Especially good for large facilities.	Very good. Chemical usage varies with varying water quality.	Good. Very mature.	Very good	Good. Requires handling of chemicals.	Good. Relatively flexible.	Good. Requires handling of chemicals.	Good. Requires chemical feed system.	Good. BAT for arsenic removal.	Good.	Good. Residuals produced in filtration process must be handled.	Good. Can remove some fluoride.	Good.
Enhanced Coagulation	Included (as an operational strategy)	No significant impacts.	Especially good for large facilities.	Especially good for large facilities.	Very good. Chemical usage varies with varying water quality.	Good. Mature.	Good	Good. Requires handling of higher quantities of chemicals compared to coagulation.	Good. Relatively flexible. Same facility can be operated in both conventional and enhanced coagulation mode.	Good. Requires handling of chemicals.	Good. Requires chemical feed system.	Good. BAT for arsenic removal.	Good.	Good. Produces higher quantities of residuals in filtration process compared to coagulation.	Good. Same facility can be operated in both conventional and enhanced coagulation mode.	Good.
Lime Softening	Included	No significant impacts.	Especially good for large facilities.	Especially good for large facilities.	Good. Chemical usage varies with varying water quality.	Good. Mature.	Not very familiar but similar to other chemical precipitation facility.	Good. Requires handling of higher quantities of chemicals compared to coagulation. Lime can be messy to handle.	Good. Relatively flexible.	Good. Requires handling of chemicals. Lime system is more complicated than coagulation facility.	Good. Requires chemical feed system.	Good. BAT for arsenic removal.	Good. Lime is messy but relatively safe to handle.	Good. Produces higher quantities of residuals in filtration process compared to coagulation. Residuals are easier to treat.	Good. Can remove some fluoride.	Good.

Notes:
(1) The effectiveness of the chemical pretreatment unit operations ultimately depends on the main treatment process it is paired with (i.e., microfiltration/ultrafiltration, or granular media filtration).
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

6.6 Filtration Unit Operations

Filtration removes particulate matter from water. These particulates are either naturally occurring (such as clays, silts, bacteria) or are generated during upstream treatment processes (coagulant precipitates). Filtration involves forcing a fluid through a porous medium with an effective pore size less than the size of the particles that need to be removed. As water, laden with solids, passes through the media, the particles are trapped on the top of or within the filter material. A drain beneath the filter bed collects filtered liquid. Deposition of solids in the filter may reduce the filtration rate or require higher pressures to force liquids through the media. To prevent plugging, the system is backwashed at a high velocity to dislodge accumulated particles. The backwash water and solids are further treated as liquid phase residuals.

The mechanism of filtration, type, and operation modes of filters and their anticipated performance are described in detail in this section. Some types of filters, such as granular media filters and low-pressure membrane filters (ultrafiltration and microfiltration), are often used in groundwater treatment coupled with pre-oxidation, coagulation/flocculation or softening pretreatments. Oxidizing filters combine oxidation and filtration steps and is often used in arsenic removal. Drinking water biological filtration is a relatively new technology for inorganic contaminants such as nitrate and perchlorate.

6.6.1 Granular Media Filters

- Granular media filters are the most common and economical type of filter used in water treatment.
- Multiple configurations of granular media filters are available to provide a barrier for particulate matter, turbidity, and pathogens.
- With chemical pretreatment and/or pre-oxidation, granular media filters can effectively remove arsenic.

Granular media filters can be classified by media type, hydraulic configuration, flow rate, and depth of media. The media types of granular media filters include dual media filters (sand and anthracite), mono media filters (anthracite only), and mixed media (anthracite over sand over garnet). The hydraulic options include pressure or gravity filtration. It is more typical to use a pressurized system for a groundwater application to avoid breaking head from the well. Gravity filters can use concrete structures or be skid-mounted, and can be equipped with either variable declining rate (as headloss increases, flow decreases) or constant rate (as headloss increased, flow remains constant) flow control.

Gravity rapid or high-rate filtration is generally conducted at surface loading rates ranging from 2 to 10 gpm/ft^2. Terminal filter run lengths between backwashes are determined by filter headloss due to particulate accumulation, turbidity breakthrough, or run hours. Most media filter plants at least occasionally use filter aid polymer to achieve low effluent turbidities and to improve filter run times. Media grain size and type determines the penetration depths of particulate matter into the media. Effective operation of media filters also requires pretreatment of the water to aid in the formation of floc adequate for the particular filter type (pretreatment unit operations are reviewed in Section 6.5). Generally speaking, granular media filters are reliable and sufficient for the City's groundwater treatment. Several types of granular media filters are discussed in the following section, focusing on their applicability for the City's groundwater treatment.

6.6.1.1 Slow Sand Filters

Slow sand filtration is a process through which raw water is filtered through sand at a very low surface loading rate (typically 0.1 g/ft^2/minute) to remove particulate (and to some extent dissolved organic) matter. Biological activity occurring at the slow sand filter surface may contribute partially to the removal.

Slow sand filters are manually cleaned periodically by removing the top layer of particulate and biological material that forms over time. Labor required for maintaining the slow sand filters precludes its use at all but small treatment plants. Slow sand filtration is not recommended for the City of Surprise because the technology required a large land area based on its design surface area loading rate range of 0.04 to 0.2 gpm/ft^2.

6.6.1.2 Monomedia Filters

The type of monomedia deep bed filters (approximately 4 to 6 feet deep) considered for the City of Surprise consist of anthracite media (effective size [ES] of 0.9 to 1.1 mm) or sand media (ES 0.45 to 0.55 mm) placed directly on top of the filter underdrain system. The deep bed can provide longer filter runs than dual media filters since more media is available for particle removal, and the coarser anthracite grain size allows deeper particle penetration.

Deep bed monomedia sand or anthracite filters provide satisfactory removal of turbidity and pathogens for adequately pretreated water. Pinpoint flocs are normally desired for deep bed filters, to allow deeper penetration into the beds. One advantage of monomedia filters is that the media does not have to be restratified like dual or mixed media filters at the end of a backwash. The addition of more media to a monomedia filter is relatively simple. Monomedia deep bed filters are recommended for the City of Surprise and were included for further evaluation in the SurpriseTree™ Water Model.

6.6.1.3 Dual Media Filters

A dual media filter consists of a sand layer overlaid by anthracite coal. The anthracite layer is about 18 – 30 inches deep and relatively coarse (effective size of 0.8 to 1.2 mm) and the silica sand (ES 0.45 to 0.55 mm) layer is typically about 6 to 12 inches thick. The more coarse anthracite provides a deeper bed for particulate penetration while the finer sand underneath serves to aid in the removal of particles that pass through the anthracite layer.

Dual media filters have been successfully used at many WTP, and will provide satisfactory removal of turbidity and pathogens for adequately pretreated water. Dual media filters were recommended to be further evaluated using the SurpriseTree™ Water Model for the City of Surprise.

6.6.1.4 Mixed Media Filters

Mixed media filters are sometimes referred to as triple media filters and consist of three layers of media (anthracite on top of sand on top of garnet). Garnet is a higher density and finer grained media than sand or anthracite. Theoretically, mixed media filters should provide even better performance in terms of effluent quality because of the garnet layer. However, this has not been conclusively demonstrated in actual installations (AWWA 1990).

Mixed media filters are not recommended for the City of Surprise since their clean bed headloss is generally higher than for dual or monomedia filters. The filters do not offer significant advantage over dual media filters but require additional investment and maintenance.

6.6.1.5 GAC Filter Caps

The use of GAC in filter beds (i.e., filter absorbers) has increased due to the dual advantages of improved filtration and organics absorption. For a GAC cap configuration, the GAC layer is typically 15 to 42 inches or more over the sand layer in dual media configurations. For GAC in a monomedia configuration, the depth can range from approximately four to six feet. GAC capped filters have some disadvantages when compared to monomedia GAC filters including added difficulties in removing only GAC (and not sand) for regeneration, GAC abrasion is accelerated by the sand during backwashes, and control of backwash flow rates to properly backwash the sand and GAC without losing GAC in the filter troughs. In addition, the GAC filter cap will need to be removed for regeneration more often than the monomedia due to the shallower media depth.

In addition to the issues listed above, GAC caps have been reported to be less effective for taste and odor removal (shorter/insufficient empty bed contact times). GAC filter caps are not recommended for the City of Surprise, considering the groundwater source quality.

6.6.1.6 Arsenic and Fluoride Removal

Coupled with the right pretreatment, granular media filters are an established technology and provide a cost-effective way to reduce high concentrations of arsenic and fluoride. However, depending on the feed water arsenic and fluoride levels, the effluent arsenic and fluoride concentrations may not be as low as the product water generated by ion exchange and adsorption treatment processes. Considering the amount of adsorbent and ion exchange media used for a large facility and the opportunity to utilize common wall construction for the coagulation filtration facilities, this technology is particularly good for large treatment facilities.

6.6.1.7 Anticipated Turbidity Removal

Granular media filters, coupled with proper pretreatment, can yield water with sufficient quality in terms of particulate matter removal.

6.6.1.8 Anticipated Iron and Manganese Removal

Filtration is used as the final step in iron and manganese treatment. The overall iron and manganese removal efficiency highly depends on the level of pretreatment achieved in the pre-oxidation process. With sufficient pre-oxidation or coagulation, granular media filters, can effectively remove the oxidized iron and manganese. When oxidation is not sufficient, iron and manganese may pass through the filter, negatively impact the downstream treatment processes, or result in taste and color issues in the treated water.

6.6.1.9 Pilot Testing Requirements

Pilot study is recommended to address the effectiveness of iron and manganese, arsenic and fluoride removal through filtration and the synergistic effects with the proposed pretreatment unit operations (pre-oxidation and coagulation/flocculation).

6.6.1.10 Residuals Handling Requirements

Residuals generated from the granular media filtration process are mainly backwash wastes. Backwash wastes are relatively easy to treat. However, the volume of the residual may be large. The residuals produced by backwashing filters are comprised of floc particles carried over from the coagulation and flocculation processes of direct filtration and can contain metal precipitates, and organic particles. For the coagulation filtration process, residuals are removed during the filter backwash process and typically contain less than 1.0 percent solids. The volume of backwash residuals (typically 3 to 5 percent of the plant flow) is dependent upon the amount of floc carried over to the filters, the frequency of backwashing, and the length of the backwashing cycle. Backwash wastes are typically equalized and then discharged to the sewer (for small applications) or further treated. Refer to Section 6.11 for more residuals treatment discussion.

Anticipated Performance for the City of Surprise

Monomedia and dual media granular media filters are **recommended** filtration technology alternatives for the City of Surprise and were included for further evaluation using the SurpriseTree™ Water Model.

6.6.2 Low-Pressure Membranes: Microfiltration (MF) and Ultrafiltration (UF)

- Low pressure membranes provide a physical barrier between particles/colloidal contaminants and the finished water.
- Membrane technology is capable of producing a high finished water quality.

Low-pressure membranes in water treatment are similar to gravity filtration media filters in that they both are used to remove particulate matter and turbidity from water including iron, manganese, arsenic, and fluoride. In fact, membrane technologies can be a cost-effective way to reduce high concentrations of arsenic and fluoride. However, the effluent arsenic and fluoride concentrations from membrane filtration are not as low as ion exchange and adsorption treatment processes. However, membranes unlike granular filtration media, also provide a physical barrier between the particles/colloidal contaminants and finished water, provided that the integrity of the membrane system is properly maintained. Due to the physical barrier, membrane filtration produces a better water quality than granular media filtration. The two major low-pressure membrane types used for potable treatment are MF and UF. MF/UF systems use size exclusion to strain out particulate matter from the raw water. Typical MF membrane pore size ratings range from 0.1 to 0.5 microns. Commonly used UF membranes range from about 2,000 to 150,000 dalton molecular weight cut off (approximately 0.005 to 0.2 microns). Membranes can clog due to fouling, ultimately changing their filtration characteristics.

Water travels through the membrane pores, leaving behind the particulate matter on the surface of the membrane. The flux rate, a unit measure for the ability to treat water on a unit gallon per square foot of membrane basis, varies with the feed water quality, pretreatment processes, and membrane model and manufacturer (20 to 100 gpd/ft^2 has been reported). The flux rate will also vary depending on the driving force (pressure or vacuum) used to move raw water through the membrane. Low-pressure membranes do not remove appreciable amounts of dissolved materials, unless chemical pretreatment is used to create floc material that entraps the dissolved components so it can be filtered out. Coagulant aid polymer generally cannot be used, since it will foul the membranes.

6.6.2.1 Anticipated Arsenic Removal

Low-pressure membrane filters can be used to remove arsenic adsorbed on the flocs formed in the coagulation and flocculation pretreatment process. Coagulation assisted MF/UF is considered as a reliable arsenic removal technology.

6.6.2.2 Anticipated Fluoride Removal

The removal of fluoride is highly dependent on the effectiveness of the chemical pretreatment. Coupled with the right pretreatment, low-pressure membrane filtration can reduce high concentrations of fluoride. However, depending on the feed water arsenic and fluoride levels, the effluent fluoride concentrations may not be as low as the product water generated by ion exchange and adsorption treatment processes.

6.6.2.3 Anticipated Turbidity Removal

Filtration performance is dependent on the level of pretreatment, type of particles, hydraulic configuration, and other operational parameters. However, low-pressure membrane filters generally produce better quality water in terms of turbidity and particle size distribution than conventional filtration. Unlike granular filtration media, membrane filtration provides a physical barrier between the particles/colloidal contaminants and finished water, provided that the integrity of the membrane system is properly maintained. Manufacturers report that MF/UF systems can sometimes handle raw water up to several hundred NTU, although production may be down rated in such conditions.

6.6.2.4 Anticipated Iron and Manganese Removal

The overall iron and manganese removal efficiency highly depends on the effectiveness of the pretreatment achieved in the pre-oxidation process. With sufficient pre-oxidation, membrane filtration can effectively remove the oxidized iron and manganese. When oxidation is not sufficient, iron and manganese will foul the membrane, pass through the filtration step and negatively impact the downstream treatment processes, or result in taste and color issues in the treated water.

6.6.2.5 Organics Removal

Similar to gravity media filters, MF/UF membranes are not anticipated to provide significant reductions in other dissolved compounds, unless pretreatment is used to first coagulate and flocculate these compounds.

6.6.2.6 No TDS Removal

Unlike high-pressure membranes such as nanofiltration (NF), and reverse osmosis (RO), low pressure membranes (MF/UF) are not designed to remove TDS. To illustrate the differences between the MF/UF and NF/RO, Table WT.31 summarizes the types of CoC removed or partially removed for different types of membrane systems. NF and RO will be further discussed in Section 6.9.

6.6.2.7 Pilot Testing Requirements

Pilot study is recommended to address the effectiveness of iron and manganese, arsenic and fluoride removal through filtration and the synergistic effects with pretreatment unit operations (pre-oxidation and coagulation/flocculation).

Table WT.31 Overview of Membrane Performance Removals
Drinking Water Technology Assessment
City of Surprise

Parameter	MF	UF	NF	Low Pressure RO
Cysts	> 99.9% (3 log) Note 3	> 99.9% Note 3	Note 1	Note 1
Bacteria	> 99% (2 log) Note 3	> 99% Note 3	Note 1	Note 1
Virus	0 - 99% (0 - 2 log) Note 3	0 - 99% Note 3	Note 1	Note 1
TOC	0 -20 %	0 - 20%	90 - 98%	90-98%
Color	Note 2	Note 2	96%	96%
DBP-Precursors	Note 2	Note 2	96%	98%
Atrazine	Note 2	Note 2	90%	96%
Hardness (Ca & Mg)	0	0	80 - 85%	98%
TDS	0	0	40 - 60%	90-98%
Arsenic	Note 2	Note 2	<40%	95%
Chloride	0	0	10 - 50%	99%
Fluoride	0	0	10 - 50%	98%
Nitrate	0	0	10 - 30%	96%
Sulfate	0	0	80 - 95%	99%

Notes:
(1) MF & UF are generally credited with at least 2.5-log removal of cysts by state agencies. NF & RO would typically not be applied for pathogen removal if only a percentage of raw water is treated.
(2) Without chemical pretreatment, MF does not remove dissolved material and removal by UF is limited.
(3) Different membrane manufacturers can claim various removal rates for pathogens and particle sizes.

6.6.2.8 Residuals Requirement

Membrane filtration processes produce a larger volume of residuals as compared to granular media filtration. In fact, the residuals produced from membrane filtration processes are generally harder to treat than residuals produced from granular media filtration. Chemicals are required for the clean in place process as well as to stabilize the clean in place wastes. Backwash wastes are typically equalized and then discharged to the sewer (for small applications) or further treated. Refer to Section 6.11 for additional residuals treatment discussion.

Anticipated Performance for the City of Surprise

Low-pressure membranes are a **recommended** filtration alternative for the City of Surprise and were included for further evaluation using the SurpriseTree™ Water Model. In many applications, MF/UF systems can be cost competitive with conventional treatment. Situations that may tend to favor membranes include a need for an absolute barrier to provide cyst and/or turbidity control, and limited available land area.

6.6.3 Oxidizing Filters

- Oxidizing filters combine the processes of oxidation and filtration into one process.
- Oxidizing filters can effectively remove iron, manganese, and arsenic.

Oxidizing filters, often referred to as iron filters or red water filters, employ “greensand” resin beds (coated with manganese), manganese zeolite beds, or other oxidizing media, as both the oxidizing source and the filter media.

6.6.3.1 Iron and Manganese Removal

As water flows through the resin bed, iron and manganese are oxidized and changed from a soluble form to an insoluble form. The media also acts as a filter and traps iron and manganese precipitates that have been oxidized prior to reaching the filter.

6.6.3.2 Arsenic Removal

Arsenic is also oxidized and filtered out of the water through this previously described process as it is precipitated with the iron present in the water. Arsenic removal is highly dependent on iron concentration in the water. Arsenic removal of approximately 80 percent can be achieved when the iron to arsenic ratio in the water is greater than 20:1.

Oxidizing filters are most effective in water with a pH of 7 or above. If water is acidic (pH below 7), pH adjustment may be needed. When iron and manganese concentrations are above 1 mg/L, or if the water is pH below 7, a strong oxidizing substance, such as chlorine or potassium permanganate, should be applied prior to oxidizing filtration.

Oxidizing filters do not tolerate slimy material produced by iron bacteria, which fouls the filter by coating the media. In such cases, chlorine or potassium permanganate can be used to kill the bacteria and recover the filter bed.

6.6.3.3 Removal of Other CoC

Oxidizing filters are not designed to remove fluoride or nitrate. Although when coupled with pretreatment they may reduce turbidity and potentially organic matter concentrations, it is generally not economical to use this type of filter for particulate matter removal.

6.6.3.4 Residuals Requirements

Oxidizing filters require considerably more intensive backwashing compared with ion exchange or granular media filters due to the media weight and density. This often means a larger volume of backwash waste.

Once the oxidizing capacity of the bed is exhausted, soluble iron and manganese breakthrough occurs. To prevent such breakthrough, the oxidizing filters must be regenerated with a solution of potassium permanganate or chlorine. When the arsenic removal capacity is exhausted, the media should be replaced.

Anticipated Performance at City of Surprise

Oxidizing filters are an effective way to remove arsenic, iron, and manganese from water. Oxidizing filters are a **recommended** alternative for the City of Surprise and were included for further evaluation using the SurpriseTree™ Water Model.

6.6.4 Drinking Water Biological Filtration

- Unlike other filtration processes reviewed in this section, biological filtration does not remove arsenic and fluoride.
- This process can effectively remove nitrate, perchlorate, and organic compounds.
- Biological filtration is a treatment alternative to ion exchange and RO/NF, which does not produce difficult to manage concentrate streams.

Biological filtration is a filtration process in which the filter serves as a media for bacteria to live. Bacteria, in conjunction with the filtration process, can effectively remove nitrate, phosphate, perchlorate, TOC, taste and odor, and some compounds of EDCs and PCPPs at a high efficiency. The design and operation of this type of filtration is comparable to the design and operation of conventional granular media filters. Depending on the water quality (the ratio of organic carbon to nitrate to phosphate), advanced biological augmentation techniques can be used to greatly enhance the removal efficiencies of the target contaminants. This process is relatively new in the water treatment industry due to biased perceptions of potential biological contamination in the finished water. Significant technical breakthrough occurred recently through research, pilot and full-scale implementation. The technology is now gaining momentum nationally and locally because it eliminates the brine / concentrate wastes that other nitrate removal processes produce.

6.6.4.1 Iron and Manganese Removal

With sufficient pre-oxidation or coagulation, biological filters can effectively remove the oxidized iron and manganese. When oxidation is not sufficient, iron and manganese may pass through the filter and negatively impact the downstream treatment processes or result in taste and color issues in the treated water.

6.6.4.2 Nitrate Removal

The biological filtration nitrate removal process utilizes a stationary bed of GAC on which biofilms containing nitrate-reducing bacteria develop. Bacteria in the bed convert nitrate to N_2 gas and water. This process is very robust. The process is not appreciably impacted by fluctuations in raw water quality or changes in operational conditions.

6.6.4.3 Residuals Requirement

This process does not produce residuals other than low volumes of backwash wastes. Backwash is used to maintain a healthy biofilm and is less frequent compared to coagulation filtration processes, since there are no chemical flocs plugging the filters.

Typically for drinking water applications, a low-cost high-rate polishing filter will be provided downstream of the biological filters to prevent potential biomass sloughing. The biological filtration process is an alternative to ion exchange and RO/NF processes to avoid the generation of costly and difficult to manage concentrate streams. Biological filtration also has lower O&M costs as compared to ion exchange and RO/NF. The most important aspect of this technology is that nitrate destruction eliminates the need for concentrate handling, making the process sustainable. As costs for concentrate handling continue to increase, the biological filtration process will likely become an increasingly important option for utilities dealing with nitrate contamination.

Applicability to City of Surprise

Drinking water biological filtration is an effective way to remove nitrate and perchlorate along with trace organic compounds. Biological filtration is a **recommended** alternative for the City of Surprise and was included for further evaluation using the SurpriseTree™ Water Model.

6.6.5 Summary of Filtration Unit Operations

Table WT.32 summarizes the anticipated performance for each filtration technology alternative and their applicability to the City of Surprise groundwater sources. Table WT.33 summarizes the evaluation results using the implementation-based criteria. Granular media filters, low-pressure membrane filtration, oxidizing filters, and biological filters were all recommended for further evaluation in the SurpriseTree™ Water Model.

It is worthwhile to note the dependencies on water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size (as noted by the shaded cells in the tables). These are examples explaining why a conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges considering the unknown but anticipated water quality variations for the City's future water sources. Refer to Section 7.0 for detailed descriptions about the SurpriseTree™ Water Model and its utility in determining the most appropriate treatment technology for a given water source.

6.7 Adsorption Unit Operations

The process of adsorption involves potential partitioning of substances from gaseous or liquid phase onto the surface of a solid substrate. The adsorbing solid substrate is called adsorbent, characterized first by surface properties such as surface area and polarity. A large specific surface area is preferable for providing large adsorption capacity. Many adsorption media are commercially available that are approved by NSF/ANSI and accepted by Maricopa County for drinking water treatment. The adsorbents commonly used in groundwater treatment include granular iron media (GIM), iron modified media (IMM), activated alumina (AA), granular activated carbon (GAC), and synthetic resins.

Table WT.32 Filtration Unit Operations – Performance-Based Criteria
Water Technology Assessment
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal
Granular Media Filters (dual media filters)	Included with pre-oxidation, coagulation and/or softening	Very good with sufficient pretreatment.	Good. Removes DBP precursors.	Good.	Very good with sufficient pretreatment.	**Very good with effective pretreatment. Best removal when Fe:As > 20:1.**	N/A	**Fair. With coagulation or softening, some removal is achieved at high F concentrations. Requires polishing.**
Low Pressure Membrane Filters	Included with pre-oxidation, coagulation and/or softening	Excellent water quality.	Very good with coagulation or softening pretreatment.	Very good. Provides a physical barrier.	Very good with sufficient pretreatment, May foul the membrane	**Very good with effective pretreatment. Best removal when Fe:As > 20:1.**	N/A	**Fair. With coagulation or softening, some removal is achieved at high F concentrations. Requires polishing.**
Oxidizing Filters	Included with or without coagulation	Very good	Fair. Some removal of DBP precursors.	Good	Excellent. No need for pre-oxidation	**Excellent. No need for pre-oxidation. Best removal when Fe:As > 20:1.**	N/A	N/A
Drinking Water Biological Filtration	Included	Fair. Requires a polishing filter.	Excellent. Removes DBP precursors.	Good.	Very good with sufficient pretreatment.	N/A	Excellent	N/A

Notes:
(1) The effectiveness of the filtration unit operations may depend on the oxidation and/or chemical pretreatment process it is paired with.
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.33 Filtration Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Granular Media Filters (dual media filters)	Included with pre-oxidation, coagulation and/or softening	Good. Neutral.	Good. Cost effective for large facilities.	Good. Cost effective for large facilities	Good.	Very good.	Very good.	Good. Requires handling of residuals.	Good.	Good. Requires handling of residuals.	Good.	Good.	Good.	Good. Residuals produced in filtration process.	Good.	Good.
Low Pressure Membrane Filters	Included with pre-oxidation, coagulation and/or softening	Good. Neutral.	Good. Cost effective for large facilities. More expensive than granular media filters.	Good. Cost effective for large facilities. More expensive than granular media filters.	Very good.	Good.	Good.	Good. Requires handling of residuals.	Good.	Good. Requires handling of residuals.	Good.	Good.	Good.	Good. Residuals produced in filtration process.	Good.	Good.
Oxidizing Filters	Included with or without coagulation	Good. Neutral.	Good. Cost effective for large facilities	Good. Cost effective for large facilities	Very good arsenic removal when sufficient Fe is present.	Good.	Good.	Good. Maintenance intensity for media replacement.	Good. Relatively easy to operate.	Good. Relatively simple.	Good.	Good.	Very good.	Good. Backwash wastes are produced.	Fair.	Good.
Drinking Water Biological Filtration	Included	Excellent. Green technology.	Good. May require methanol addition depending on water quality.	Good.	Very good nitrate removal. Very robust and stable. No arsenic or fluoride removal.	Fair. Relatively new technology.	Fair. New to City.	Very good compared to other nitrate removal technologies (IX or RO).	Good. Easy to operate compared to other nitrate removal technologies (IX or RO).	Very good. Simple process compared to other nitrate removal technologies (IX or RO).	Very good. Compact footprint.	Very good. Green technology that is sustainable.	Very good. Very little chemical handling	Very good. No brine generation.	Very good. Good removal for EDCs, PPCPs, T&O compounds, perchlorate.	Very good.

Notes:
(1) The effectiveness of the filtration unit operations may depend on the oxidation and/or chemical pretreatment process it is paired with.
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Adsorption media such as AA is effective in removing both arsenic and fluoride. IMM and GIM are effective for arsenic removal, but not for fluoride. GAC is not effective in removing arsenic or fluoride, but is used for organic compound removal. The characteristics of each media and their target CoC are discussed in this section.

The adsorption media can be placed into parallel or series pressure vessel systems depending on the required removal concentrations. If a consistent 90 percent reduction is needed across the system, the series design is used. However, if the percentage is less than 90 percent, then the parallel design is typically applied.

To describe how a parallel system works, assume there are three vertical pressure vessels in service. Each vessel is designed to treat a third of the incoming flow at a hydraulic loading rate of 5 gpm/sq. ft. (12.2 m/hr). For granular ferric hydroxide (GFH), a five-minute Empty Bed Contact Time (EBCT) is typically provided for the parallel system. During start-up, one vessel is placed on-line where it begins the exhaustion curve. Subsequently, the second vessel is started and later the third one is activated. This process causes all the vessels to operate at varying degrees of exhaustion, and the blended effluent concentration is below the desired level. When the blended effluent concentration eventually approaches the acceptable limit, the media in the longest running vessel is replaced.

In a series system, two vessels are operated in a lead/lag mode with a third vessel in stand-by. The hydraulic loading rate is 8 gpm/sq. ft. (19.6 m/hr) and, similar to the parallel system, provides an EBCT of five minutes total or 2.5-minute EBCT per vessel. When the lead vessel media is exhausted, it is isolated and the lag vessel shifts to the lead vessel. At that time, the stand-by vessel progresses to the lag sequence. Following this process, the exhausted media is replaced in this vessel and it becomes the stand-by vessel. The series flow systems include a bypass line in order to blend raw water with the treated water until the desired effluent is achieved. In a series design, the lag unit receives a lower concentration of contaminants, which creates a more consistent removal throughout the system. The series system, however, treats a lower flow rate than the same size vessels in a parallel unit. Refer to Appendix B - Technology Assessment Presentation Slides for more information.

6.7.1 Granular Iron Media Adsorption

	• Granular iron media is effective for arsenic and other heavy metals removal with and without pre-oxidation. • Granular iron media is a single use media that must be replaced once the adsorption capacity is exhausted. • pH adjustment may be necessary to extend the life of granular iron media.

Granular iron media (GIM), also known as granular ferric hydroxide (GFH) is a ferric-based media used in an adsorption process to remove arsenic and other heavy metals from surface or groundwater supplies. Removal of arsenic by GFH adsorption media is typically more economical than other adsorption processes. Pre-oxidation is not required for arsenic removal applications using GFH adsorption. Once the media has exhausted its adsorption capacity, it is removed from the vessel and replaced with new media. The simplicity of this process with single use media is very attractive for small installations and wellhead applications - especially where no treatment currently exists. GFH media-based systems have demonstrated full-scale arsenic removal operating experience in Europe and the United States. GFH media provided at City of Phoenix is producing less than 2 ppb effluent arsenic.

Lower influent concentrations lead to a longer media life. Lower raw water pH also has a positive impact on media life. In many cases, pH may not require adjustment. For higher influent pHs, a correction step can be included to extend media life. The most interesting operating parameter is the duty cycle. Systems that allow the media a “rest” period will see an increase in effective media life in terms of bed volumes treated. The rest period allows for an inter-particulate diffusion of arsenic to expose fresh adsorption sites, thus extending the media’s useful life.

6.7.1.1 Arsenic Removal

The typical contaminants removed by GFH media include arsenic (III & V), phosphate, chromium, selenium, antimony, and copper. GIM is capable of achieving low arsenic concentrations in the treated water. However, the removal capacity can be impacted by the water chemistry such as pH and competitive contaminants. The removal efficiency decreases with high phosphate, silica, and vanadium concentrations. Also, the arsenic removal efficiency rapidly decreases as pH increases. pH adjustment may be required to achieve optimum removal of contaminants. Many local groundwater arsenic treatment

facilities constructed recently are using GFH media. It is more economical than AA media and IMM media when arsenic is the main constituent of concern.

6.7.1.2 Fluoride Removal

Fluoride is not removed by GFH media. If a groundwater source contains both arsenic and fluoride, other media may be more appropriate.

6.7.1.3 Pilot Testing Requirements

Bench or pilot scale testing is recommended prior to implementing the GFH adsorption processes for the City of Surprise groundwater source - especially when the source water pH is high or when high levels of competitive ions are present.

6.7.1.4 Residuals Handling Requirements

After use in the adsorption process, the spent media must be replaced with new or regenerated media. The exhausted media must be disposed of. Typically, for groundwater arsenic removal installations in the Valley, arsenic concentrations in the adsorption media are lower than the TCLP requirements. Therefore, the exhausted adsorbents are not considered a hazardous material and can be disposed of in a landfill. For most arsenic treatment systems, it is generally more economical to dispose of the exhausted media than regenerate the media. Refer to Section 6.11 for more discussions on adsorption residuals.

Anticipated Performance for the City of Surprise

Adsorption using GFH media is a **recommended** alternative for the City of Surprise and was included for further evaluation using the SurpriseTree™ Water Model. Many recent local groundwater arsenic treatment facilities are using GFH media. It is more economical than AA media and IMM media when arsenic is the main constituent of concern.

6.7.2 Activated Alumina and Iron Modified Activated Alumina

- Activated alumina is effective for removing both fluoride and low levels of arsenic.
- Iron modified activated alumina is effective for both fluoride and arsenic.
- Activated alumina media can be regenerated once the adsorption capacity is exhausted to 50 to 70% capacity, but disposal is typically more economical.

Granular activated alumina (AA) based media is designed to remove heavy metals and arsenic from potable water. Standard regenerated AA has traditionally been used to remove fluoride from water. Although AA can remove arsenic, testing has shown that it has a very low capacity for arsenic removal. The optimum pH for AA is 6 to 7 units to achieve the longest media run lengths.

Consequently, processes have been developed to add an iron component to AA, which significantly increased its capacity for arsenic, while retaining its fluoride removal capabilities. The iron modified AA has shown arsenic capacities up to five times greater than unpromoted (non-modified) AA. Also, the iron-modified media effectively removes arsenic at a wider range of pH than unpromoted AA, requiring little or no pH adjustment of the raw water.

6.7.2.1 Arsenic Removal

In general, AA or IMM can effectively remove arsenic. However, site-specific water quality can influence AA adsorption capabilities. For example, the capacity significantly decreases in the presence of fluoride. Phosphate can slightly impact the capacity as well. The City staff is aware of AA installations treating arsenic where the media capacity was less than expected. Media replacement and residuals handling required intensive maintenance efforts. This may potentially be attributed to the specific water quality. It was reported that the following contaminants can interfere with the arsenic removal capacity at specific levels:

- Chloride, problem level = 250 mg/L
- Fluoride, problem level = 2 mg/L
- Silica, problem level = 30 mg/L
- Iron, problem level = 0.5 mg/L
- Manganese, problem level = 0.05 mg/L
- Sulfate, problem level = 720 mg/L
- Dissolved organic carbon, problem level = 4 mg/L
- Total dissolved solids, problem level = 1,000 mg/L

Besides competitive ions, pH also influences the removal capacity. The arsenic removal capacity reduces moderately as pH increases. AA is a best available technology (BAT) for arsenic treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.7.2.2 Fluoride Removal

AA and IMM are more effective for removing fluoride than GFH. For groundwater sources that contain both arsenic and fluoride, AA and IMM should be considered in lieu of GFH. Depending on the arsenic to fluoride ratio and the levels of other competitive ions, it may be more economical for certain facilities to use GFH media for arsenic treatment followed by AA for fluoride removal and arsenic polishing. AA is a best available technology (BAT) for fluoride treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

6.7.2.3 Pilot Testing Requirements

Bench or pilot scale testing is recommended prior to implementing the AA or IMM adsorption processes for the City of Surprise groundwater source - particularly when the source water pH is high or when high levels of competitive ions are present.

6.7.2.4 Residuals Handling Requirements

Once AA media is exhausted, it can be replaced or regenerated. Regeneration can be performed by using strong bases and strong acids. Regenerate waste solution will have a high pH and be high in dissolved solids and other absorbed materials such as arsenic and fluoride. The brine stream from the regeneration process requires disposal, which may be difficult.

For arsenic removal, the regeneration process can recover 50 to 70 percent of the media capacity. Often replacement is cheaper than regeneration. For fluoride removal, it is more economical to regenerate the media. Systems that replace the media only have a more simple operation that requires only disposal of the spent media and not both disposal of the spent media and concentrated brine. Refer to Section 6.11 for additional descriptions of residual handling alternatives.

Anticipated Performance for the City of Surprise

Adsorption using AA or IMM media is a **recommended** alternative for the City of Surprise and was included for further evaluation using the SurpriseTree™ Water Model. This technology is especially viable for water that contains both arsenic and fluoride. Many recent local groundwater arsenic treatment facilities are using GFH media in lieu of AA due to economics. Specific water quality (especially competitive ions) impacts the arsenic removal capacity of AA and may pose operation and maintenance challenges. Instead of excluding AA from consideration, it is recommended that design engineers consult with media suppliers and consider conducting bench or pilot testing once specific water quality data is available.

6.7.3 Granular Activated Carbon

- GAC is not effective for arsenic and fluoride removal.
- GAC is effective for a reduction in taste and odor, SOCs, VOCs, NOMs, and DBPs.
- Carbon adsorption systems are proven, and reliable.

GAC is a porous material produced by heating coal in the absence of oxygen. It has a high affinity for organic molecules and is an extremely good adsorbent of organic chemicals. GAC is widely used in drinking water treatment. In the United States, GAC is commonly used in place of granular media in conventional rapid filters (GAC adsorber) for the removal of organic compounds, taste and odor, and turbidity. GAC is also used after granular media filtration in post-filter adsorbers (contactors) for the removal of natural organic matter, taste and odor components, and specific trace organic compounds (GAC contactors). While GAC is generally effective in reducing NOM concentrations, its effectiveness is a strong function of pretreatment. The carbon can be “reactivated” or “regenerated” after use.

Other than GAC contactors and GAC adsorbers, the configuration of a series of vessels containing GAC is commonly used for groundwater treatment. When extracted groundwater is pumped through these vessels, dissolved organic compounds adsorb onto the GAC. Once carbon in the vessels has been saturated with contaminants, the carbon has to be replaced or regenerated thermally. This physical, non-destructive process may achieve low levels of contaminants in the treated groundwater

6.7.3.1 Arsenic Removal

Unlike the GFH and AA media, GAC does not effectively remove arsenic or heavy metals.

6.7.3.2 Fluoride Removal

Unlike the AA media, GAC does not effectively remove fluoride.

6.7.3.3 Organic Removal

GAC is utilized for the reduction of taste and odor, soluble organic carbon (SOCs), volatile organic carbon (VOCs), NOMs, and DBPs. It can also be used as a medium for biological activity and the reduction of assimilable organic carbon (AOC). For GAC adsorption from the liquid phase, target contaminants are halogenated and nonhalogenated semi-volatile organic compounds. This technology is less effective for treating halogenated volatile organic compounds, fuel hydrocarbons, pesticides, and inorganics.

GAC contactor and GAC adsorber modes of operation will become biologically active when ozone oxidation precedes the GAC. When carbon supports a significant microbiological population, it is referred to as biologically active carbon (BAC).

Biological matter and metals can foul carbon filters and cause poor performance. The addition of chlorine or chlorine dioxide ahead of the filters minimizes biological activity. Complete elimination of biological activity by chlorination is not likely due to the complex pore structure of GAC. In general, the practice of chlorination should be avoided because it reduces the adsorptive capacity of GAC for some taste and odor causing compounds.

Carbon adsorption systems are proven, reliable, and commercially available in a variety of configurations and sizes. They are compact, easy to install, and not sensitive to small fluctuations in influent organic concentration.

By using this non-destructive technology, contaminants are transferred from extracted groundwater to carbon. When the concentration of contaminants in the effluent exceeds an established level, the carbon has to be replaced, and the spent carbon can be disposed of or regenerated.

6.7.3.4 Pilot Testing Requirements

It is not recommended that the City of Surprise pilot test GAC adsorption given the low levels of TOC present in the groundwater.

6.7.3.5 Residuals Requirements

Spent GAC can be regenerated by re-heating or by using chemical methods such as solvent recovery, steam regeneration, and nitrogen regeneration. Heating has the advantage of destroying the organic chemicals held in the carbon. When the effective lifespan of the carbon is complete, the carbon has to be disposed of in a responsible and environmentally sensitive manner. Methods of disposal include disposal in landfills, or using the intrinsic energy value of the spent carbon as a secondary or waste derived fuel.

Anticipated Performance for the City of Surprise

The technology of granular activated carbon (GAC) does not remove any of the City's critical CoC, (i.e., arsenic, nitrate and fluoride). This technology is **not recommended** for the City's WSF given the low concern of DBP formation from the City of Surprise groundwater sources.

6.7.4 Summary of Adsorption Unit Operations

Table WT.34 summarizes the anticipated performance for each adsorption technologies and their applicability to the City of Surprise groundwater sources. Table WT.35 summarizes the evaluation results for these adsorption technologies using the implementation-based criteria. Granular iron media, activated alumina and iron modified activated alumina are all recommended for further evaluation in the SurpriseTree™ Water Model.

It is worthwhile to notice that there are many cells in these tables (shaded), which highlight the dependencies of water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size in the selection of a given process. These are examples of why a conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges when considering potential variations in water quality of future water sources. (Refer to Section 7.0 for detailed descriptions about the SurpriseTree™ Water Model.)

Table WT.34 Adsorption Unit Operations – Performance Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance Based Criteria						
		Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal Improvement	Nitrate Removal	Fluoride Removal
Granular Iron Media	Included	Good for low turbidity. Requires pretreatment for high turbidity water.	Good. Removes some DBP precursors.	Good. Not main barrier.	**Very good, but may foul the media.**	Very good - absorbed in media. Very pH dependant.	N/A	Poor
Activated Alumina	Included	Good for low turbidity. Requires pretreatment for high turbidity water.	Good. Removes some DBP precursors.	Good. Not main barrier.	**Very good, but may foul the media.**	Good - absorbed in media. Moderately pH dependent.	N/A	Very good. Can remove both fluoride and arsenic.
Iron Modified Activated Alumina	Included	Good for low turbidity. Requires pretreatment for high turbidity water.	Good. Removes some DBP precursors.	Good. Not main barrier.	**Very good, but may foul the media.**	Very good - absorbed in media. Less pH dependant. Higher arsenic removal capacity.	N/A	Very good. Can remove both fluoride and arsenic.
Granular Activated Carbon	Not Included	Good for low turbidity. Requires pretreatment for high turbidity water.	Very good. High removal of DBP precursors.	N/A	N/A	N/A	N/A	N/A

Notes:
(1) The effectiveness of the adsorption unit operations may depend on the oxidation and/or chemical pretreatment process paired with.
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.35 Adsorption Unit Operations – Implementation Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Granular Iron Media	Included	Good. Neutral.	Good for As removal. More cost effective for small facilities compared to coagulation/ filtration. Less expensive than AA.	Good for As removal. More cost effective for small facilities compared to coagulation/ filtration.	Very good. Performance may be influenced by water quality.	Good.	Good.	Very good. Relatively easy to operate.	Very good.	Very good. Relatively simple operation.	Good. No significant difference.	Good.	Very good. No regeneration in disposal mode.	Good. Requires replacement and disposal of exhausted media.	Good for As.	Very good.
Activated Alumina	Included	Good. Neutral.	Good for As and F removal. More cost effective for small facilities compared to coagulation/ filtration.	Good for As and F removal. More cost effective for small facilities compared to coagulation/ filtration.	Good. Performance may be influenced by water quality. BAT for arsenic and fluoride removal.	Good.	Good. Previous City experience not favorable.	Good. Relatively easy to operate. Previous City experience not favorable.	Good.	Very good. Relatively simple operation.	Good. No significant difference.	Good. BAT for fluoride and arsenic treatment.	Good. No regeneration in disposal mode. If used for fluoride removal only, regeneration requires disposal of brine solution.	Good. Requires replacement and disposal of exhausted media.	Excellent for F. Good for As.	Good.
Iron Modified Activated Alumina	Included	Good. Neutral.	Good for As removal. More cost effective for small facilities compared to coagulation/ filtration. Less expensive than regular AA.	Good for As removal. More cost effective for small facilities compared to coagulation/ filtration.	Very good. Performance may be influenced by water quality.	Good.	Good.	Very good. Relatively easy to operate.	Good.	Very good. Relatively simple operation.	Good. No significant difference.	Good.	Good. No regeneration in disposal mode. If used for fluoride removal only, regeneration requires disposal of brine solution.	Good. Requires replacement and disposal of exhausted media.	Excellent for F and As.	Very good.
Granular Activated Carbon	Not Included	Good. Neutral.	Poor. Not effective for the City's water source.	Poor. Not effective for the City's water source.	Good.	Good.	Fair.	Poor. Maintenance intensity involved with media replacement.	Good.	Good.	Good.	Good.	Good.	Good. Required replacement and disposal of exhausted media.	Poor.	Good.

Notes:
(1) The effectiveness of the adsorption unit operations may depend on the oxidation and/or chemical pretreatment process paired with.
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

6.8 Ion Exchange Unit Operations

- Ion exchange is effective in removing nitrate, arsenic, and fluoride.
- Ion exchange produces a brine waste that must be handled appropriately.
- Difficulty and expense associated with handling the brine waste makes ion exchange most economical for small plants.
- Water quality (such as concentrations of competition ions) impacts ion exchange performance.

Ion exchange systems rely on the process of exchanging harmful positive and negative ions in solution for harmless ions on a solid phase exchange material. This process has wide application in water softening and is also used for removal of regulated contaminants such as arsenic, fluoride, and / or nitrate. Ion exchange is appropriate for water low in particulate matter, organics, iron, manganese, sulfate, and TDS. It is not effective with source water having high TDS and sulfate. Pretreatment to remove iron and manganese should precede ion exchange if such ions are present in the source water. High concentrations of NOM also can foul some ion exchange resins.

Various types of ion exchange resins are available for use. These include strong or weak acid resins and strong or weak base resins. Ion exchanger systems with negatively charged sites (acid resins) are cation exchangers because they take up positively charged ions. The positively charged sites on anion exchangers (base resins) take up negative ions. Each type of resin has a specific exchange sequence and capacity. It is important to have sufficient feed water quality data prior to selecting the right ion exchange resin.

The ion exchange process utilizes a small percentage of product water for periodic backwashes and a resin rinse after regeneration. Typically, a recovery rate of 95 to 98 percent can be expected.

Magnetic ion exchange (MIEX) is a type of ion exchange resin developed for the reversible removal of negatively charged organic ions. However, unlike conventional ion exchange processes, the MIEX resin has been developed to enable removal of arsenic and organic precursors in a stirred contactor, much like a flocculation basin in a conventional water treatment plant.

During normal operation, MIEX resin is recovered as a concentrated underflow stream from the settler units. The efficiency of the resin recovery generally exceeds 99.9 percent at very high settler rise rates (4 gpm/ft^2). A small amount of recycled resin is continuously removed for regeneration and replaced with regenerated resin. The regeneration process is a sequential batch process consisting of 1) removal of carrier water, 2) treatment of drained resin with regenerate, 3) removal of used regenerate, re-suspension of resin, 4) and transfer to the fresh resin tank. The resin is regenerated using salt. Since the regenerate is reused, the waste production rates are minimized. The maximum number of reuse cycles will be dependent upon changes in the regenerate composition after each use. This is a function of the quality of source water being treated.

6.8.1 Hardness Removal

Cation exchange can be used where extracted groundwater contains soluble metallic species. Cations commonly removed by ion exchange are calcium and magnesium for softening processes.

Cation exchange, such as the residential type of softener, offer advantages over lime softening for source waters with varying hardness concentrations and high non-carbonate hardness due to the selective nature of removing the selected ions. However, certain type of softeners (such as the timer based self-regeneration softeners) could be controlled in the City, based on their inefficient regeneration capabilities and resulting discharge of high salinity waste into the sewer system.

6.8.1.1 Iron and Manganese Treatment

Removing iron and manganese with a cation exchange system is not recommended. If the groundwater has not been exposed to oxygen, the resins in the softener will remove the iron and manganese ions from the water. If the water contains any dissolved oxygen, the resin can be fouled with iron and manganese deposits. The resin can be cleaned, but the process is expensive and the capacity of this resin is reduced with each cleaning. Therefore, if selected for removing other ions, cation exchange shall follow the iron and manganese removal process, such as oxidation and filtration.

6.8.2 Arsenic, Fluoride and Nitrate Removal

Anions commonly removed by ion exchange are halides, sulfates, nitrates, arsenic, and cyanides. The critical CoC identified for the City's groundwater sources are arsenic, fluoride, and nitrate. Anion exchange systems can be designed to effectively remove these CoC.

Arsenic can be treated to a relatively low concentration at a low empty bed contact time (EBCT) of 1.5 to 5 minutes using anion exchange. High levels of sulfate (> 150 mg/L) and TDS (500 mg/L) in the source water can significantly reduce arsenic removal efficiency.

The same resins utilized for removing arsenic often can remove nitrate, although more specific nitrate removal resins are also available. Removing fluoride typically requires a different type of resin. More than one ion exchange system is required when the source water contains more than one of the three critical CoC. Ion exchange is a best available technology (BAT) for fluoride, arsenic, and nitrate treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

In addition to the critical CoC, anion exchange systems have been found to effectively remove perchlorate from drinking water. These systems remove perchlorate to levels below the provisional MCL (as established by the State of California). Resin disposal and treatment are drawbacks with this technology. For nitrate and perchlorate applications, biological filtration (reviewed in Section 6.6) offers a more sustainable alternative.

6.8.3 Pilot Testing Requirements

Bench and pilot scale studies and modeling work are recommended to properly select the right ion exchange resins for a given source water. This important strategy will often result in capital and O&M savings caused by the misapplication of resin types.

6.8.4 Residuals Handling Requirements

Spent ion exchange resin can be regenerated. This results in a contaminated ion exchange regeneration solution of extracted inorganics that will require disposal. When available, sanitary sewer disposal is the least expensive option when the volume of brine is small in comparison to the volume of wastewater in the sewer. Onsite storage of regeneration waste can be employed such that the waste stream can be slowly discharged to prevent overloading of the sewer system.

For applications involving arsenic removal, the regeneration waste must be stored and disposed of as a hazardous waste. This can become an expensive operations and maintenance task for larger facilities.

For nitrate and other inorganic contaminants such as perchlorate, a sustainable alternative to the generation of an unmanageable brine is the use of biological filtration technology. (Refer to Section 6.6 for details.)

Periodic replenishment and replacement of resin is required due to resin degradation over time due to physical wear and oxidation. Proper disposal of the spent resin is required.

Applicability to the City of Surprise

Anion exchange is a **recommended** alternative for nitrate, arsenic, and fluoride removal for the City's groundwater sources and is included for further evaluation using the SurpriseTree™ Water Model. Ion exchange systems are not usually the most economical treatment option for large water systems due to difficulties and expense associated with the handling and disposal of the regeneration wastes. Ion exchange is appropriate for water low in particulate matter, organics, iron and manganese, sulfate, and TDS. It is important to have sufficient feed water quality data in order to select the proper ion exchange resins.

6.8.5 Summary of Ion Exchange Unit Operations

Table WT.36 summarizes the anticipated performance for the ion exchange unit operation and its applicability to the City of Surprise groundwater sources. Table WT.37 summarizes the evaluation results using the implementation-based criteria. Ion exchange is recommended for further evaluation in the SurpriseTree™ Water Model.

It is worthwhile to note that there are many cells in these tables (shaded), which highlight the dependencies on water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size in the selection of a process. These are examples of why a conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges when considering potential variations in water quality of future water sources. (Refer to Section 7.0 for detailed descriptions about the SurpriseTree™ Water Model.)

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Table WT.36 Ion Exchange Unit Operations – Performance-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Fouling and Removal	DBP Control	Pathogens	Fe and Mn Removal	Arsenic Removal Improvement	Nitrate Removal	Fluoride Removal
Ion Exchange (In comparison to chemical pretreatment / filtration, adsorption, desalination)	Included	Good. Not main barrier.	Good. Not main barrier.	Good. Not main barrier.	**Good, Depending on resins and water quality . Fe and Mn may foul the resin.**	**Very good depending on resin. High sulfate and TDS can interference with IX process, making process less effective and less economical.**		

Notes:
(1) Ion exchange resins are ion selective. Multiple ion exchange resins are required to treat for multiple contaminants including arsenic, nitrate, and fluoride. SurpriseTree™ Water analyzes the treatment of arsenic, nitrate, and fluoride as three separate ion exchange processes.
(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.37 Ion Exchange Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Foot-print	Regulatory	Safety	Residuals	Versatility	Expand-ability
Ion Exchange (In comparison to chemical pretreatment / filtration, adsorption, desalination)	Included	Good. Neutral.	**Good. High sulfate and TDS can interfere with IX process, making process less effective and less economical.**	**Good. High sulfate and TDS can interfere with IX process, making process less effective and less economical.**	Very good. Very reliable. Performance and resin selection could be impacted by water quality.	Good. Very mature. Many resins available.	Good.	Fair. Regeneration requires handling of hazardous materials and wastes.	Good. Relatively flexible.	Good. Relatively simple.	Good.	**Fair. Regeneration or waste disposal for large facilities is an issue. BAT for arsenic and nitrate treatment.**	Fair. Requires handling of hazardous regeneration chemicals.	**Fair. Regeneration wastes disposal for large facilities is an issue. High sulfates and other competitive constituents can increase residual generation.**	Good. System can be designed to treat multiple contaminants.	Very good.

Notes:

(1) Ion exchange resins are ion selective. Multiple ion exchange resins are required to treat for multiple contaminants including arsenic, nitrate, and fluoride. SurpriseTree™ Water analyzes the treatment of arsenic, nitrate, and fluoride as three separate ion exchange processes.

(2) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

6.9 Desalination Unit Operations

Thermal distillation and membranes are two major types of desalting technologies. Distillation processes are cost prohibitive for groundwater supplies and therefore will not be discussed in this Water Technology Assessment Report.

The fundamentals and operation principles of the two major membrane desalination processes, (nanofiltration (NF)/reverse osmosis (RO), and electrodialysis/electrodialysis reversal (ED/EDR) processes) are described in this section along with the applicability of these processes in treating the local groundwater to meet the proposed water quality standards.

6.9.1 Nanofiltration / Reverse Osmosis

- NF/RO processes are effective at removing TDS, arsenic, nitrate, and fluoride.
- NF/RO produces superior finished water quality and addresses the removal of most emerging constituents of concern.
- Concentrate disposal is expensive for inland communities (such as the City of Surprise), presenting a major challenge when using this technology.

NF/RO membranes provide the highest degree of filtration and remove dissolved organic and inorganic compounds, pathogens, bacteria and virus, and trace organic compounds such PPCPs and EDCs. NF/RO can effectively address the removal of the City's CoC in a single technology. This includes arsenic, nitrate, fluoride, THMs, and pathogens.

NF/RO generates a high salinity concentrate waste stream, which can typically represent 10 to 20 percent of the treated flow given the City's typical groundwater quality range. With limited concentrate management and disposal options for inland communities, concentrate management can be very expensive and often hinders the implementation of this technology.

6.9.1.1 NF/RO Fundamentals

The NF/RO processes uses hydraulic pressure to force pure water from saline feed water through a semi-permeable membrane. Water naturally flows through such membranes from the low salinity side to the concentrated side. When the osmotic pressure of the water is overcome (by an outside pressure source called the "driving pressure"), the flow of water can be reversed towards the side with a lower TDS concentration.

Membrane pore size for NF systems are in the nanometer range. Strictly speaking, RO membranes do not have pores. The membrane is formed using a thin film of polyamide on a layer of polysulfone. The molecular gaps in the polyamide layer block contaminants from passing while allowing water molecules and low concentrations of small ions to flow through. Because the pore size of NF and low-pressure RO systems is very small, these membranes often are characterized by their molecular weight cut-off (MWCO) as determined with test compounds.

Flux and salt passage are two key descriptive parameters of NF/RO membranes that affect membrane performance. Flux is often characterized by the water coefficient, and salt passage is referred to as salt transport coefficient. Flux is proportional to the net applied pressure, depending on operating conditions, while the salt transport coefficient is supposed to be a function of the membrane material itself, i.e., an intrinsic quality of the membrane.

NF/RO water treatment can be performed in various configurations for multi-stage and multi-pass systems. Multi-stage configurations are typical for municipal water treatment. A membrane facility utilizes membrane racks (arrays) and is often very compact.

From a pretreatment standpoint, it is easier to apply NF/RO to groundwater treatment than surface water treatment. A sand strainer followed by cartridge filters are sufficient for pre-treating groundwater, while surface water often requires chemical pretreatment such as coagulation, flocculation, with or without sedimentation, followed by filtration using either granular media or membrane filters.

6.9.1.2 NF/RO Membranes Materials of Construction

Choosing a suitable membrane material for a water treatment system is critical because the type of membrane material will dictate its performance and durability for a given water quality. The majority of membranes used for drinking water treatment are either organic or polymeric membranes. Organic membranes are made from organic polymers such as cellulose acetate, polysulfone, polyamide, or polycarbonate. Each of these materials offer advantages and disadvantages depending upon the water source. Consequently, a specific type of membrane is usually recommended for a given feed water quality. For example, polysulfone membranes are known to be stable at alkaline pH values (such as those of softened waters) and are less prone to organic fouling, whereas cellulose acetate membranes are more prone to organic adsorption at higher pHs and are subject to possible hydrolysis.

Organic membranes are available in different configurations. They can be tubular or hollow-fiber bundles, stacks of flat sheets of membrane (also referred to as plate and frame), or spiral wound assemblies. Each of these types of configurations offers advantages and disadvantages for treatment and operation, depending on the feed water quality. The flow pattern can be either dead-end or cross-flow. NF and low-pressure RO systems are always cross-flow to prevent inorganic scaling.

Ceramic membranes in tubular assemblies are also available. Although these membranes are mechanically stronger than organic membranes, are tolerant to a variety of oxidants, and can handle high or low pH and temperatures, ceramic membranes are not common in the potable water industry due to its high capital cost. In addition, recent advancements to organic membranes have increased their resistance to oxidants.

Membranes are also categorized as hydrophilic ("water-loving") or hydrophobic ("water-hating"). For waters containing substantial organic concentrations, such as those of surface waters, hydrophilic membranes are usually recommended, because organic adsorption onto hydrophilic membranes is less than hydrophobic membranes.

6.9.1.3 Power Consumption

The electrical energy consumed by the NF/RO process is primarily for pumping. In the past 10 years, the net driving pressure (NDP) required for permeation has been significantly reduced, and the in-process electrical energy needs have declined.

The NDP required for any given membrane application in NF/RO is a function of both the osmotic pressure change and hydraulic resistance. The NDP required is influenced by the concentration factor in the process and, thus, the water recovery.

Temperature also impacts energy consumption in RO feed pumps, since temperature affects flux, and flux impacts NDP. Flux increases as NDP increases.

6.9.1.4 Membrane Scaling and Fouling

As water is forced through the membrane, certain particles in the feed water are rejected by the membrane (due to physical size and surface charge). As these particles collect on the membrane surface, they cause the required pressure for water production to increase. This build up of material is referred to as membrane fouling (if irreversible) and colmatage (if reversible).

NF/RO systems are susceptible to fouling by organic compounds. The small pore size of NF/RO systems allow organic compounds to become imbedded in the membrane material.

NF/RO systems are not backwashed, yet inorganic precipitate formation occurs on or near the membrane surface and must be controlled. Calcium carbonate, sulfate, fluoride, strontium and barium sulfate, ferric hydroxide, aluminum hydroxide, and silica are common scale-forming inorganic salts. To control membrane scaling, either ion removal prior to membrane treatment (e.g., precipitation or acidification) or scale-inhibitor chemicals are used. Low dosages (e.g., 3 mg/L) of proprietary polyphosphate scale inhibitors are often used to prevent deposition on the membrane surface. There are relatively low fouling concerns for groundwater applications at 85 percent recovery. NF/RO systems that treat surface water are commonly protected by a pretreatment system upstream (such as MF/UF membranes) to reduce the loading of foulants onto the membranes.

Biological fouling is also a concern for the City's groundwater source. However, if fouling caused by other mechanism occurs first and provides a habitat for biological growth, microorganisms can secrete organic polymers that form a gel at the membrane surface. Chlorine cannot be added to the feed-water stream because polyamide membranes are not chlorine tolerant. However, a low dosage chloramines can be used if biofouling is significant.

6.9.1.5 NF/RO Membrane Life

The useful life of NF/RO membranes is usually a function of the membrane material and the application.

Polyamide membranes can operate over a wide range of pH. Most, however, have a limited resistance to chlorine and other strong oxidants. Typically, for the City's groundwater supply, for planning purposes, the lifespan for noncellulosic elements is estimated at 5 to 7 years.

6.9.1.6 Removal Efficiency

NF/RO is often used for brackish water desalination. Even though the City's groundwater sources generally contain TDS less than 500 mg/L (considered as fresh water), this technology can be used to remove arsenic, nitrate, fluoride, as well as other contaminants. It is an applicable option if the source water contains multiple contaminants that would require multiple treatment steps (e.g., three ion exchange systems for nitrate, arsenic and fluoride or a coagulation filtration facility for arsenic and ion exchange units for nitrate). If the groundwater is contaminated from agricultural chemicals (e.g., atrazine), NF/RO provides reliable alternative for removal of these types of compounds.

Given the superior product water quality, NF/RO facilities can be designed to treat a partial stream and blend the product water with the remaining untreated stream to achieve a target treatment goal. This type of treatment scenario helps to reduce the total treatment costs and the volume of concentrate stream.

Information on the rejection rates for individual ions by a specific membrane element is readily available and fairly accurate. For a typical RO membrane, salt rejection rates for most ions are high (90 to 99 percent).

Even though this section has been using NF/RO to refer to both membranes as a single technology, there are differences between the two processes. RO can be used for removing various groundwater CoC, including TDS, hardness, arsenic, nitrate, bromide, iron, manganese, thallium (and other metals), VOCs, SOCs, and as a mechanism to control DBPs. NF is effective in removing TDS, hardness, arsenic, and bromide. It also removes some levels of thallium (and other metals) and SOCs depending on the specific characteristics of groundwater. However, the removal of nitrate, iron, manganese, and VOCs is low in comparison to RO. It is also expected that RO will provide a better barrier

for the removal of emerging contaminates. RO is a best available technology (BAT) for fluoride, arsenic, and nitrate treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

It is important to have sufficient water quality data for the specific source prior to the selection of the actual membrane and design configurations. This effort will for the selection of the right membrane for the right application, minimizing capital and operational costs. For example, even though NF cannot sufficiently remove nitrate or other small monovalent ions such as fluoride, the operational cost for a NF membrane unit is lower than or about the same as the RO membrane unit. Operated at lower pressure (60 to 90 psi) compared to RO (100 to 150 psi), a NF system typically requires smaller pump stations and consumes less power than a low pressure RO system of the same capacity. If the water contains high TDS but the nitrate was not a quite a concern, NF is still a viable option. The capital costs for the entire membrane system must be determined considering rejection and flux rate, which determine the membrane facility capacity that is required to achieve the same treatment goal (say arsenic, fluoride, or nitrate) of the product water after blending.

6.9.1.7 Pilot Testing Requirements

Pilot scale testing is recommended prior to implementing NF/RO processes for the City's groundwater source.

6.9.1.8 Residuals Handling Requirement

The disposal of residuals from an NF/RO membrane system possesses a serious challenge to the implementation of this technology. Typically, a concentrate stream equal to approximately 10 to 30 percent of the treated water volume must be dealt with as a waste. The concentrate stream discharged from the membranes is heavily concentrated with the ions and other compounds removed from the raw water. TDS concentrations will vary with the removal efficiency of the specific membranes. For example, an 85 percent TDS rejection rate membrane system will create lower concentrations of TDS in the concentrate stream as compared to a 90 percent rejection rate system.

Potentially viable concentrate disposal options include disposal to the sanitary sewer, using zero-liquid discharge (ZLD) systems, and combinations of ZLD technologies with partial sewer discharge. ZLD systems are very often cost prohibitive. Therefore, if discharge to the sewer is not a feasible concentrate disposal option, NF/RO cannot be implemented for the City's WSF. Refer to Section 6.11 for descriptions of residual handling alternatives.

Applicability to the City of Surprise

NF/RO with sanitary sewer discharge of the brine concentrate for a small facility is **recommended** for the City's consideration and is included in the SurpriseTree™ Water Model. NF/RO with ZLD concentrate disposal is not recommended due to the prohibitive costs.

6.9.2 Electrodialysis / Electrodialysis Reversal (ED/EDR)

- ED/EDR processes remove ions from water by the use of electrical forces.
- ED/EDR processes do not remove organic material or micro-organisms from water.
- Concentrate disposal is expensive for inland communities (such as the City of Surprise), presenting a major challenge when using this technology.

Electrodialysis (ED) is an electrical driven membrane. Salt components are present in solution as ionized particles with positive or negative charges (i.e., Na+ and Cl-). When a direct current is imposed on the solution, the positive ions migrate to the negative electrode, or cathode. The negative ions migrate to the positive electrode, or anode. A cation permeable membrane allows positive ions to pass, but blocks negative ions. An anion permeable membrane does the opposite, allowing negative ions to pass, but blocks positive ions.

The electrodialysis reversal (EDR) process is based on the same principles of electrochemistry as ED. However, the fundamental difference in operation is the periodic automated reversal of polarity and cell function. This change is typically done three or four times per hour to reverse the flow of ions across the membrane.

In an ED/EDR process, a unit composed of an anion membrane, a diluting spacer, a cation membrane, and a concentrating spacer is called a “cell pair.” Multiple cell pairs between an anode and a cathode comprise a “stack.” The basic ED stack consists of an inlet feed water channel, semi-permeable membranes, spacers, two electrodes, and end plates to form a rigid device. The edges of the cell pairs are sealed by the pressure applied to the end plates by tie rods. Each electrode is connected to a source of direct current. The spacers separate the membranes and contain and direct the flow of water uniformly across the exposed face of the membrane. Spacers are generally about 1 mm thick and designed to cause turbulent mixing. Stacks are arranged either vertically or horizontally.

ED/EDR processes typically occur in multiple stages and multiple trains. Multiple stages are used to increase the amount of salt removed. Each stage progressively removes more salt. ED/EDR trains are typically designed at a standard capacity. Multiple trains are used to produce the necessary treatment capacity.

6.9.2.1 Power Consumption

In the operation of the ED/EDR process, electric energy is consumed proportionally to the quantity of salts to be removed. Economics usually limit its application to feed waters of less than 10,000 mg/L TDS.

6.9.2.2 Scaling and Fouling

ED/EDR only removes ions. Any bacteria, colloidal material, or silica present in the feed water stream will remain in the product stream. Compared to NF/RO, ED/EDR has much higher tolerance toward fouling. However, even when operated in conjunction with pretreatment processes, fouling and scale deposits may still form on the membrane surfaces with extended continuous ED/EDR operation. The amount of deposits depends on feed water quality. Fouling and scale result in an increase in stack resistance thus increasing power requirements.

Scaling occurs when the concentrate stream becomes saturated with the less soluble alkaline scale or nonalkaline scale, such as calcium sulfate. Pretreatment is required to remove the scale potential. The cost of pretreating the feed water for ED/EDR will vary with feed water quality, and is related to the salt concentration that can be permitted in the concentrate stream. A soft source water with no oxidized iron or manganese will require minimum pretreatment. Pretreatment for removing iron is recommended where feed waters contain more than 0.3 ppm of iron. Normal pretreatment of the feed waters of ED/EDR units includes iron and manganese removal, acid addition, and final polishing filters.

Techniques for in situ cleaning have been developed to increase the interval between stack disassembly for manual cleaning. More significantly, the introduction of EDR improves the tolerance of the technology to operations treating scaling-prone or turbid waters. The periodic reversing of polarity and cell function in EDR units helps to clean surfaces of scaling and fouling materials and can reduce or eliminate the need for adding acid to the feed water. Thus, EDR has less stringent pretreatment requirements, and permits operation at higher levels of supersaturation for scale-forming compounds.

6.9.2.3 ED/EDR Membrane Life

ED/EDR membrane life significantly influences the process economics, and membrane replacement can be tedious and time consuming. Membrane damage can be caused by oxidation by disinfectants, and “hot spots” or shorts inside the stack. Typically, cation membranes last longer than anion membranes. In general, a 10-year overall membrane life is realistic for determining membrane replacement needs. Effective and timely in situ cleanings will extend membrane life and improve product quality and reduce power consumption.

6.9.2.4 ED/EDR Electrode Life

Electrode materials have changed over the years as experience and process understanding have increased. Material science has developed new techniques for plating and deposition. Electrode life in the last decade varied with the application and type of feed water, and experience of the operators. It was not unusual to get a consistent 5-year life from a platinum-plated electrode in a unidirectional plant. Anode life was typically less than cathode life. However, with the advent of EDR, the electrode life was reduced at both ends of the stack. Typically, electrode life is now 2 to 3 years.

6.9.2.5 Comparing ED/EDR with NF/RO

ED has several advantages over RO. ED does not separate nonpolar substances, so ED is not as constrained by silica concentration in the feed water. Because of the open-channel design, a significant level of suspended materials can be tolerated in the feed water if the reversal feature is incorporated. With improved spacer design and membrane materials, electrical efficiency has been much improved. The reversal process permits inherently higher recovery with a given feed water, and product quality can be tailored to meet established goals. The process operates at relatively low pressure, and stacks are fabricated predominantly from corrosion-resistant material.

On the negative side, the ED process is not a barrier to organics or microorganisms. Therefore, ED receives no credit for reduction in cyst or virus populations. ED does not remove taste and odor compounds. Energy consumption increases rapidly with increases in TDS. There is limited tolerance for oxidizable components in the feed water, such as hydrogen sulfide (H_2S) and iron (Fe). ED is a best available technology (BAT) for fluoride, arsenic, and nitrate treatment as identified in the Safe Drinking Water Act (as discussed in Section 3.4).

There are many large NF/RO membrane suppliers. However, EDR is a proprietary system, sole sourced by GE Ionics. There are several ED manufacturers; however, the prices for NF/RO are generally less expensive given the City's typical groundwater quality.

6.9.2.6 Pilot Testing Requirements

Pilot scale testing is recommended prior to implementing ED/EDR processes for the City's groundwater source.

6.9.2.7 Residuals Handling Requirements

ED/EDR produces a concentrate stream similar to NF/RO processes, except that the ED/EDR concentrate stream consists almost exclusively of inorganic ions. The residuals from an ED/EDR system pose a serious challenge for the implementation of this technology. Typically, a concentrate stream equal to approximately 10-30 percent of the treated water volume must be dealt with as a waste. The concentrate stream discharged from the membranes is heavily concentrated with the ions and other compounds removed

from the raw water. Potentially viable concentrate disposal options include disposal to the sanitary sewer, using zero-liquid discharge (ZLD) systems, and combinations of ZLD technologies with partial sewer discharge. ZLD systems are very often cost prohibitive. Therefore, if discharge to the sewer is not a feasible concentrate disposal option, NF/RO cannot be implemented for the City's WSF. Refer to Section 6.11 for descriptions of residual handling alternatives.

Applicability to the City of Surprise

ED/EDR with sanitary sewer discharge of the brine concentrate for a small facility is **not recommended**, when compared with an NF/RO alternative (which will also remove organic compounds and emerging contaminants). However, it is included in the SurpriseTree™ Water Model with a lower ranking when compared with NF/RO. ED/EDR with ZLD concentrate disposal is not recommended due to the prohibitive costs.

6.9.3 Summary of Desalination Unit Operations

Table WT.38 summarizes the anticipated performance of the desalination unit operations as well as their applicability to the City of Surprise groundwater source. Table WT.39 summarizes the evaluation results for desalination technologies using the implementation-based criteria. NF/RO and ED/EDR with sanitary sewer discharge of the brine concentrate is recommended for further evaluation in the SurpriseTree™ Water Model.

It is worthwhile to note that there are many cells in these tables (shaded), highlight the dependencies of water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size on the implementation of the process. These are examples of why a conventional technology assessment approach, which results in a single fixed set of recommended technologies, cannot address the City's unique challenges when considering potential variations in water quality of future water sources. (Refer to Section 7.0 for detailed descriptions about the SurpriseTree™ Water Model.)

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Table WT.38 Desalination Unit Operations – Performance-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Removal	DBP Control	Pathogens	Fe and Mn Removal	Arsenic Removal Improvement	Nitrate Removal	Fluoride Removal
ED/EDR	Included.	Fair. Not a particulate matter barrier.	Fair. Not a DBP precursor barrier.	N/A	Very good. Iron and manganese shall be removed in pretreatment. Membrane has limited tolerance to them.	Excellent. BAT for arsenic treatment.	Very good. BAT for nitrate treatment.	Very good. BAT for fluoride treatment.
NF / Low Pressure RO	Included.	Excellent. Produces the best water quality.	Very good. Produces the best water quality.	Very good. Produces the best water quality.	Very good. Fe and Mn may foul the membrane.	Excellent. BAT for arsenic treatment.	Very good. BAT for nitrate treatment.	Very good. BAT for fluoride treatment.

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.39 Desalination Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
ED/EDR	Included.	Good. Neutral.	Good. Expensive but affordable if non-ZLD.	Good. Expensive but affordable if non-ZLD.	Very good.	Good. Mainly sole sourced by GE Ionics.	Fair. New to the City.	Fair. More complex than RO.	Good. Flexible.	Fair. Fairly complex system.	Very good. Compact.	Poor for large facilities. Possible for small facilities. Brine disposal for large facilities is an issue.	Good. The combination of water and electricity may create a challenge for operation.	Poor for large facilities. Possible for small facilities. Brine disposal for large facilities is an issue.	Very good. Removes most inorganic contaminants.	Very good.
NF / Low Pressure RO	Included.	Good. Neutral.	Good. Expensive but affordable if non-ZLD.	Good. Expensive but affordable if non-ZLD.	Very good.	Good. Many membrane manufacturers available.	Fair. New to the City.	Good. Relatively simple.	Very good. Flexible.	Relatively good.	Very good. Compact.	Poor for large facilities. Possible for small facilities. Brine disposal for large facilities is an issue.	Good. Relatively safe.	Poor for large facilities. Possible for small facilities. Brine disposal for large facilities is an issue.	Excellent for NDMA control, EDCs and PCPPs.	Very good.

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

6.10 Disinfection Unit Operations

Disinfection is the inactivation, or killing, of pathogens in drinking water. This process is a necessary barrier to prevent the transmission of waterborne diseases by microorganisms. Chemical disinfection is the accepted practice within the drinking water industry in the U.S. All water treatment systems, whether they provide filtration or not, must provide disinfection. For surface water treatment systems where the source water contains high levels of natural organic matters (measured as TOC), another important consideration driving disinfection process selection is the control of disinfection byproduct (DBP) formation. The local groundwater is expected to contain essentially no microorganisms and very low TOC. In general, the disinfection requirement for groundwater is simply maintaining residuals in the distribution system using chlorine or other disinfectants that can provide measurable residuals. Two types of commonly used disinfectants that can meet this requirement are free chlorine (gaseous chlorine and sodium hypochlorite), and chloramines.

6.10.1 Ultraviolet and Ozonation

Ultraviolet (UV) disinfection is another widely used disinfection alternative. UV disinfection utilizes UV light instead of chemicals to inactivate pathogens without the formation of DBPs. It is a viable alternative to mitigate DBP formation in high TOC water sources. Considering the City's low TOC groundwater source, UV may not be necessary. Moreover, UV does not provide residual disinfection. A secondary disinfectant must be used to maintain a residual within the distribution system. The implementation of UV requires an additional chemical feed system.

Applicability to the City of Surprise

UV is **not recommended** for the City's WSFs at this time. If in the future treatment standards for trace organic compounds and other emerging contaminants are set, UV at high doses may be a viable advanced oxidation process to consider.

Ozonation is another disinfection alternative. Ozone was introduced in Section 6.4 as a pre-oxidation alternative. It is a strong oxidant and disinfectant and it does not form chlorinated DBPs. However, like UV disinfection, ozonation still requires a secondary disinfectant to maintain a residual within the distribution system. It reacts with bromide and forms another regulated DBP; bromate. Considering the bromide levels in the City's groundwater sources, bromide reduction technologies must be implemented if ozone is used as a primary disinfectant. High capital and O&M costs are also associated with the use of ozone as well as safety concerns associated with the storage and use of liquid oxygen. Ozone is effective in addressing taste and odor, trace organic compounds, EDCs, PPCPs.

Applicability to the City of Surprise

Ozonation is **not recommended** for the City's WSFs at this time. If in the future, treatment standards for trace organic compounds and other emerging contaminants are set, ozonation may be a viable alternative to consider.

6.10.2 Chlorination

For years, chlorination has been used by water utilities as a primary and secondary disinfectant. Chlorination can be accomplished using gaseous chlorine, liquid chlorine, (bulk or on-site generated) or chloramines.

In general, chlorine is an effective disinfectant. It is very effective for virus inactivation, but is not as effective a disinfectant for *Cryptosporidium* when compared to UV and ozone. Free chlorine is also not necessarily as effective as chloramines to control biofilm growth in distribution system piping.

6.10.2.1 Gaseous Chlorine

- Chlorine gas has a long history of successful use as a disinfectant in water treatment.
- Chlorine gas is an economical means of providing disinfection.

  Safe storage and handling of chlorine gas is an important concern to prevent accidental releases to neighboring communities.

Gaseous chlorine has a long history of successful operation for disinfection in water treatment plants. It is readily available in cylinders, 1-ton containers, or 17-ton tank trucks. It is an economical chemical to use for disinfection. However, there are many safety concerns associated with the use of chlorine gas. The accidental release of chlorine gas during transportation or operation at the treatment facility can cause clouds of the poisonous gas to travel great distances potentially endangering surrounding communities. A risk management plan is also required by the Clean Air Act for locations having more than 2,500 pounds of chlorine gas on site.

Anticipated Performance at City of Surprise

Chlorination using chlorine gas is **not recommended** for the City due to its safety concerns.

6.10.2.2 Bulk Sodium Hypochlorite

- Bulk Sodium Hypochlorite has a long history of successful disinfection in water treatment.
- 12.5% sodium hypochlorite is considered a hazardous material.
- Degradation can occur over time due to exposure to high temperatures and UV.

Bulk sodium hypochlorite is also known as bleach. The 12.5 percent sodium hypochlorite solution is widely used and has a long history of successful disinfection in the water treatment industry. Bulk sodium hypochlorite is considered a hazardous material, but is much safer to transport, store and handle than gaseous chlorine. The storage and feed systems are inexpensive to construct, but the chemical costs associated with bulk deliveries are expensive compared to gaseous chlorine and the O&M costs for using on-site generated sodium hypochlorite.

Bulk sodium hypochlorite solutions degrade rapidly under evaluated temperature and exposure to UV, thus reducing the concentration of the effective chlorine content. In addition, the potential for air binding, plugging, and mechanical malfunction can be operational challenges associated with the use of this chemical.

Anticipated Performance at City of Surprise

Chlorination using bulk sodium hypochlorite is a **recommended** alternative for groundwater disinfection for the City of Surprise water supply facilities. The technology is included for further evaluation using the SurpriseTree™ Water Model. A life-cycle cost evaluation and payback analysis is recommended to compare this alternative with on-site sodium hypochlorite generation based on market conditions at the time of implementation.

6.10.2.3 On-Site Generation Sodium Hypochlorite

	• On-site generation has a history of successful disinfection in water treatment. • On-site generation of chlorine occurs through a reaction of salt, water, and electricity. • <1% sodium hypochlorite is considered a non-hazardous material.

Liquid chlorine can be generated on-site in the form of sodium hypochlorite solution by combining salt, water, and electricity. The generated solution is typically less than 1 percent concentration, which is considered a non-hazardous material. Since the chemical is generated on-site and at a lower concentration, there is less concern for chemical degradation compared to bulk chlorine. Consequently, and consistent solution strength is provided for disinfection. On-site generation systems have a higher capital cost than bulk chlorine but require less frequent deliveries of chemical to the treatment site. Producing a chemical on-site provides operational staff with flexibility in chemical production and operations. On-site generation systems generally have high power consumption requirements. On-site generation systems also have a greater addition of TDS and sodium to the water as compared to bulk solution. An increase in TDS of 10 to 14 mg/L and an increase in sodium of 5 to 6 mg/L can be expected in the disinfected water from the use of on-site generated sodium hypochlorite versus bulk sodium hypochlorite due to differing methods of chemical creation. On-site generation systems produce a hydrogen gas byproduct that must be carefully vented and monitored to avoid potential safety issues.

There are two types of systems available for on-site generation. The first and most common systems generate a very dilute (0.8 percent) sodium hypochlorite solution directly from salt water. The second system generates pure chlorine gas directly and sodium hydroxide as a byproduct. In the second method, the chlorine can be fed in two distinct ways. The generated chlorine can be fed either directly via a conventional chlorine feed system or generated chlorine can be remixed with the generated sodium hydroxide to generate a concentrated (12.5 percent) sodium hypochlorite solution, which is stored on-site and fed with conventional metering equipment. The first system has seen widespread use in the U.S. while the second system is much more complex and has seen limited use.

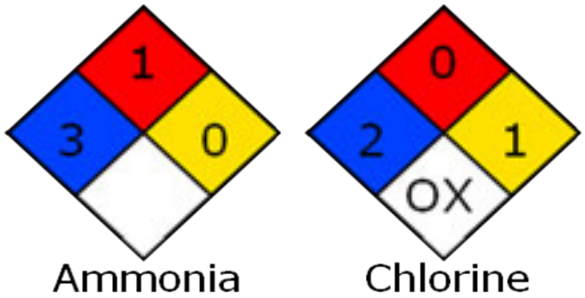
Disinfection can also be achieved by using a mixed oxidant on-site generation system. A mixed oxidant on-site generation system is similar to a sodium hypochlorite on-site generation system. However, mixed oxidants are used to accomplish disinfection in lieu of sodium hypochlorite.

On-site sodium hypochlorite generation generally requires a higher initial capital investment than comparable bulk or gaseous chlorine systems. However, the O&M costs are generally considerably lower than comparable bulk systems. From a life cycle standpoint, on-site generation could offer cost savings, especially for high chemical use or large facilities.

Anticipated Performance at City of Surprise

Chlorination using on-site sodium hypochlorite generation is a **recommended** alternative for groundwater disinfection for the City of Surprise water supply facilities. The technology is included for be further evaluation using the SurpriseTree™ Water Model. A life-cycle cost evaluation and payback analysis is recommended to compare this alternative with bulk sodium hypochlorite based on market conditions at the time of implementation.

6.10.2.4 Chloramine Disinfection



$$NH_3 + HOCl = NH_2Cl + H_2O$$
$$NH_3 + 2HOCl = NHCl_2 + 2H_2O$$
$$NH_3 + 3HOCl = NCl_3 + 3H_2O$$

- Chloramines disinfection is a viable secondary disinfectant used to maintain a residual.
- The use of chloramines reduces the formation of DBP compared to free chlorine.

The use of chloramines has become more widespread due to their ability to provide a degree of disinfection without substantial THM formation. Chloramination is accomplished by combining free chlorine with ammonia or an ammonium salt to form chloramine. Chloramines provide additional benefits including taste and odor control and maintenance of a more stable residual in distribution systems. If improperly managed, the application of chloramines can support bacterial growth in the distribution system, due to biological nitrification of the free ammonia.

Chloramine is not as strong as chlorine for disinfection and it is not recommended as a primary disinfectant by the USEPA. Chloramine, does however form a persistent disinfectant residual, and is used by numerous water utilities for maintenance of a residual in the distribution system. Chloramine is slower to react with substances on the walls of water mains and thus is more effective at penetrating tubercles and biofilms and killing resident bacteria.

Chloramine is known to reduce the production of chlorinated DBPs compared to free chlorine, since the free chlorine first reacts with ammonia to form the chloramines molecule. However, chloramination in the presence of bromide can produce DBPs including bromamines and bromochloramine.

Per the California Department of Health Services "Studies of Occurrence of NDMA in Drinking Water" (March 2004), N-Nitrosodimethylamine (NDMA) was found to occur in drinking water at several California water systems, and was linked to disinfection practices as a disinfection byproduct. During disinfection, NDMA appears to be formed by several different reactions, depending on the water matrix and chemicals used.

Chloramination, cationic polymers, and detention times appear to be factors that may increase the levels of NDMA. Chloramination provides nitrogen species that may trigger the formation of NDMA. Some cationic polymers may be releasing precursors of NDMA into the water.

In some instances, NDMA is formed slowly, so long detention times in the distribution system may increase levels. Nitrification by nitrifying bacteria may occur in systems that practice chloramination. Similarly, other bacteria species may cause the formation of NDMA. By controlling these factors, water systems should be able to reduce the formation potential of NDMA.

Anticipated Performance at City of Surprise

Given the City's low TOC water source and low THM formation concerns, chloramines are generally **not recommended**. However, the technology was included in the SurpriseTree™ Water Model, should future conditions require its further evaluation.

6.10.3 Summary of Disinfection Unit Operations

Table WT.40 summarizes the disinfection unit operations that were selected for further evaluation and ranking. Table WT.41 summarizes the evaluation results for disinfection technologies using the implementation-based criteria. Bulk sodium hypochlorite and on-site generated sodium hypochlorite are the recommended disinfection alternatives for the City. Several other chlorination alternatives, including chloramination, are also included in the SurpriseTree™ Water Model should future conditions warrant their further evaluation.

Table WT.40 Disinfection Unit Operations – Performance-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operation	Included for SurpriseTree™ Water Evaluation	Performance-Based Criteria						
		Particle Removal	DBP Control	Pathogen	Fe and Mn Removal	Arsenic Removal Improvement	Nitrate Removal	Fluoride Removal
Bulk Sodium Hypochlorite	Included	N/A	Poor. Chlorination can create DBPs. Chlorate is formed when sodium hypochlorite decays.	Very good	Good. Effective when also used as an oxidant.	Good. Effective, when also used as an oxidant.	N/A	N/A
Onsite Generation Sodium Hypochlorite	Included	N/A	Poor. Chlorination can create DBPs. Chlorate is formed when sodium hypochlorite decays.	Very good	Good. Effective, when also used as an oxidant.	Good. Effective when also used as an oxidant.	N/A	N/A
Gaseous Chlorine	Included	N/A	Poor. Chlorination can create DBPs.	Very good	Good. Effective, when also used as an oxidant.	Good. Effective when also used as an oxidant.	N/A	N/A
Chloramine	Included	N/A	Good. Less chlorinated DBPs, but may form NDMA.	Good. Weaker than chlorine, but provides longer residual.	Fair. Weaker when used as an oxidant.	Fair. Weaker when used as an oxidant.	N/A	N/A

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.41 Disinfection Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Included for SurpriseTree™ Water Evaluation	Implementation-Based Criteria														
		Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Bulk Sodium Hypochlorite	Included	Good. Potential for off gassing.	Fair. Expensive for large facilities.	Very good. Low capital.	Good. Relies on chemical deliveries.	Good. Simple and mature.	Very good. City is familiar with technology.	Very good. Relatively easy to handle, similar to other chemicals.	Very good.	Very good. Simplest system.	Good.	Good. 12.5% sodium hypochlorite is a hazardous material.	Good. 12.5% sodium hypochlorite is a hazardous material.	Good. Potential for chemical decay and off gassing.	Good.	Very good. Easy to expand.
Onsite Generation Sodium Hypochlorite	Included	Good. Potential for chlorine or hydrogen gas leaks.	Good. Less expensive compared to bulk for large facilities.	Fair. High capital.	Good. Relies on salt deliveries and onsite storage capacity.	Good. Relatively mature.	Very good. City is familiar with technology.	Complex system. Requires electrode replacement.	Very good.	Fair. Complex system.	Very good.	Very good. 0.8% sodium hypochlorite is not a hazardous material.	Very good. 0.8% sodium hypochlorite is not a hazardous material. Hydrogen vent is a potential safety concern.	Good. Requires hydrogen gas ventilation.	Good.	Good. Expands with modular generators.
Gaseous Chlorine	Included	Poor. Potential for chlorine gas leak.	Excellent. Least expensive alternative.	Very good. Least expensive alternative.	Good. Relies on chemical deliveries.	Excellent. Long history.	Familiar but the City has concerns about chlorine gas.	Relatively simple but many safety concerns.	Fair.	Good. Simple but requires additional safety equipment.	Good.	Poor due to safety requirements.	Poor. Significant safety concerns.	Good.	Good.	Good.
Chloramine	Included	Poor. Potential for chlorine and ammonia leaks.	Fair. Requires two chemical systems.	Fair. Requires two chemical systems.	Good. Relies on chemical deliveries.	Good. Similar to chlorine.	Poor. The City is not familiar with chloramines.	Good. Requires two chemical systems.	Good.	Good. Two chemicals.	Good. Two chemical systems.	Poor. Two chemicals. Safety concerns with chlorine gas.	Two chemical system. Can be liquid or gaseous.	Good.	Good. Requires two chemical systems.	Good.

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

6.11 Residual Handling Unit Operations

In the previous sections, treatment processes such as direct filtration, low pressure membranes, desalination, adsorption and ion exchange were evaluated as potential treatment alternatives for the City of Surprise groundwater sources. Section 6.11.1 describes typical alternatives utilized for residuals handling. Section 6.11.2 describes the types of residuals associated with various primary liquid treatment processes.

6.11.1 Residuals Treatment Alternatives

The following sections discuss the various unit processes that can be used to handle residuals, including thickening and dewatering for backwash wastes and concentrate management options for desalination technologies and / or ion exchange brine handling.

6.11.1.1 Thickening Processes

Thickening processes reduce the volume of residuals prior to dewatering and final disposal. Residuals are most commonly concentrated using reclamation ponds and conventional gravity thickeners but can also be concentrated in dissolved air flotation (DAF) thickeners, gravity belt thickeners, or thickening centrifuges.

Reclamation Ponds

Reclamation ponds, or lagoons, are one of the oldest processes used to handle water treatment residuals. Ponds can be used for storage, thickening, dewatering, or drying. In some instances, they have also been used for final disposal of residuals. Solids in a reclamation pond settle to the bottom and are retained in the pond. Sedimentation and compression mechanisms used to separate the solids from the liquid. Liquid can be decanted from various points and levels in the pond. The ponds are typically deep, which allows efficient sedimentation and higher detention times (on the basis of unit volume). Evaporation may also be used in the separation process if the residuals are to be retained in the pond for an extended period. Additional dewatering of the solids is achieved through air drying subsequent to decanting.

The traditional pond consists of earthen berms built at the ground surface or a large basin excavated into the ground. The A.A.C12-15-1203 establishes limitations on berm height for structures retaining water. Any structure that exceeds the berm limitations is considered a dam and regulated by the government. Reclamation ponds shall be designed to meet the berm height limitations so they can be exempt from the dam regulations. For the purposes of this report, a reclamation pond is referred to as a lagoon if it is utilized for supplemental drying to achieve 50 percent dewatered solids. Otherwise, it is referred to as a reclamation pond or simply a pond.

To prevent the percolation of liquid into the soil, reclamation ponds are generally lined. Impermeable liners can be constructed of high-density polyethylene (HDPE) or similar material. Leachate collection systems and monitoring wells are becoming common features of reclamation ponds. Pond depths typically vary from 4 to 20 feet and the surface area ranges from 0.5 to 15 acres. Typical hydraulic and solids loading rates for lagoons range from approximately 40-80 gpd/ft^2 to 0.3-1.0 lbs./day/ft^2. Space requirements of a reclamation pond can be reduced by installing floatable inclined plates to enhance settling of solids. Advantages of reclamation ponds include their proven effectiveness over a wide range of hydraulic loading rates and their low capital costs. Disadvantages of reclamation ponds include their large footprint, long processing times, labor intensiveness, potential to attract wild life and potential for odor generation (particularly due to algae die off).

Anticipated Performance at the City of Surprise

A reclamation pond is a potentially feasible residuals management alternative for the City of Surprise. The process has been used successfully at other WTPs in the Valley and can provide thickening and dewatering in the same unit. However, the land requirements associated with reclamation ponds can be much higher than other treatment processes. As developers are typically interested in minimizing the land required for treatment, this technology is **not recommended** for the City's WSF.

Gravity Thickeners

In a gravity thickener, the residuals are conveyed to tanks at a flow rate that allows the residuals sufficient retention time to settle. A compression layer of solids is formed in the bottom (3 to 5 foot) of the tank allowing the solids concentrations to increase.

Gravity thickeners are generally circular and are usually constructed of concrete (depending on flows), although smaller tanks can be constructed from steel. They are typically equipped with a rake mechanism to remove solids. The floors are often conical in shape with a slope of between 10 to 20 percent. This slope enables the rake mechanism to more efficiently move solids to the discharge hopper.

Gravity thickeners can be operated in either batch feed or continuous flow mode. In a continuous feed thickening operation, the solids slurry enters the thickener solids settle to the bottom of the tank. The clarified supernatant flows over discharge weirs located on the periphery of the tank. Batch fill thickening tanks are often equipped with bottom hoppers. Residuals flow into these tanks, usually from the batch removal of solids from the sedimentation basin, until the thickening tank is full. The thickened solids are then pumped out of the bottom hoppers for further treatment or disposal.

Metal hydroxide residuals thicken to approximately 2 to 5 percent solids at loading rates of 4 to 10 lb/day/ft^2. The degree of thickening is generally dependent on the hydroxide - to - total suspended solids (TSS) ratio in the influent solids. Generally, as the ratio increases, thickening efficiency decreases due to more intrinsic water in the hydroxide molecules. Lime softening residuals easily thicken to 20 to 40 percent at similar loading rates.

Advantages of gravity thickeners include simple design and operation, low energy consumption, low maintenance requirements, low capital and O&M costs, and familiarity of the City with the technology. The disadvantages of gravity thickeners include variation in thickened residuals concentrations, the need for residuals equalization prior to thickening (in small WTPs), and thickened residuals pumping requirements. For poor quality residuals, such as membrane filtration residuals with high volume and low solids concentration, gravity thickener may not be an effective option.

Anticipated Performance at the City of Surprise

Gravity thickening is a cost-effective technology for filter backwash residuals. Gravity thickeners are a **recommended** alternative for consideration, depending on the character of the residuals generated by the primary treatment process and other site specific conditions. Refer to Section 6.11.2 for additional information on the applicability of gravity thickening for specific primary treatment alternatives.

Lamella Gravity Settler and Thickener (LGST)

The LGST is a packaged settling unit that consists of inclined plates and a residuals hopper where the settled solids are collected and thickened using a rake system. The residuals stream enters the LGST, flows through the inlet chamber in the center of the unit, and enters the inclined plates through side entry slots. As the liquid flows upward, the solids settle on the inclined, parallel plates and slide into the residuals hopper at the bottom. The clarified liquid leaves the plate assembly through orifices or weirs at the top and is distributed into collection channels leading to an outlet. This creates a pressure drop across the collection channels that ensures uniform flow distribution across the plates in order to utilize the full area for settling.

The primary design criterion for a plate settler is the surface loading rate for each plate. Typical loading rates range from 0.3 to 0.7 gpm/ft^2, depending on the settling characteristics of the solids, water temperature, and desired effluent quality. The LGST process may not be cost effective for a treatment capacity over 3 mgd when compared with other thickening alternatives.

Anticipated Performance at the City of Surprise

LGST is in effect a high rate gravity thickener which requires less footprint than a conventional gravity thickener. It is a viable and **recommended** alternative for the City's WSFs, particularly for applications where land is limited/valuable.

Dissolved Air Flotation Thickening

DAF thickening is a solids handling option for residuals concentrates consisting of low-density particles such as solids generated by removal of organics and/or color from water. One of the primary benefits of DAF is its lower sensitivity to changes in influent feed solids concentration and solids feed rates.

DAF thickening uses air bubbles to absorb to particles through either DAF, dispersed air flotation, or vacuum flotation. Floated solids can be separated from the liquid stream. Several sources indicate that European facilities have had success in concentrating hydroxide residuals to levels between 3 to 4 percent solids. Loading rates for hydroxide residuals vary from 10 lb/ft^2/day to 30 lb/ft^2/day for facilities achieving a 2 to 4 percent float solids concentration. Hydraulic loading of DAF units is reported at less than 2 gpm/ft^2. The lack of historic operating data for this process indicates the need for bench- and pilot-scale testing prior to selection of the process. Advantages of flotation thickening include consistent thickened residuals and smaller footprint. Disadvantages of DAF thickening include high energy consumption, a mechanically intensive process, and relatively unproven technology relative to water treatment residuals.

Anticipated Performance at the City of Surprise

DAF thickening is a viable thickening technology but may not be necessary for the City's groundwater sources, which generally produce much lower volumes of residuals compared to surface water sources. The process is more energy and maintenance intensive than gravity thickener and is therefore **not recommended** for the City's WSFs.

Gravity Belt Thickeners

A gravity belt thickener concentrates solids by utilizing gravity to pull the water through a moving porous belt. Water passing through the belt is called filtrate. A polymer solution is normally injected and mixed into the solids in a chamber that feeds the gravity thickening zone. Fixed or adjustable plows guide the solids as water drains through the moving belt. Thickened solids are then discharged from the end of the thickener as the belt reaches the end rollers.

The actual loading rate for the unit is typically determined by pilot or bench testing. Typical loading rates are approximately 100 gpm per meter of belt width. The process can typically achieve thickened residuals concentrations between 2.5 percent to 4.5 percent solids for metal hydroxide residuals. Provisions must be made to furnish equipment with a wash water supply of approximately 45 to 60 gpm at the pressure specified by the manufacturer and to receive and dispose of the spent wash water. Other design considerations include furnishing of a polymer dosing system, splash control, and providing building humidity and ventilation control. Advantages of gravity belt thickeners include its simple design, low operating costs, limited operator attention, minimal chemical conditioning, and suitability for

rapidly settling residuals. Disadvantages of the process include two waste streams (filtrate and belt wash water), “messy” operation, and chemical conditioning requirements.

Anticipated Performance at the City of Surprise

Gravity belt thickeners are a viable thickening technology, but may not be necessary for the City’s groundwater sources. For facilities where land to accommodate a thickener or Lamella plate enhanced thickener is not available, gravity belt thickening may be an option. However, other mechanical dewatering technologies, such as belt filter presses or centrifuges may be better options for such applications.

DensaDeg™ Thickener

The DensaDeg™ thickener is a high-rate solids contact clarifier-thickener that utilizes optimized flocculation, internal and external solids recirculation, and tube settling in two conjoined vessels to maximize the hydraulic loading and treatment efficiencies. The blend of energy input and high volume of solids recirculation reduces the waste residuals volume and results in rapid settling to optimize unit and operation and treatment results.

Because it both clarifies and thickens, DensaDeg™ is especially effective for plants where waste residuals volumes are a problem or where there are site constraints. Integrated functions within a single unit require approximately 50 percent less space than conventional solids contact clarifiers. Combined internal and external residuals recirculation and high reactor solids concentration reduce start up time, increase treatment rates, and optimize unit operation and overall treatment chemistry. Automatic startup, shutdown, metering, and draw-off control are based on flow rate and turbidity data and require minimal operator attention. Waste residuals are dense (2 to 4 percent solids concentration), which minimizes handling and storage. Hydraulic loading management enables operation over a broad range of flows and raw water characteristics. Typical design hydraulic rates for DensaDeg™ range between 7.7 to 8.2 gpm/ft^2. No abrasive material is added to the system; so there is less wear on pumps, mixers, or scrapers.

Advantages of the DensaDeg™ thickener include a smaller footprint, reduced operator attention, and consistent thickened residuals solids concentrations (2 to 4 percent) from dilute feed residuals. Disadvantages of the process include the fact that it is a relatively new, proprietary technology, it is energy intensive, and it employs extensive mechanical equipment (potentially increasing long-term maintenance costs).

Anticipated Performance at the City of Surprise

DensaDeg™ is a high rate thickening technology which is more maintenance and energy intensive than gravity thickening. While it offers benefits such as higher thickened residuals concentrations and reduced footprint, it is proprietary and mechanically intensive. Consequently, the technology is **not recommended** for use with the City’s groundwater residuals.

Microsand Enhanced Settling Process

In addition to a clarification process, microsand enhanced settling (MES), also referred to as Actiflo®, may also be used for thickening clarified solids. Since the blowdown solids from the MES clarification process have low solids concentration, high volume and slightly different chemistry compared to other clarification processes, MES may not be an effective thickening process. Advantages of the MES process include its smaller footprint and its capability to thicken MES clarified residuals containing microsand. Disadvantages of the process include its lack of performance data (newer proprietary technology), its high chemical requirements, and the potential negative impact of microsand on downstream treatment processes.

Anticipated Performance at the City of Surprise

MES is a viable clarification process. However, MES is more costly and maintenance and energy intensive than gravity thickening. While it can offer benefits such as higher thickened residuals concentration and reduced footprint it **not recommended** for use with the City's groundwater residuals.

Other Thickening Processes

In addition to gravity thickening, various mechanical devices used for dewatering may also be utilized for thickening applications. Examples include the continuous-feed polymer thickener, drum thickener, and centrifuges.

6.11.1.2 Dewatering Processes

After residuals equalization and thickening, the solids are dewatered prior to their disposal to reduce the waste volume. Several mechanical and non-mechanical processes are available to dewater WTP residuals including centrifuges, belt filter presses, plate and frame filter presses, and solar drying beds.

Belt Filter Press

Belt filter press design is based on a very simple concept. Residuals are sandwiched between two porous belts and passed over and under rollers of various diameters. As the roller diameter decreases, pressure is exerted on the residuals, squeezing out water. Although many different belt press designs are used, they all incorporate the same basic features: a polymer conditioning zone, a gravity drainage zone, a low pressure zone, and a high pressure zone. The type and characteristics of the solids to be dewatered are very important in determining the effectiveness of belt press dewatering. Alum residuals are more difficult to dewater because of the gelatinous nature of the solids. The dewatering results are variable depending on the source of the water. The belt press generally provides lower capital and O&M costs compared to other mechanical dewatering processes. Disadvantages of the process include high maintenance requirements and reduced performance with pure chemical residuals (i.e., higher hydroxide to TSS ratios).

Anticipated Performance at the City of Surprise

The belt filter press is an effective dewatering process used commonly in the water treatment industry. It is a **recommended** alternative for the City's consideration at sites where dewatering of residuals are required and land is limited.

Centrifuges

Centrifugal dewatering of solids is a process that uses the force developed by fast rotation of a cylindrical bowl to separate solids from liquids. When a mixture of solids and water enters the centrifuge, it is forced against the bowl's interior walls, forming a pool of liquid that separates into two distinct layers – solid cake and liquid centrate. The solid cake and the liquid centrate are then separately discharged from the unit. Based on the above principle, two types of centrifuges are commercially available - basket and solid bowl. These two methods are differentiated by the method of solids feed, magnitude of applied centrifugal force, cost, and performance. The solid bowl centrifuge is typically used for dewatering WTP residuals. Smaller centrifuge units can process approximately 50 to 75 gpm of thickened residuals and larger units can process between 250 to 300 gpm of thickened residuals while achieving 30 percent solids concentration. Approximately 8 to 10 pounds of polymer is required per dry ton of solids for a centrifuge to operate effectively on surface waters.

Cake solids concentrations vary considerably, depending on the source of the water and the type of primary treatment. High turbidity source waters yield higher cake solid concentrations than low turbidity waters. Advantages of this process include its easy, effective, and reliable operation over a range of influent solids concentrations and ability to produce high cake solids concentrations (30 percent). Disadvantages of this process include higher energy consumption and maintenance requirements.

Anticipated Performance at the City of Surprise

Centrifuges are an effective dewatering process used commonly in the water treatment industry. The technology is a **recommended** alternative for the City's consideration at sites where dewatering of residuals are required and land is limited.

Plate and Frame Filter Press

Although plate filter presses were first developed for industrial applications, there are currently numerous municipal installations used to dewater residuals. The equipment commonly used to dewater WTP residuals is either the fixed-volume recessed plate filter or the diaphragm filter press. A recessed plate filter consists of a series of plates, each with a recessed section that forms the voids into which the solids are pumped for dewatering. Filter media are placed against each wall and retain the solids while allowing passage of the filtrate. A plate and frame press is operated in a batch mode to process solids.

The diaphragm filter press is a machine that combines the high pressure pumping of the recessed plate filter press with the capability of varying the volume of the press chamber. A flexible diaphragm is used to compress the cake held within the chamber. In the two-step dewatering process, the chamber is first filled with the solids and then diaphragm pressure is applied. The diaphragm pressure is applied using either air or water on the reverse side of the diaphragm. Pressures of up to 200 to 250 psi are applied at this stage for dewatering. Lime can be added to alum residuals to achieve 30 to 60 percent cake solids. Advantages of this technology include its proven effectiveness and availability of multiple vendors for competitive bidding. Disadvantages of this process include higher chemical, energy and maintenance requirements, and larger space requirements for large WTPs.

Anticipated Performance at the City of Surprise

The plate and frame filter press is an effective dewatering technology. However, the technology is slightly less cost effective due to its modular nature and the City has little familiarity with the technology. Consequently, it is **not recommended** for implementation at the City of Surprise's water supply facilities.

Reclamation Ponds (Dewatering Lagoons)

As described in Section 6.11.1.1, reclamation ponds, or lagoons, are one of the oldest processes used to handle water treatment residuals. Ponds can be used for storage, thickening, dewatering, or drying. In some instances, they have also been used for final disposal of residuals. Solids in a reclamation pond settle to the bottom and are retained in the pond. Sedimentation and compression mechanisms are used to separate the solids from the liquid. Liquid can be decanted from various points and levels in the pond. The ponds are typically deep, which allows efficient sedimentation and higher detention times (on the basis of unit volume). Evaporation may also be used in the separation process if the residuals are to be retained in the pond for an extended period. Additional dewatering of the solids is achieved through air drying subsequent to decanting. See Section 6.11.1.1 for additional detail, including alternative advantages and disadvantages, associated with Reclamation Ponds for dewatering.

Anticipated Performance at the City of Surprise

A reclamation pond is a potentially feasible residuals management alternative for the City of Surprise. The process has been used successfully at other WTPs in the Valley and can provide thickening and dewatering in the same unit. However, the land requirements associated with reclamation ponds can be much higher than other treatment processes. As developers are typically interested in minimizing the land required for treatment, this technology is **not recommended** for the City's WSFs.

Solar Drying Beds

Residuals on solar drying beds dewater primarily by evaporation. When designing a solar drying bed, the following factors should be considered:

- Required solids concentration of the dewatered residuals.
- Solids concentration of the residuals slurry applied to the bed.
- Type of residuals to be dewatered (lime, ferric or alum).
- Evaporation rates.

Solar drying beds are generally constructed of concrete to prevent any percolation into the ground and to facilitate removal. The required solids concentration depends on the technical or regulatory requirements for final residuals disposal. The rate of evaporation varies with local climatic conditions and the solids surface characteristics. Seasonal evaporation rates can be obtained from local pan values. Thin layers of solids dry faster than thick layers, but the annual solids loading is the sum of the depths of the individual layers applied. Using too thin a layer has several disadvantages, including more frequent operation and maintenance activities.

Dewatering processes using solar drying beds typically involve four steps, 1) solids application; 2) development of a compression zone at the bottom of the bed; 3) solar drying; and 4) removal of the dewatered solids and disposal to a landfill. The depth of solids applied to the solar beds can range from approximately two to six feet, based on the evaporation rate. Design criteria from other solar drying facilities in the Phoenix metropolitan area include multiple loadings, 5 feet maximum solids depth, average solids processing time of 3.3 months (100 days) and a solids loading rate of 300 lbs/ft^2/year. To keep operation and maintenance costs as low as possible, the design goal is to achieve the maximum solids loading with the minimum number of application and removal cycles. These criteria must be optimized based on the land available for drying.

Drying Beds with Underdrain Systems

Use of an underdrain system can enhance the solar drying process. In a sand-based underdrain system, drainage (percolation), decanting, and evaporation are the primary mechanisms of dewatering. Following residuals application to the drying beds, free water is allowed to drain from the residuals into a sand layer where it is transported via an underdrain system consisting of series of lateral collection pipes. This process continues until the sand is clogged with fine particles or until all the free water has been drained - which may take several days. Sand drying beds are typically used where evaporation rates are insufficient for adequate dewatering. Advantages of drying beds equipped with underdrain systems include their effectiveness in variable climates, ease of operation and lower overall costs. Disadvantages of drying beds equipped with underdrain systems include significant land requirements, labor requirements associated with unloading beds, and the potential for odors and mosquitoes.

Wedgewire Beds and Sand Drying Beds

The wedgewire process uses a vacuum-assisted drying system where a vacuum is applied to the underside of rigid, porous media plates on which chemically thickened residuals have been placed. The vacuum draws free water through the plates, retaining residuals solids on top and forming a cake of fairly uniform thickness. The medium (porous plate) consists of a septum with wedge-shaped slots approximately 0.01 inches wide. This septum serves to support the residuals cake and allow drainage through the slots. Through controlled drainage, a small amount of hydrostatic suction is exerted on the bed, thus removing water from the residuals. As in other dewatering processes, the cake solid concentration depends on the type of solids being dewatered and the type and amount of conditioning agents used. Challenges associated with this technology stem from two sources: improper conditioning and cleaning of the screens. Wedgewire drying beds are typically used where evaporation rates are insufficient for adequate dewatering. Advantages of Wedgewire beds include faster dewatering times compared with more conventional drying beds and the ability to produce a uniform thickness solids cake. Disadvantages of Wedgewire beds include higher power consumption, frequent cleaning, or replacement of the porous plates or screens, and high operational sensitivity to polymer dose and polymer mixing.

Anticipated Performance at the City of Surprise

Drying beds are effective residual treatment processes, especially for the Phoenix area where evaporation rates are much higher than other parts of U.S. However, land requirements associated with drying beds, compared to other dewatering processes, may be a major disadvantage. Drying beds are a **recommended** alternative for the City's consideration if land is available and neighborhood/aesthetic issues are not a concern.

6.11.1.3 Final Disposal

The following sections provide a brief description of the available final disposal options and dry solids handling alternatives.

Dewatered Solids Storage, Conveyance, and Transportation

Conveying dewatered solids from a mechanical, or non-mechanical, dewatering technology to a vehicle and subsequently to a landfill is an important consideration in the design of WTP residuals handling facilities. It is more practical and economical to transport dewatered residuals (high solids concentration) in a truck or a similar vehicle as compared to high pressure pumping. However, if the solids concentration is significantly lower, the waste can be pumped via pipelines or hauled using tankers to a nearby liquid or waste processing facility.

There are three methods that can be used to efficiently load residuals to a truck.

- A truck drive-through directly under the dewatering equipment
- A series of conveyors from the dewatering equipment to the truck loading dock

- Use of special cake-handling pumps

Conveyors

Once the solids are dewatered, they will need to be conveyed to storage bins, roll-off bins, or trucks. This can be accomplished using either screw or belt conveyors. In general, the use of conveyors is preferred over pumping due to the maintenance issues and high pressure piping associated with pumping.

Storage Bins

Storing dewatered solids on-site for an extended period is not recommended. Permanent storage bins equipped with conveyors can be installed to store and unload dewatered solids. This approach requires a multi-story structure and an elaborate conveyor system. Storage of dewatered residuals can be avoided by storing residuals in liquid form, prior to dewatering.

Roll-off Bins

Many water treatment facilities transport residuals or solids using roll-off bins and flat bed trucks. A staging area may be required to load solids into the bin from the dewatering equipment. The bins would be offloaded to the staging area using a ramp and a flatbed trailer. The maximum grade that flat bed trucks can climb is between 10 and 15 percent. Alternatively, a conveyor system can be used to load the solids into the bin. Typically, roll-off bins have a maximum capacity of 20 to 30 cubic yards. Some compaction of the solids may occur during transportation. Therefore, the bottom of the bins can be equipped with screens or porous media to facilitate collection of any free water.

Truck Hauling

Trucks are the most common means of transporting solids to a landfill. Typically, one truck has a maximum capacity of 20 to 30 cubic yards of solids, and the frequency of trucking is based on the pounds of solids generated per day. Since, transportation represents a major cost component, the time to load and unload the truck must be optimized to minimize the costs.

Recommended Dried Solids Handling Process

The recommended method for handling dried solids from a mechanical dewatering process includes conveyor belts followed by truck hauling. For non-mechanical dewatering processes, dried solids can be removed from the bottom of the drying bed (or pond) using mechanical scraping equipment (usually a large front-end loader). Solids can then be loaded directly to a truck for offsite disposal.

Final Disposal of City of Surprise Residuals

Dewatered solids can be disposed of in a landfill, land applied for beneficial purposes, or incinerated. The available land for application is very limited in Maricopa County and the limited benefits of traditional water treatment residuals further reduces opportunities. Incineration of residuals is not viable due to associated energy and air pollution issues. Consequently, most utilities ultimately dispose of dewatered residuals via landfill. Based on the current volume of and character of residuals generated by the City of Surprise's facilities, landfill disposal is recommended. This recommendation should be reevaluated on a regular basis to determine if changing conditions warrant a modified approach.

6.11.2 Types of Residuals

Many of the primary treatment processes generate residuals that must be further treated for ultimate disposal. Generally, the residuals handling processes at a groundwater treatment facility consist of spent filter backwash water equalization, thickening and dewatering of the solids (for filtration based processes), regeneration wastes and media disposal (for ion exchange or adsorption based processes), or brine disposal or brine treatment (for desalination processes). This section describes the character of the residuals associated with each the following processes:

- Chemical Pretreatment and Filtration Processes
- Ion Exchange Processes
- Adsorption Processes
- Desalination Processes

6.11.2.1 Residuals Associated with Chemical Pretreatment and Filtration Process

Residuals generated from a coagulation/filtration, softening/filtration, or oxidation/filtration process consist of filter backwash water and thickened sludge (if a clarification step is included).

The residuals produced by backwashing filters are comprised of floc particles carried over from the coagulation and flocculation processes of direct filtration and can contain metal precipitates, and organic particles. Filter backwash is typically 5 to 7 percent of the treated flow and can be high in arsenic levels depending on the application.

The economical option is to equalize the residuals and discharge to sewer, if arsenic levels are not high and sewer discharge permits can be obtained. If sewer discharge is not permitted, on-site backwash treatment can include a backwash equalization basin with or without a clarification process, thickening, and dewatering. Due to the intermittent nature and large volumes associated with granular media filters and low-pressure membrane (MF/UF) backwashing, an equalization basin is usually required to store and equalize the residual stream prior to any further treatment. The decant is recovered and recycled to the

front of the treatment process. This approach can help reduce the total volume of residuals to less than 5 percent of treated flow. Thickening and dewatering processes are available to recover additional process water and further reduce the volume of residuals for treatment.

If the dewatered sludge meets the paint filter tests and the TCLP requirements, it can be disposed of at an off-site non-hazardous waste landfill.

The USEPA promulgated the Filter Backwash Recycling Rule (FBRR) in 2001. This rule requires that conventional and direct filtration plants return recycled water including backwash water to a point in the main treatment process such that all processes of a plant's treatment trains are utilized. Recycled water consists of not only spent backwash water, but also residuals thickener supernatant, and any liquids from the dewatering processes. The rule has several requirements including recording plant recycle flow rates, backwash flow rates and durations, and general operating data, although actual flow rates are not regulated. USEPA has indicated a 10 percent value as guidance for maximum recycle stream return flow rate as a fraction of total water production rates. ADEQ has primacy over collecting FBRR data and identifying "at-risk" systems.

For the coagulation/filtration process, residuals are removed during the filter backwash process and typically contain less than 1.0 percent solids. The volume of backwash residuals (typically 3 to 5 percent of the plant flow) is dependent upon the amount of floc carried over to the filters, the frequency of backwashing, and the length of the backwashing cycle. Since the spent filter backwash water (SFBW) is low in solids concentration, clarification may be required prior to thickening and dewatering of solids. Clarification of SFBW can be achieved by conventional sedimentation, high rate sedimentation (plate tube settlers), etc.

Compared to the residuals generated from the granular media filters, backwash wastes from membrane filtration are thinner in solids content (less than 0.5 percent) and therefore harder to treat. These wastes may require additional or more efficient clarification and thickening processes such as dissolved air floatation (DAF), DensaDeg™, microsand enhanced settling (MES, as referred as Actiflo), or MF/UF membrane residual thickening processes.

The frequency of backwashing cycles for MF/UF systems used in a potable water filtration mode depends on the membrane type, flow pattern in the membrane system, and water quality. In addition, polymers used in the plant used water recovery system and dewatering operations may also significantly increase the required frequency of clean-in place cycles for MF/UF membranes. Membrane manufacturers have developed specific backwashing techniques for their systems including air backwash, pulsing, and water backwash. Although backwash routines are fairly effective for restoring the permeability of the membrane, they do not restore 100 percent of the permeability with each backwash cycle. Over time, the permeability of the membrane after backwashing is compromised by particles and dissolved constituents become embedded into or adsorbed onto the

membrane surface. A chemical cleaning cycle is then needed to dissolve the contaminants and restore the membrane's permeability. The spent chemical solution must then be disposed of - typically via discharge to the sewer after neutralization.

Similarly, thickening of solids can also be achieved using MES, DensaDeg™ and DAF. Solar drying beds or reclamation ponds with longer detention times can also be utilized to clarify, thicken, and dewater the SFBW solids. Mechanical dewatering technologies are recommended if on-site dewatering of solids is required at sites with limited land availability. Widely used mechanical dewatering methods such as filter press dewatering methods are capable of achieving a solids content of 35 to 50 percent and centrifuge dewatering methods are capable of achieving a solids content of 15 to 30 percent for filter backwash residuals.

Residuals treatment for groundwater applications is generally more simple to accomplish and less expensive compared to a surface water treatment facility with the same production capacity. The chemical pretreatment and filtration process produces spent filter backwash water (SFBW). The required residuals treatment processes may consist of an equalization tank (may also act as a clarifier), a gravity thickener, and a centrifuge for dewatering of thickened sludge. For details on residuals treatment process selection, refer to Section 6.11.4.

Further discussion and design considerations associated with the residual handling processes for chemical pretreatment / filtration can be found in Appendix D - Implementation Package for Chemical Pretreatment / Filtration Process.

6.11.2.2 Residuals Associated with Adsorption Process

Residuals generated from a typical adsorption process (AA, IMM, or GIM) consist of backwash and media rinse water (liquid residuals), and spent media (solid residuals). Media rinse is performed after media installation and backwashing the media is performed once every few months. Backwash and rinse water are high in iron and particulate matter. Representing a low volume (2 to 3 percent of treated flow), these wastes are typically sent to an on-site backwash equalization basin and ultimately disposed of via discharge to the sewer (if sewer discharge is permitted).

When sewer discharge is not an option, the backwash wastes must be treated on-site. Unlike surface water, groundwater does not contain high particulate solids. The SFBW from the adsorption process is easy to treat and low in volume and load compared with a surface water treatment facility. The following residual train is recommended for treating the adsorption process residuals: SFBW equalization (may act as clarification) using conventional clarification, thickening of clarified solids using gravity thickening, and centrifuge dewatering followed by final disposal at a landfill.

For arsenic treatment systems for the City's groundwater sources, it is anticipated that replacing the media will be more cost effective than regenerating the media. The spent media from these facilities are typically considered as non-hazardous waste and can pass

TCLP requirements (arsenic level of 5 mg/L). They can be disposed of at a non-hazardous landfill. If the adsorption system is used for fluoride treatment, the spent media is also considered non-hazardous. A spent media staging area or a roll-off bin is required on-site to unload the media prior to landfill disposal.

Further discussion and design considerations for the residual handling processes associated with adsorption can be found in Appendix F - Implementation Package for Adsorption Process.

6.11.2.3 Residuals Associated with Ion Exchange Process

The residuals generated from an IX process consist of backwash, rinse water (slow and fast rinse) and spent regenerate (brine). Backwash and rinse water may represents 1 to 2 percent of the treated flow and could be discharged directly to the sanitary sewer if permitted, or treated with other on-site residual treatment processes if no significant water quality impacts are expected. Disposal of spent regenerate may require special considerations, especially for arsenic ion exchange systems.

A typical ion exchange reaction is reversible, which allows the exhausted adsorbent to return to its original form. This process is called regeneration. The regeneration frequency depends on raw water quality, type of resin, and the treatment goal. For a typical arsenic ion exchange system, approximately 400 to 800 pounds of salt is used per million gallons of water treated. Regeneration of resin would produce approximately 400 gallons spent brine per million gallons of treated water. The regenerate may be reused for up to five regenerations before it becomes a residual.

Once the resin is exhausted, it is regenerated using an excess of salt solution. The spent regenerate brine is a major environmental consideration and poses a significant disposal issue due to TDS levels (> 40,000 mg/L) and the presence of trace metals concentrated during treatment. The brine would require further treatment using various brine volume reduction processes. The brine could be disposed of in lined evaporation ponds or concentrated on-site using brine concentrators or other brine regeneration / disposal technologies - which are generally very expensive. The dewatered solids from the ponds or brine concentrators may exceed the hazardous waste thresholds. The concentrated and solidified brine may be disposed of in lined locations in permitted landfills.

When the ion exchange resin reaches the end of its usable life and cannot be effectively regenerated, the media has to be replaced. If the spent resin contains high concentrations of arsenic, it can only be disposed of in permitted landfills.

Further discussion and design considerations for the residual handling processes associated with ion exchange processes can be found in Appendix G - Implementation Package for Ion Exchange Process.

6.11.2.4 Residuals Associated with Desalination Process

Desalination processes require disposal of the concentrate. This residual is very concentrated with inorganic contaminants. There are two alternatives for desalination concentrate management: Non-Zero Liquid Discharge (Non-ZLD) and Zero Liquid Discharge (ZLD). Non-ZLD alternatives include sewer discharge if permitted (more typical for small system). ZLD alternatives may involve thermal brine concentrators, evaporation ponds, etc. and are typically extremely costly.

Further discussion and design considerations for the residual handling processes associated with desalination can be found in Appendix H - Implementation Package for Desalination Process.

6.11.3 Residuals Handling versus Discharge to Sanitary Sewer

Discharge of residuals to the sanitary sewer may not be acceptable for a variety of reasons. Developers shall consult the City's public works department regarding obtaining a sewer discharge permit prior to planning for this option. The economics and adverse impacts of sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer. New projects should assume direct discharge to the sewer is not permitted, particularly if arsenic is a contaminant of concern, as the concentrations in the waste stream would likely violate the City's local limit criteria. Unless approved by the City, residuals handling must be accomplished on-site through an alternative means.

6.11.4 Summary of Residuals Handling

Table WT.42 summarizes the evaluation results for thickening solids handling technologies using the performance-based criteria. For residuals thickening, reclamation ponds, gravity thickeners, Lamella gravity settlers and thickeners, gravity belt thickeners, DensaDeg™ thickeners, and microsand enhanced settling processes could be considered as potential alternative technologies for the City. Table WT.43 summarizes the evaluation results for dewatering solids handling technologies using the performance based criteria. For residuals dewatering, belt filter presses, centrifuges, reclamation ponds, plate and frame filter presses, and solar drying beds could be considered as potential alternative technologies for the City. The most appropriate residuals handling process should be selected based on the primary liquid stream treatment process and the desired end residual concentration and disposal/beneficial reuse.

Table WT.42 Residuals Handling Thickening Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Implementation-Based Criteria														
	Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Reclamation Ponds	Poor. Potential for odors.	Poor due to maintenance intensity.	Very good. Least expensive option.	Very good. Can achieve thickening/ dewatering at varying loading rates	Very good.	Good.	Fair. Maintenance intensive.	Very good. Must achieve high detention time.	Very good. Very few mechanical components.	Poor. Very large footprint required.	Good. May have odor control issues.	Good.	Very good. Produces thickened or dewatered solids.	Good.	Good.
Gravity Thickeners	Good. Low potential for odors.	Very good. Low energy consumption.	Very good.	Good. Thickened residuals concentration can vary.	Very good.	Good.	Very good. Low maintenance requirements.	Good. Must achieve high detention time.	Very good. Simple design and operation.	Good. Compact footprint. Additional equalization basin may be necessary.	Good.	Good.	Very good. Produce consistent thickening of residuals (2%-5% solids).	Good.	Good.
Lamella Gravity Settler and Thickener	Good. Low potential for odors.	Good.	Good. Lamella settlers help to reduce the size of the clarifier/thickener.	Good. May not perform well for very high solids concentration.	Good.	Good.	Good.	Good.	Very good. Packaged system from manufacturer.	Very good. Compact footprint with high loading rate.	Good.	Good.	Very good.	Good.	Good.
Dissolved Air Flotation Thickening	Good. Low potential for odors.	Poor due to maintenance intensity and high polymer usage.	Good.	Very good. Able to treat low density particles. Less sensitive to changes in influent quality.	Fair. Not much experience in the water treatment industry.	Fair.	Fair. Maintenance intensive.	Good.	Fair. Complex system.	Very good. Compact footprint.	Good.	Good.	Good. Produce thickening of hydroxide residuals (3%-4% solids).	Good.	Good.
Gravity Belt Thickener	Good. Low potential for odors.	Very good. Low operating costs.	Good.	Very good. Better performance and high thickened solids concentration.	Very good.	Good.	Very good. Minimal maintenance issues compared to other mechanical dewatering units.	Good.	Very good. Simple design.	Very good. Mechanical thickening with very compact footprint.	Good.	Good.	Very good. Produce consistent thickened residuals (2.5%-4.5% solids).	Good.	Good.
DensaDeg™ Thickener	Good. Low potential for odors.	More expensive than gravity thickener.	More expensive than gravity thickener.	Very good. Less sensitive to changes in influent quality and flow rates.	Fair. Relatively new technology.	Fair. New to the City.	Fair. Maintenance intensive.	Good.	Poor. Requires extensive mechanical equipment.	Very good. Compact footprint with high loading rate.	Good.	Good.	Very good. Produce consistent thickened residuals (2%-4% solids).	Good.	Good.
Microsand Enhanced Settling Process	Good. Low potential for odors.	More expensive than gravity thickener.	More expensive than gravity thickener.	Very good. Less sensitive to changes in influent quality and flow rates.	Fair. Relatively new technology.	Fair. New to the City.	Fair. Maintenance intensive.	Good.	Good. Requires high chemical additions.	Very good. Compact footprint.	Good.	Good.	Very good. Produce higher concentration thickened residuals.	Good.	Good.

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

Table WT.43 Residuals Handling Dewatering Unit Operations – Implementation-Based Criteria
Water Technology Assessment Report
City of Surprise

Unit Operations	Implementation-Based Criteria														
	Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Belt Filter Press	Good. Higher odor potential compare to centrifuge.	Good. Relatively lower energy consumption compare to centrifuge.	Good. Relatively lower costs compared to centrifuge.	Very good. Good solids concentration (lower than centrifuge). Sensitive to incoming sludge feed characteristics.	Very good.	Very good.	Fair. Less complex and easier to maintain compared to centrifuges. Need operator attention / semi-automatic operation.	Good.	Very good. Relatively Simple operation. Minimal effort required for system shutdown.	Good. Compact footprint.	Good.	Good.	Very good.	Good.	Good.
Centrifuges	Good. Low potential for odors.	Good. Relatively high energy consumption.	Good. Relatively expensive.	Very good. Can produce high solids concentration if feed is relatively stable.	Excellent. The City has lots of experience.	Very good.	Fair. Maintenance intensive.	Good. Fast start-up and shut-down.	Skilled maintenance personnel required.	Very good. Compact footprint.	Good.	Good.	Very good. Able to produce 30% solids concentrations.	Good.	Good.
Plate and Frame Filter Press	Good. Low potential for odors.	Good. High energy consumption.	Good. Expensive.	Very good. Very high solids concentration with low feed solids.	Fair. Relatively new to the City.	Fair.	Fair. Maintenance intensive. Batch operation.	Good.	Fair. Complex system with many mechanical components and high chemical addition.	Poor. Requires a larger footprint than centrifuges and belt press.	Good.	Good.	Very good. Able to produce 30%-60% solids concentrations with lime addition.	Good.	Good.
Reclamation Ponds	Poor. Potential for odors due to high detention time.	Very good. Low cost option.	Very good. Low cost option.	Very good. Can achieve thickening/ dewatering at varying loading rates.	Very good.	Good.	Fair. Maintenance intensive.	Very good.	Very good. Very few mechanical components.	Poor. Very large footprint required.	Good.	Good.	Very good. Produces thickened or dewatered solids.	Good.	Good.
Solar Drying Beds	Poor. Potential for odors due to high detention time.	Very good. Low cost option. Very low energy consumption	Very good. Low option.	Very good. Less sensitive to sludge variability.	Very good.	Good.	Fair. Small amount of operator attention and skill required.	Very good.	Very good. Very few mechanical components.	Poor. Very large footprint required.	Good.	Good.	Very good. Solids concentration depends on evaporation rate and retention time.	Good.	Good.

Note:
(1) Bold and shaded cells highlight dependencies on water quality (competitive ions, pH, etc.) or facility size.

As noted previously, unlike surface water, groundwater does not contain high particulate solids. The spent filter backwash waste treatment for groundwater is less complex and less expensive when compared with a surface water treatment facility with the same production capacity. The following residual train is recommended for the groundwater treatment residuals from chemical precipitation and filtration or adsorption process (when sewer discharge is not an option): equalization tank (may act as clarifier), thickening of clarified solids using gravity thickeners, and centrifuge dewatering followed by final disposal at a landfill.

For adsorption, it is anticipated that replacing and landfilling the spent adsorbent will be more cost effective than regenerating the media. For ion exchange, the management and disposal of the spent regenerate is expensive. For desalination technologies such as NF/RO or EDR, if sewer discharge is not an option, brine management is likely cost prohibitive.

Further discussion on the residuals handling associated with the recommended treatment technologies can be found in the Implementation Packages, presented in Appendices E through H.

7.0 EVALUATIONS OF GROUNDWATER TREATMENT TRAIN ALTERNATIVES USING SURPRISETREE™ WATER

Based on a review of the available data from the City's current wells in SPA 1 and SPA 2, groundwater quality varies significantly. It is anticipated such variations could be even more significant when development in other special planning areas occur in the future. As discussed throughout this document, the optimum groundwater treatment technology for a new well greatly depends on the specific water quality (competitive ions, pH, etc.) or site-specific inputs such as facility size. For example, water quality parameters and site-specific conditions for a future facility cannot be determined at this time but can have a significant impact on the results of the cost-benefit analyses, which contributes to the selection of the treatment process, e.g., adsorption versus chemical pretreatment and filtration versus ion exchange. Levels of the target contaminants and the competitive ions can dramatically change the selection of adsorption media and ion exchange resins, the capacity, the replacement and/or regeneration frequency, and both capital investment (e.g., number of vessels and tanks) and the O&M associated with the primary treatment as well as the residuals handling. A slight change in water quality can result in a misuse of a technology (such as AA) and lead to operation and maintenance challenges. It can quickly shift the economics and could put water quality compliance and public safety at risk.

There is likely no single technology that can fit the exact needs of the all of the City's future WSFs. In order to provide a useful tool for the City in selecting the optimum treatment technology for future WSFs, a more holistic and flexible approach must be provided.

This Water Technology Assessment Report is designed to serve as a water quality and technology master planning document that governs future efforts such as site-specific planning, technology selection/feasibility studies, preliminary design, and detailed design. At this master planning level, the main objectives of the effort were identifying current and future key water quality concerns, establishing water quality treatment standards, identifying multiple technology options that could be used collectively to meet the City's drinking water treatment standards, and providing high-level implementation guidelines on applicable technologies.

In general, this planning document was created to assist in establishing a mechanism and an evaluation methodology for the City to perform site-specific evaluations when actual water quality and other site information is more clearly defined for a given facility. It provides a baseline for technology selection and outlines the general required design criteria and considerations for a specific application in an effort to give the City confidence in their ultimate treatment technology selection. However, it leaves detailed design decisions, facility layouts, and other site-specific decisions to the design engineer to promote more informed and effective decision making.

To provide the City with a useful tool that can assess available treatment alternatives for a given set of water quality inputs and site-specific conditions, Carollo employed an innovative, advanced macro-based excel model named SurpriseTree™ Water. A copy of this model is located on a CD attached to this report.

Using SurpriseTree™ Water, the results of the technology alternative assessment are not limited to a single fixed set of recommendations. Instead, the model provides a dynamic and customized solution, which automatically generates the most technically feasible and cost-effective treatment options in response to the water quality and site-specific condition inputs.

The SurpriseTree™ Water Model computerizes the documentation of the evaluation methodology in a logical way. Criteria established by the City staff and developer representatives (referred to as implementation-based criteria) are utilized in the SurpriseTree™ Water, supplemented by performance-based evaluation and capital, O&M and lifecycle cost analysis developed by engineers. Weighting factors for the implementation-based criteria were developed by averaging the City staff and developer representatives' inputs. All weighting factors, ranking scores, and unit costs are fully adjustable by the City, providing significant flexibility to adjust to changing future conditions. The model employs a user-friendly spreadsheet structure, powered by macro-based selector buttons to make the site-specific analysis prompt and easy.

While the SurpriseTree™ Water Model can provide detailed analyses for a given set of inputs, it is designed to be a master planning level tool. As with any similar application, the model and its outputs are only as accurate as the input information. For example, inputs like capital and O&M cost information must be updated regularly to ensure the recommendations are valid. Ultimately, the model provides a practical tool to document the

City's decisions and incorporate the City's institutional and technical knowledge. Through continuous efforts by the City (assisted by the engineer when necessary), this platform can be "calibrated" and improved to meet the City's needs now and in the future.

7.1 Description of SurpriseTree™ Water

SurpriseTree™ Water is a Microsoft Excel© spreadsheet program that allows a raw groundwater quality to be entered and resulting treatment technologies be ranked based on the treatment capabilities of the water. The SurpriseTree™ Water program was customized for the City of Surprise water treatment evaluation and focuses on groundwater treatment processes for arsenic, nitrate, and fluoride. A brief step-by-step description of the model is included in the following sections. Appendix C provides reports from the SurpriseTree™ Water Model. Appendix I includes a SurpriseTree™ Water Model User's Guide to assist the City with using the model for determining treatment technologies for future water supply facilities.

7.1.1 Introduction, Instruction Sheets and Tool Bars

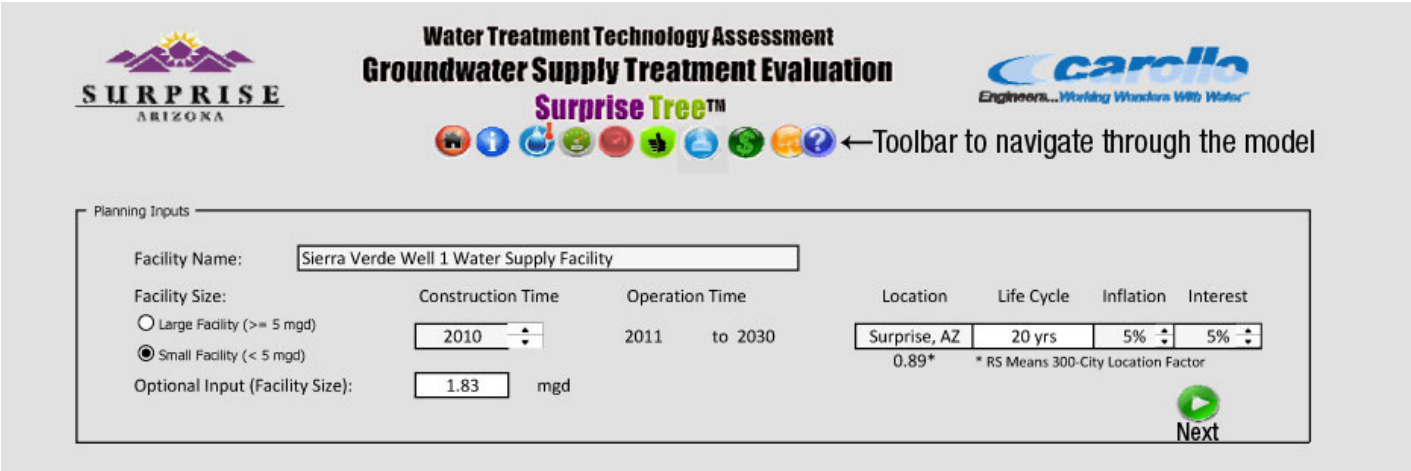
After opening the SurpriseTree™ Water file, the first interface is the introduction sheet. Clicking on the introduction image brings users to the instruction page (Help). The "help" page is designed for first time users.

The tool bars across the top of the screen are accessible throughout the SurpriseTree™ Water Model. Placing the mouse cursor over the icons shows the user the button's function.

When closing out of the SurpriseTree™ Water Model, be sure to go back to the introduction sheet and save the changes. This will allow the next user to begin with the introduction sheet the next time the file is opened.

7.1.2 Input 1 – Information

The information sheet allows the user to input general information about the project including: facility name, facility size, estimated construction and operation time, length of life cycle, and inflation and interest rates. Some information, such as the facility name and project description, is automatically transferred onto other sheets and the final SurpriseTree™ Water report. Other information, such as the facility size and construction time, is used throughout the model in the calculation of costs and various ranking scores. When the location is selected, the cost analysis is automatically adjusted using RS Means 300 City Location Factor. When the life cycle length is selected (20 years or 50 years) and the construction time is chosen, the operation life span will be automatically set to the year after the construction plus the life cycle length. When the inflation rates / interest rates are changed, the life cycle analysis is automatically adjusted. A screen shot of the SurpriseTree™ Water Input 1 – Information sheet is shown in Figure WT.6.



SURPRISE TREE™ INPUT 1 – PROJECT INFORMATION

FIGURE WT.6

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

7.1.3 Input 2 – Water Quality

The groundwater quality data for the specific water supply can be entered into SurpriseTree™ Water to analyze the best treatment alternative for the application. Figure WT.7 shows a screen shot for the SurpriseTree™ Water water quality input sheet, which includes parameters such as treatment flow, arsenic, nitrate, fluoride, chloride, TDS, iron, and manganese concentrations. Warning messages and implementation considerations will be trigged when the change in water quality data exceeds the City's water quality standards, other regulatory standards or technical design thresholds. For example, when the input arsenic value is above 0.008 mg/L, a warning message indicates that the arsenic level is above the MCL and therefore requires arsenic treatment.

This sheet also defines an important parameter labeled Scenario Factor. Seven scenarios are defined in Table WT.44.

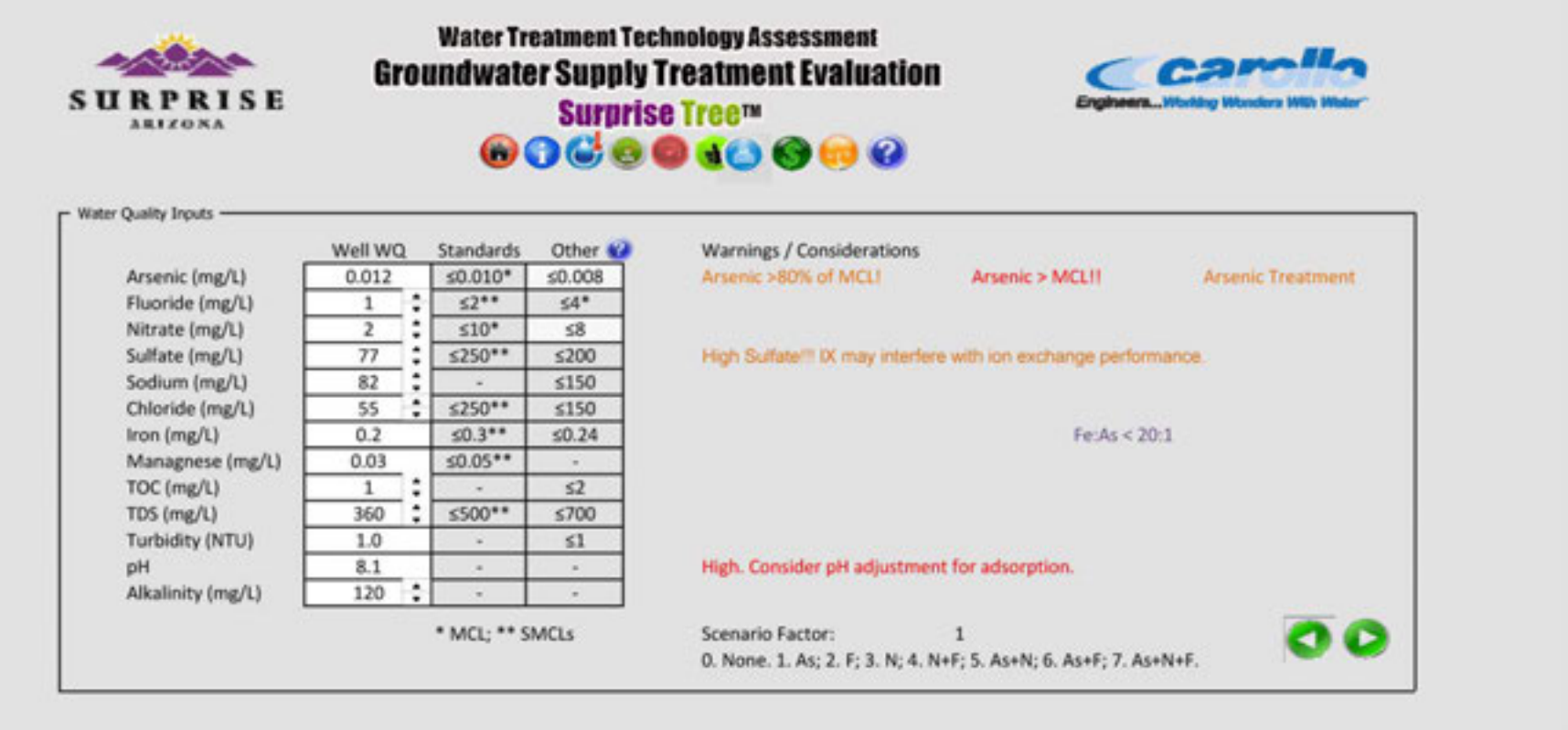
Table WT.44 SurpriseTree™ Water Scenario Factors
Water Technology Assessment
City of Surprise

Scenario Factors	Abbreviation	Treatment Required
0	None	No Treatment Other Than Disinfection and Blending
1	As	Arsenic Treatment
2	N	Nitrate Treatment
3	F	Fluoride Treatment
4	NF	Nitrate and Fluoride Treatment
5	AsN	Arsenic and Nitrate Treatment
6	AsF	Arsenic and Fluoride Treatment
7	AsNF	Arsenic, Nitrate and Fluoride Treatment

7.1.4 Input 3 – Weighting 1 Performance-Based Criteria Evaluation

In general, the two most important factors in the evaluation/selection of a technology are 1) The effectiveness and reliability of the technology alternative in removing the target CoC and 2) The cost effectiveness (capital and O&M) of the alternative in achieving the City's water quality treatment standards. As outlined in Section 6.3, the technology assessment was designed to address a full spectrum of evaluation factors while providing the flexibility to emphasize treatment performance and cost effectiveness, through the use of a three-tire evaluation:

- Implementation based evaluation using a comprehensive set of criteria including capital and O&M costs, technology effectiveness, operability, implementability, and to a lesser extent, the environmental, economical, and social aspects. This set of criteria and weighting factors was developed by the City and the developer representatives.



SURPRISE TREE™ INPUT 2 – WATER QUALITY

FIGURE WT.7

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- Performance based evaluation emphasizing technical feasibility and removal efficiency of target CoC. This evaluation was developed by the engineer and serves as an optional evaluation to supplement the primary implementation based criteria set by the City and the developer representatives.
- Financial analysis using order-of-magnitude level capital, O&M, and life cycle costs. Because the implementation-based evaluation covers qualitative capital and O&M costs, this tier of evaluation can be considered as supplementary information to provide more accurate quantitative costs information.

Inputs for the performance based criteria evaluation are presented in Figure WT.8. The performance-based criteria are designed to provide more specific information on how a technology compares with other alternatives in terms of target CoC removal. The weighting factors were assigned to each performance based criterion on a 0 to 10 scale, with 0 representing the least important / applicable and 10 representing the most important / applicable. The weighting factors were assigned by the engineer and can be adjusted to reflect the relevance of different treatment categories to a specific target CoC. For example, the oxidation treatment category is important for arsenic removal but not for fluoride and nitrate removal. Therefore a weighing factor of 10 is set for arsenic removal and weighting factors of 0 are set for fluoride and nitrate removal. Similarly, the disinfection category would receive a weighting factor of 10 for DBP control and pathogen reduction but 0 for nitrate and fluoride removal. Because it is very likely that the primary disinfectant selected will also be used for pre-oxidation (which enhances arsenic removal), the disinfection category has a weighting factor of 5 for the Arsenic Removal criterion.

In SurpriseTree™ Water Model, the user can place the mouse cursor over each criterion, to display a definition of the associated criterion. As a supplemental evaluation focusing on technology performance, the performance based criteria evaluation is more flexible than the implementation based evaluation. The user is allowed to adjust these weighting factors. However, because developing and updating these factors requires a reasonable technical background and engineering judgment, the default (which can be reset by clicking the reset button) should be used unless the user has a specific knowledge or understanding of the associated treatment technologies.

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Groundwater Supply Treatment Evaluation

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Performance Based Weighting Factors

	Particle Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal
Oxidation	0	5	5	5	10	0	0
Arsenic	3	0	3	5	10	0	0
Fluoride	3	0	3	3	0	0	0
Nitrate	3	0	3	3	0	0	0
Disinfection	0	10	10	5	5	0	0

SURPRISE TREE™
INPUT 3 – WEIGHTING 1

FIGURE WT.8

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7.1.5 Input 4 – Weighting 2 Implementation-Based Criteria Evaluation

The implementation-based criteria, which were developed by the City and the developer representatives, were defined in Table WT.24. Nine individuals (City and developer) participated in assigning weighting factors for these criteria. The averaged weighting factors of the nine were used for the final ranking evaluation as presented in Table WT.45.

Table WT.45 Treatment Process Implementation Based Weighting Criteria as Assigned by City of Surprise and Developer Representatives Water Technology Assessment Report City of Surprise

Water Process Screening Criteria	Average	Standard Deviation
O&M Costs	9.0	1.2
Capital Costs	8.8	1.4
Process Robustness	7.9	0.6
Maturity of Technology	6.9	1.6
City of Surprise Familiarity	4.1	2.5
Maintenance Intensity	6.4	2.0
Operation Flexibility	6.5	1.7
System Complexity	5.0	2.7
Footprint	4.6	2.6
Regulatory	5.9	2.8
Risks and Safety	6.8	1.6
Residuals	6.6	1.8
Versatility	6.5	0.9
Expandability/Ultimate Capacity	6.5	2.1
Air Quality Impacts	6.0	-

A screen shot of the implementation based weighting factors from the SurpriseTree™ Water Model are shown in Figure WT.9. If the user places the mouse cursor over each criterion, the associated criterion definition is displayed. The user is permitted to adjust these weighting factors as appropriate. To reset to the default value (averaged weighting factors established by the City and the developer representative), simply click the reset button.

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Implementation Based Weighting Factors

Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint
6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6

Regulatory	Safety	Residuals	Versatility	Expandability
5.9	6.8	6.6	6.5	6.5

* The default were the average weighting factors assigned by the City Staffs and Developer Representatives.

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INPUT 4 – WEIGHTING 2

FIGURE WT.9

7.1.6 Input 5 – Decision Making

Using the implementation and performance criteria established on previous input sheets, each treatment alternative included for further evaluation in the SurpriseTree™ Water Model was ranked on a 0 to 10 scale, with 0 representing the least favorable / effective and the 10 representing the most favorable / effective. The ranking scores were developed by the engineer based on the qualitative descriptions presented in the two series of tables at the end of each subsection of Section 6.0 (for example, Table WT.32 for Performance Based Evaluation and Table WT.33 for Implementation Evaluation). The City's inputs are incorporated. Users can easily make changes to these scores at any time when running the analysis. The user can also perform sensitivity analysis by changing the water quality inputs and comparing the recommendations. After changing the inputs, simply click the calculate button to update the recommendation and avoid error values on the report.

The ranking scores are presented in Figure WT.10 and displayed on the "All Options" sheet in the model. For example, utilizing the primary disinfectant (e.g., bulk sodium hypochlorite) as a pre-oxidant is very effective and does not introduce significant additional capital and O&M costs. The chlorine (liquid form) alternative under the oxidation category receives scores of 10 under capital costs and O&M costs (under implementation evaluation), respectively and a score of 9 in the arsenic removal category (under performance evaluation).

The SurpriseTree™ Water Model calculates the ranking scores using the following procedures:

- Implementation Scores for Each Technology Alternative (e.g., GFH):
  - Total Implementation Score for a technology alternative (e.g., GFH) is the weighted average (summation of the products) of the score for each alternative (e.g., GFH) for a given criterion (e.g., Footprint or Expandability) and the corresponding Weighting factor for the given criterion (e.g., 4.6 or 6.5).
  - The total implementation score is then normalized to 100 by multiplying by 100 and dividing by the maximum Total Implementation Score for a technology alternative (e.g., GFH) in its category (e.g., adsorption).
  - The higher the score is, the better a technology alternative is based on this comprehensive evaluation.
- Performance Scores for Each Technology Alternative (e.g., GFH):
  - Total Performance Score for a technology alternative (e.g., GFH) is the weighted average (summation of the products) of the score for each alternative (e.g., GFH) for a given criterion (e.g., Arsenic Removal or Fluoride Removal) and the corresponding Weighting factor for the given criterion (e.g., 10 or 0).

Category	Unit Operations	Recom-mendation	Normalized Unit Capital Cost Factor	Normalized Unit O&M Cost Factor	Normalized Life Cycle Cost Factor	Unit Capital Costs ($/gpd)	Relative Unit O&M Costs ($/gal)	Simple Life Cycle ($/gal)	Normalized Performance Total	Performance Total	Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal	Normalized Implementation Total	Implementation Total	Air Quality	O&M Cost	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Preparatory	Safety	Permanent	Incentivity	Extensibility
Oxidation	Criterion Weight (CRW)	100	100	100	100				100	20	0	5	5	5	10	0	0	100	97.5	0	9	0.5	7.9	6.9	4.1	6.4	6.5	5	4.5	5.9	6.6	6.6	6.5	6.5
Oxidation	Chlorine	100	100	46	54	0.015	0.021	0.023	87.8	210	0	4	8	9	9	0	0	100.0	146	4	10	10	8	4	3	8	10	9	8	7	8	8	8	8
Oxidation	Potassium Permanganate	90	40	100	100	0.039	0.010	0.015	83.3	200	0	6	4	7	9	0	0	45.6	178	0	6	6	8	6	4	6	4	9	6	7	6	4	4	9
Oxidation	Chlorine Dioxide	64	13	17	20	0.117	0.058	0.074	100.0	240	0	7	8	9	9	0	0	54.5	212	4	3	3	7	4	2	3	6	4	4	8	8	4	6	4
Oxidation	Ozone	55	7	4	6	0.234	0.234	0.265	100.0	240	0	6	9	9	9	0	0	53.7	243	4	1	1	9	4	2	2	4	3	1	4	3	1	6	4
Arsenic	Criterion Weight (CRW)	100	100	100	100				100	21	5	0	3	5	10	0	0	100	97.5	0	9	0.5	7.9	6.9	4.1	6.4	6.5	5	4.5	5.9	6.6	6.6	6.5	6.5
Arsenic	Granular Ferric Hydroxide or Iron Modified Media	100	92	21	29	0.634	0.791	0.869	92.7	163	6	6	6	6	9	0	0	100.0	666	6	6	6	9	6	6	6	9	9	7	6	6	6	7	6
Arsenic	Coagulation + Granular Media Filtration	96	59	46	50	0.962	0.360	0.494	80.7	169	7	6	6	6	6	0	2	95.7	639	0	7	7	8	6	6	7	7	7	4	6	6	7	7	7
Arsenic	Ion Exchange Arsenic	93	50	9	13	1.163	1.773	1.932	71.1	149	6	6	6	4	9	9	7	92.4	619	2	6	6	9	6	6	6	6	7	7	6	6	6	6	6
Arsenic	Activated Alumina	83	83	33	41	0.701	0.508	0.604	92.7	163	6	6	6	6	9	0	9	93.4	679	9	6	6	8	6	3	6	6	6	7	6	7	6	7	6
Arsenic	NF / RO Sewer	83	27	23	24	2.195	0.725	1.025	100.0	197	10	9	9	9	10	9	9	93.4	667	9	8	8	9	6	4	4	8	6	9	4	7	6	10	9
Arsenic	Greensand	80	73	59	63	0.797	0.280	0.389	61.4	121	7	6	6	9	4	0	0	75.8	541	0	6	6	6	6	6	7	6	6	7	7	6	6	3	6
Arsenic	Coagulation + MFUF	79	39	40	39	1.508	0.418	0.624	92.7	163	9	6	6	7	8	0	2	79.3	[illegible]	6	6	6	6	6	6	6	6	4	6	6	6	4	6	6
Arsenic	Oxidation + Granular Media Filtration	72	0	0	0	0.583	0.165	0.245	34.0	67	4	3	5	8	6	0	0	73.1	657	6	7	7	9	6	6	6	8	6	6	6	6	6	3	6
Arsenic	Softening + MFUF	70	36	33	34	1.606	0.502	0.722	92.7	163	9	6	6	7	6	0	2	79.8	659	6	3	3	8	6	6	4	6	4	6	6	4	4	6	4
Arsenic	Oxidation + MFUF	69	0	0	0	1.239	0.223	0.393	42.1	83	9	6	6	7	6	0	0	49.3	463	6	6	6	6	6	6	6	6	6	7	6	6	4	6	6
Arsenic	ED / EDR Sewer	69	30	21	23	1.976	0.797	1.068	98.8	175	6	6	6	9	10	9	9	[illegible]	461	6	6	6	9	6	2	2	6	3	9	6	6	9	6	6
Arsenic	Softening + Granular Media Filtration	69	50	37	41	1.160	0.445	0.604	90.7	159	7	6	6	6	6	0	6	58.8	[illegible]	6	6	6	8	6	6	6	6	6	6	6	6	6	6	6
Arsenic	NF / RO Zero Liquid Discharge	31	7	6	6	8.781	2.898	4.101	100.0	197	10	9	9	9	10	9	9	[illegible]	394	3	9	9	6	1	2	1	3	1	1	1	2	1	10	2
Arsenic	ED / EDR Zero Liquid Discharge	28	7	5	6	7.903	3.188	4.271	98.8	175	9	6	6	9	10	9	9	38.8	197	3	9	9	6	1	1	1	3	1	1	1	2	1	6	2
Arsenic	OTHER																																	
Fluoride	Criterion Weight (CRW)	100	100	100	100				100	0	0	0	0	0	0	0	0	100	97.5	0	9	0.5	7.9	6.9	4.1	6.4	6.5	5	4.5	5.9	6.6	6.6	6.5	6.5
Fluoride	Activated Alumina	#DIV/0!	92	100	100	0.623	0.592	0.677	#DIV/0!	0	6	6	6	6	6	0	6	100.0	653	6	6	6	9	6	6	6	9	9	7	6	6	6	6	6
Fluoride	Ion Exchange Fluoride	#DIV/0!	100	71	75	0.574	0.829	0.907	#DIV/0!	0	6	6	6	4	6	0	6	97.8	671	6	4	4	9	6	6	4	6	6	7	6	6	6	7	6
Fluoride	NF / RO Sewer	#DIV/0!	26	82	88	2.195	0.725	1.025	#DIV/0!	0	10	9	9	9	10	9	9	93.8	646	6	4	4	9	6	4	4	8	4	9	6	6	6	10	9
Fluoride	ED / EDR Sewer	#DIV/0!	29	74	83	1.976	0.797	1.068	#DIV/0!	0	6	6	6	9	10	9	9	79.2	518	6	6	6	9	6	2	2	6	3	9	6	7	6	6	6
Fluoride	Coagulation + Filtration + Polishing	#DIV/0!	45	76	71	1.269	0.774	0.946	#DIV/0!	0	6	6	6	6	6	0	2	73.7	657	6	6	6	9	6	6	6	6	6	6	6	6	4	6	6
Fluoride	Modified Softening + Filtration + Polishing	#DIV/0!	40	69	64	1.447	0.859	1.057	#DIV/0!	0	6	6	6	6	6	0	2	76.2	668	6	6	6	9	6	6	6	6	6	6	6	6	6	6	6
Fluoride	NF / RO Zero Liquid Discharge	#DIV/0!	7	20	17	8.781	2.898	4.101	#DIV/0!	0	10	9	9	9	10	9	9	31.3	394	3	9	9	6	1	2	1	3	1	1	1	2	1	10	2
Fluoride	ED / EDR Zero Liquid Discharge	#DIV/0!	7	19	16	7.903	3.188	4.271	#DIV/0!	0	6	6	6	9	10	9	9	38.7	197	3	9	9	6	1	1	1	3	1	1	1	2	1	6	2
Nitrate	Criterion Weight (CRW)	100	100	100	100				100	0	0	0	0	0	0	0	0	100	97.5	0	9	0.5	7.9	6.9	4.1	6.4	6.5	5	4.5	5.9	6.6	6.6	6.5	6.5
Nitrate	Biological Filtration	#DIV/0!	72	100	100	0.796	0.300	0.409	#DIV/0!	0	6	9	6	6	6	9	6	106.0	703	12	6	6	8	6	3	6	7	6	6	6	6	6	6	6
Nitrate	Ion Exchange Nitrate	#DIV/0!	100	36	45	0.574	0.829	0.907	#DIV/0!	0	6	6	6	4	9	9	7	96.8	624	6	6	6	9	6	7	6	6	6	7	6	7	6	6	6
Nitrate	NF / RO Sewer	#DIV/0!	26	41	40	2.195	0.725	1.025	#DIV/0!	0	10	10	9	9	10	9	9	93.4	579	6	4	4	9	6	3	4	6	4	9	4	7	4	10	9
Nitrate	ED / EDR Sewer	#DIV/0!	29	38	38	1.976	0.797	1.068	#DIV/0!	0	6	6	6	9	10	9	9	98.8	489	6	4	4	9	6	2	2	6	3	9	4	6	6	6	6
Nitrate	NF / RO Zero Liquid Discharge	#DIV/0!	7	10	10	8.781	2.898	4.101	#DIV/0!	0	10	10	9	9	10	9	9	35.1	394	3	9	9	6	1	2	1	3	1	1	1	2	1	10	2
Nitrate	ED / EDR Zero Liquid Discharge	#DIV/0!	7	9	10	7.903	3.188	4.271	#DIV/0!	0	6	6	6	9	10	9	9	38.8	197	3	9	9	6	1	1	1	3	1	1	1	2	1	6	2
Disinfection	Criterion Weight (CRW)	100	100	100	100				100	30	0	10	10	5	5	0	0	100	97.5	0	9	0.5	7.9	6.9	4.1	6.4	6.5	5	4.5	5.9	6.6	6.6	6.5	6.5
Disinfection	Liquid Chlorine Bulk	100	54	48	50	0.187	0.097	0.123	100.0	130	9	1	8	4	4	8	9	100.0	639	6	4	9	9	6	6	9	9	9	7	6	7	4	6	6
Disinfection	Liquid Chlorine Onsite	81	30	74	55	0.338	0.064	0.110	100.0	130	9	1	8	4	4	8	9	86.5	555	6	5	3	6	6	6	9	8	3	7	6	6	3	6	7
Disinfection	Chloramines	60	45	40	41	0.224	0.117	0.148	92.3	120	9	4	8	3	3	8	9	53.8	373	6	6	4	9	6	3	4	6	6	4	6	6	6	6	6
Disinfection	Gas Chlorine	54	100	100	100	0.120	0.047	0.081	100.0	130	9	1	8	4	4	8	9	71.4	648	6	10	6	9	6	3	6	8	6	6	6	6	6	6	6

EXAMPLE

SURPRISE TREE™ ALL OPTIONS TREATMENT PROCESS RANKING TABLE

FIGURE WT.10

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  - The total performance score is then normalized to 100 by multiplying by 100 and dividing by the maximum Total Implementation Score for a technology alternative (e.g., GFH) in its category (e.g., adsorption).
  - The higher the score is, the better a technology alternative is considering its performance / effectiveness in removing the target CoC for the specific water.
- Financial Scores for Each Technology Alternative (e.g., GFH):
  - Capital Costs ($/gpd), O&M Costs and Life Cycle Costs ($/gal) are calculated for each alternative.
  - The cost score is a normalized score on a 100 scale, with the less expensive alternative being 100.
  - The highest the score is, the less expensive (the more favorable) the alternative is.

As illustrated in Figure WT.11, the decision input sheet provides a quick, visual adjustment of the significances of the decision-making factors using scale bars. As explained previously, the decision making is a three-tier process, including:

- Evaluation using implementation based criteria
- Supplemental evaluation emphasizing performance
- Supplemental evaluation emphasizing costs

As the main evaluation of the three tiers, the implementation-based evaluation can be used as a stand-alone evaluation. This can be achieved by setting the scale bars for performance and capital and O&M and life cycle costs at 0 and the bar for implementation at 100. If the decision maker considers extra weighting for performance or cost effectiveness, adjustment can be made by dragging these bars. Normalized to 100, the final scores are weighted averages (summation of the products) of:

- The normalized implementation score times the implementation scale bar setting
- The normalized performance score times the performance scale bar setting
- The capital, O&M, and life cycle costs times the scale bar settings for each costs

The higher the final score is, the better an alternative is ranked.

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Capital Costs	0%	Performance	0%
O&M Costs	0%	Implemention	100%
Life Cycle Costs	0%		

Calculate

This source requires Arsenic Treatment

			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation	BAT	
1	Oxidation	Chlorine	100	100	43	61	88	100	-	
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90	-	
1	Arsenic	Granular Ferric Hydroxide	100	84	21	27	83	100	No	Click here for package
2	Arsenic	Coagulation + Granular Media Filtration	96	46	46	46	81	96	Yes	Click here for package
3	Arsenic	Ion Exchange Arsenic	93	49	10	13	71	93	Yes	Click here for package
4	Arsenic	Activated Alumina or Iron Modified AA Media	93	70	29	36	83	93	No	Click here for package
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100	-	
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81	-	

SURPRISE TREE™
INPUT 5 – DECISION MAKING

FIGURE WT.11

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The SurpriseTree™ Water Model Technology Assessment Tool provides recommendations on the top treatment options for a given set of inputs (water quality, project information, weighting factors, etc.). The top treatment options are recommended for further consideration. Before implementing an option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.

7.1.7 Input 6 – Costs

Adjusted USEPA Cost Curves (to match recent project cost information) along with cost information from recently completed water treatment projects were used on a relative basis to compare treatment technologies. The costs were adjusted using ENR construction cost index and location factors. An order-of-magnitude capital cost per gallon of water treated along with an O&M cost per 1,000 gallons of water was estimated for each treatment technology. Detailed information associated with these reference costs can be found in Appendix D. The Cost Input sheet from the SurpriseTree™ Water Model is shown in Figure WT.12. Figure WT.12 represents the costs associated with the input information outlined in the Input 1-Project Information and Input 2-Water Quality, as shown in Figures WT.6 and WT.7, respectively. The unit costs will vary based on the project inputs.

7.1.8 Decision Tree

To summarize the recommendations from the SurpriseTree™ Water Model for all seven scenarios (see Section 7.1.3), a decision tree was developed, as illustrated in Figure WT.13. The decision tree contains a series of branches which require a yes or no answer. The resultant answers will create a path to potential treatment options. The decision tree provides a general overview of the available treatment options for removing any combination of arsenic, nitrate, and fluoride. However, the decision tree is intended to be a simplified representation and is not as sophisticated as the model itself.

As illustrated in Figure WT.13, proper source water selection (including proper well development) is the first option in water supply management. Wherever possible, selection of source waters and associated well designs should seek to minimize the need for treatment. The Water Technology Assessment Report focuses on the evaluation of centralized treatment technologies that are applicable for the City's water supply facilities, assuming there is no treatment avoidance alternative available and a treatment facility must be built to provide reliable and safe drinking water for the City. Readers can refer to Appendix A - EPA Arsenic Treatment Technology Evaluation Handbook for Small Systems (July 2003) for the non-treatment alternatives (Decision Tree 1). Although this document was intended to help small drinking water systems (< 1.4 mgd) make treatment decisions to comply with the revised arsenic rule, the procedures considering or excluding the non-treatment alternatives can also apply to the City's water supply facilities.

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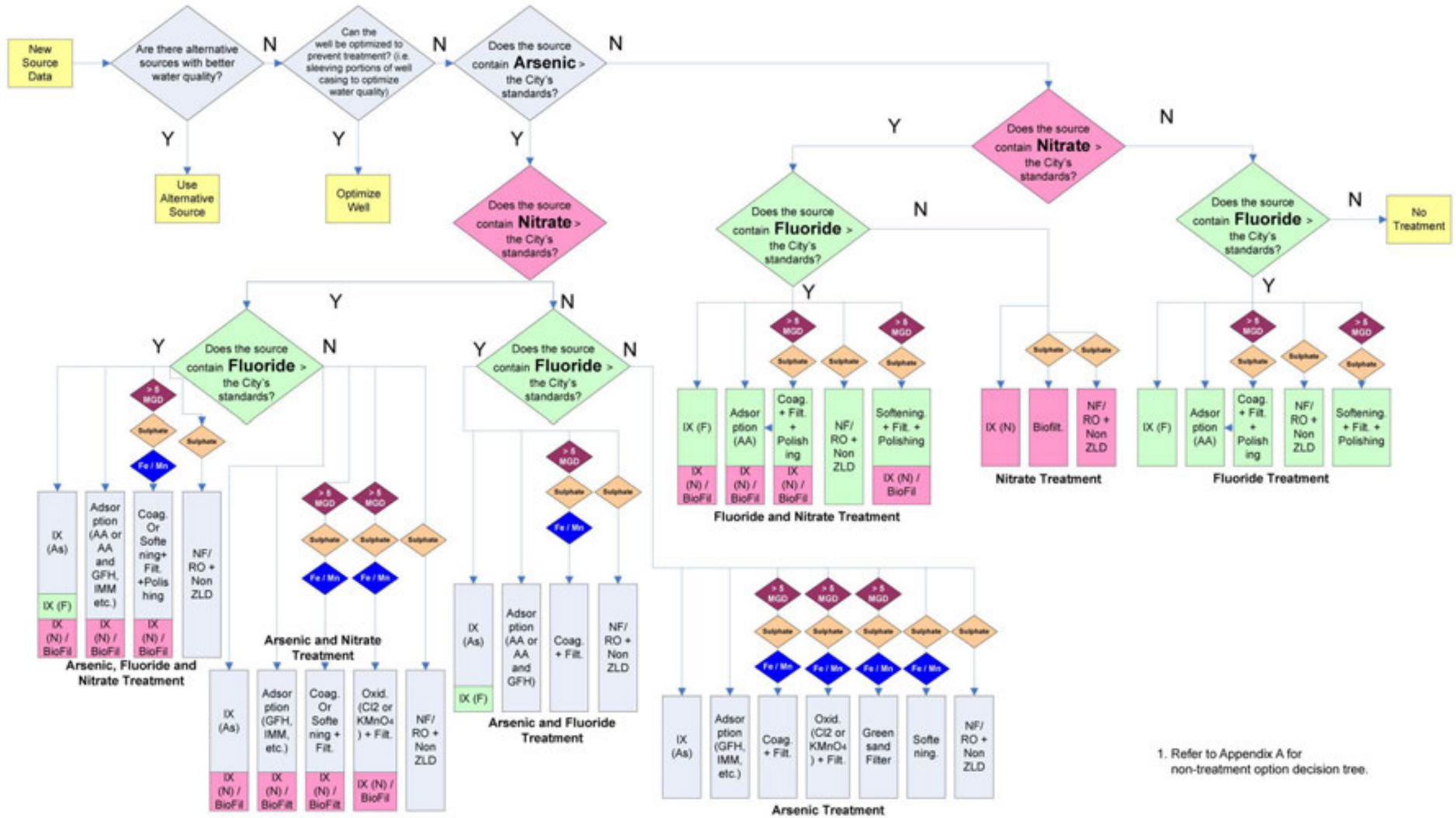
	Facility Size: 1.83 mgd						
	Default		City's Adjustment		LCA Analysis		
	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Life Cycle ($/1000gal)
Oxidation	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Chlorine	$ 0.01	$ 0.02			$0.02	$0.02	$0.02
KMnO4	$ 0.04	$ 0.01			$0.04	$0.01	$0.02
ClO2	$ 0.11	$ 0.06			$0.12	$0.06	$0.07
Ozone	$ 0.22	$ 0.22			$0.23	$0.23	$0.27
Arsenic	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Oxidation + GMF (including Residuals)	$ 0.56	$ 0.16			$0.58	$0.17	$0.25
Activated Alumina (no pH adjustment)	$ 0.59	$ 0.56			$0.62	$0.59	$0.68
Activated Alumina (w/ pH adjustment)	$ 0.67	$ 0.48			$0.70	$0.51	$0.60
GFH	$ 0.60	$ 0.74			$0.63	$0.78	$0.87
IMM	$ 0.60	$ 0.74			$0.63	$0.78	$0.87
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
Greensand	$ 0.76	$ 0.27			$0.80	$0.28	$0.39
Oxidation + MFUF (including Residuals)	$ 1.18	$ 0.21			$1.24	$0.22	$0.39
Coagulation + MFUF (including Residuals)	$ 1.44	$ 0.40			$1.51	$0.42	$0.62
Coagulation + GMF (including Residuals)	$ 0.94	$ 0.34			$0.98	$0.36	$0.49
Softening + MFUF (including Residuals)	$ 1.53	$ 0.48			$1.61	$0.50	$0.72
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
Softening + GMF (including Residuals)	$ 1.10	$ 0.42			$1.16	$0.44	$0.60
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
Anion Exchange (<20 SO4)	$ 0.45	$ 0.56			$0.48	$0.59	$0.66
Anion Exchange (20-50 SO4)	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
Anion Exchange (200 SO4)	$ 1.11	$ 1.69			$1.16	$1.77	$1.93
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Fluoride	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Activated Alumina	$ 0.59	$ 0.56			$0.62	$0.59	$0.68
Ion Exchange Fluoride	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
Coagulation + Filtration + Polishing (including Residuals)	$ 1.21	$ 0.74			$1.27	$0.77	$0.95
Modified Softening + Filtration + Polishing (including Residuals)	$ 1.38	$ 0.82			$1.45	$0.86	$1.06
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Nitrate	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Ion Exchange Nitrate	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
Biological Filtration (including Residuals)	$ 0.76	$ 0.29			$0.80	$0.30	$0.41
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Disinfection	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Gas Chlorine	$ 0.10	$ 0.04			$0.10	$0.05	$0.06
Liquid Chlorine Bulk	$ 0.18	$ 0.09			$0.19	$0.10	$0.12
Liquid Chlorine Onsite	$ 0.32	$ 0.06			$0.34	$0.06	$0.11
Chloramines	$ 0.21	$ 0.11			$0.22	$0.12	$0.15

SAMPLE

SURPRISE TREE™ INPUT 6 - COSTS

FIGURE WT.12

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT



1. Refer to Appendix A for non-treatment option decision tree.

SURPRISE TREE™ DECISION TREE FOR ARSENIC, NITRATE AND FLOURIDE TREATMENT

FIGURE WT.13

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

7.1.9 Additional Considerations

Once input is provided to all six input sheets, the SurpriseTree™ Water Model can produce a report containing all input information along with the model results. The report is a simple and convenient way to summarize and interpret the model output. An example SurpriseTree™ Water report is included in Appendix C.

Note: The SurpriseTree™ Water Model is a subjective model, created by Carollo Engineers. The model uses sound engineering judgment and City/developer representative input to characterize the relative treatment capabilities of various groundwater treatment technologies for the City of Surprise. This tool is intended to be used to rank treatment technologies against each other based on required treatment. The model is intended for internal use within the City of Surprise only.

Refer to Appendix I, SurpriseTree™ Water Model User's Guide, for a step-by-step description of how to use the model.

7.2 The Most Favorable Groundwater Treatment Technologies

The Water Technology Assessment Report is designed to provide the City and the developer with useful planning level design information for the most likely treatment alternatives to be implemented at the City's future WSFs. These treatment alternatives are viable options for the City's facilities, considering their technical feasibility and cost effectiveness. Process flow diagram, basis of design, and design considerations were developed for each of these selected treatment alternatives, including:

- Coagulation, flocculation, and granular media filtration for arsenic and/or fluoride (high concentration) removal.
- Adsorption process using GIM, AA, or IMM for arsenic and/or fluoride removal.
- Ion exchange process for arsenic, fluoride, and/or nitrate removal.
- NF/RO for arsenic, fluoride, and/or nitrate removal.

The four most favorable treatment technologies were reviewed with City personnel. These treatment technologies represent the best unit process components for removing any combination of the City's established CoC. While all four technologies may not remove each of the CoC individually, various combinations of the technologies can be used to remove all three constituents, depending on water quality.

7.2.1 Adsorption Treatment Technology

An adsorption treatment facility generally consists of prefilters, optional pH adjustment chemicals, adsorption contactors, disinfection chemicals, finished water storage, and finished water pumping. The adsorption treatment technology basis of design is included in Table WT.46. The adsorption process flow diagram is included in Figure WT.14. An implementation package for adsorption technology is also included in Appendix F.

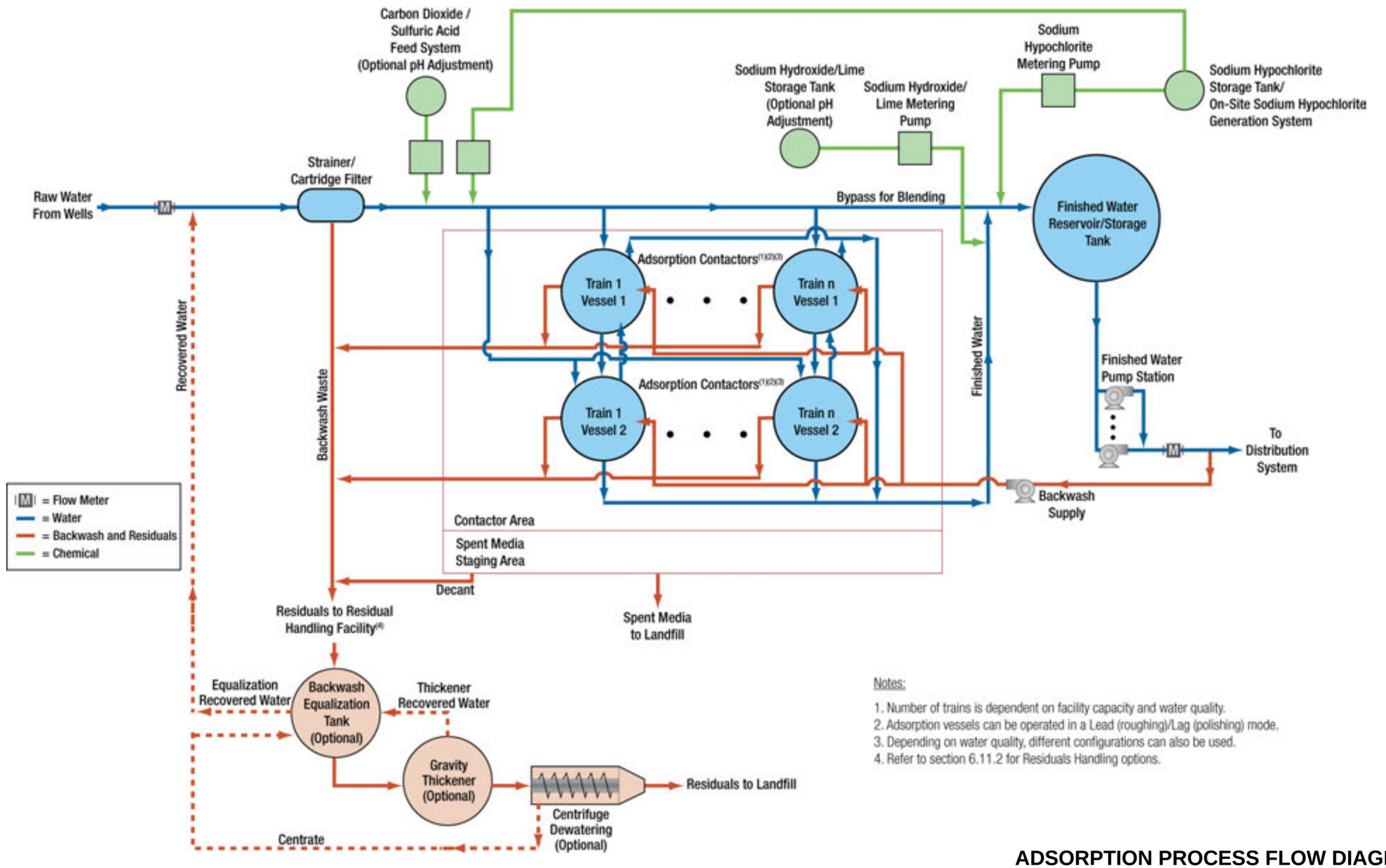
Table WT.46 Adsorption Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	95	Verify with media supplier based on specific water quality
Treatment Water Loss(3)	%	2	1 ~ 2
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	536	Example
Flow Bypassed Treatment(4)	gpm	148	Example
Flow Rate to the Final Blended Stream(3)	gpm	683	Example
Treated Flow Percentage(4)	%	78	Example
Prefiltration			
Type of Filters	-	Bag Filters / Cartridge Filters 20 micrometers nominal pore size	
Number of Filters	-	1 per train	
Size of Filters	gpm	694	
Adsorption Vessels			
Recommended Media	-	Activated alumina (Arsenic and Fluoride); Iron Based Oxide / Hydroxide (Arsenic only)	
Surface Loading Rate	gpm/sf	7	6 ~ 8
Required Surface Area	sf	77	
Vessel Diameter	feet	10	4 ~ 12
Surface Area of each Vessel	sf	79	
Vessel Train Configuration	-	Single or Lead - Lag	
Number of Vessels per Train	-	2	1 for single, 2 for Lead / Lag
Number of Duty Trains	-	1	
Total Surface Area in Operation (Single or lead vessel)	sf	79	Change vessel size to optimize the total
Number of Standby Train(s)	-	1	1 minimum
Total Number of Trains	-	2	
Media Bed Depth(5)	feet	3	2 ~ 4
Total Media Volume (single or lead vessel)	cf	236	

Table WT.46 Adsorption Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Required Empty Bed Contact Time	minutes	3	2.5 ~ 5
Actual Empty Bed Contact Time (Single or lead vessel)	minutes	3.3	
Typical Media Regeneration / Disposal Cycle(4)	-	50,000 bed volumes at pH 7; 20,000 bed volumes without pH adjustment	Check with Media Supplier
Backwash			
Backwash Frequency	-	once every 1 to 3 weeks	
Backwash Rate	gpm/sf	12	10 ~ 12
Backwash Flow Rate	gpm	950	Backwash 1 vessel at a time
Backwash Duration	minutes	15	10 ~ 20
Backwash Volume	gallons	15,000	
Optional Backwash Equalization Tank			
Equalization Tank Volume	gallons	30,000	Sized for two backwashes
Backwash Tank Diameter	feet	20	
Backwash Tank Height	feet	15	Include 2 feet of freeboard
Number of Backwash EQ	ea	1	
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / On-site Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Backwash Wastes	-	Sewer Discharge with Equalization, if permitted See Note (6) if sewer discharge not permitted.	
Exhausted Adsorption Media	-	Disposal at Landfill	

Table WT.46 Adsorption Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Optional Thickener			
Type of Thickener		Gravity thickener with or without plate / tube settler	
Design Surface Loading Rate	gpm/sf	0.4	
Design Solids Loading Rate	lb/day/sf	10	
Estimated Sizes	sf	40	
Estimated Diameter	feet	10	
Side Water Depth	feet	12	
Number of Thickeners	ea	1	
Thickened Sludge Concentration	%	5	3 - 5%
Optional Mechanical Dewatering			
Type of Dewatering		Centrifuge Dewatering	
Number of Centrifuges	ea	1 duty plus 1 standby	Or use sewer discharge as backup
Centrifuge Capacity	gpm	100	Run time < 8 hrs a day

Notes:
(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.
(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection and site-specific considerations.
(3) Flow rates assume backwash water is not recycled.
(4) The media disposal frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.
(5) Media depth will depend on the media specific contact time.
(6) If sewer discharge is not permitted, the following residuals handling alternatives are recommended for the backwash wastes. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. Number of trains is dependent on facility capacity and water quality.
2. Adsorption vessels can be operated in a Lead (roughing)/Lag (polishing) mode.
3. Depending on water quality, different configurations can also be used.
4. Refer to section 6.11.2 for Residuals Handling options.

ADSORPTION PROCESS FLOW DIAGRAM

FIGURE WT.14

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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7.2.1.1 Design Considerations for Adsorption

The following list includes design considerations associated with adsorption technology. This list should be reviewed when initially considering adsorption technologies as well as during the preliminary and final design of any adsorption treatment facilities.

- Parameters that can impact the adsorption process may include, but are not limited to pH, alkalinity, arsenic, phosphorous, silica, nitrate, calcium, magnesium, vanadium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and current market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- When specific water quality data is available, the design engineer should consult the adsorption media supplier to select the optimal adsorption media. Bench and pilot testing may be required to obtain media performance guarantees.
- Investigate the impact of feed water pH on media life and the cost: benefit ratio of pH adjustment.
- Consider the feasibility and economics of different vessel design configurations (e.g., single vessels versus lead-lag versus parallel).
- Compare the economics of disposal versus regeneration based on water quality. For example, when the source contains both arsenic and fluoride, depending on the concentration of each contaminant, disposal mode may be more economical for arsenic removal, but regeneration may be more appropriate for fluoride removal.
- Adsorption using activated alumina is a best available technology (BAT) for arsenic and fluoride treatment as identified in the Safe Drinking Water Act.
- Consider oxidation. Virtually all adsorption medias remove Arsenic (V) more efficiently than Arsenic (III). Although most groundwater sources in the Surprise area contain Arsenic (V), providing the flexibility to feed the primary disinfectant chemical (e.g., sodium hypochlorite) for pre-oxidation is recommended. This improves the system reliability and product water quality at minimal additional cost.
- If the groundwater contains only arsenic (no fluoride), granular ferric hydroxide (GFH) or iron-modified media is more economical compared to Activated Alumina (AA) media. AA is effective but more pH sensitive than GFH. Although AA is highly efficient at removing arsenic over a broad range of pH, high pH shortens the run length.
- If the groundwater contains both arsenic and fluoride, an adsorption system using AA is simpler and potentially more economical because AA removes both fluoride and arsenic. However, depending on the actual concentrations of arsenic and fluoride, a system with an AA lead vessel and a GFH lag vessel may be more economical. The

design engineer should consult the media suppliers when actual water data are available.

- AA media can be regenerated with strong bases and acid. Regeneration recovers 50 to 70 percent capacity. Because the disposal of the regeneration waste is difficult, disposal option (land filling the exhausted adsorption media) is generally less costly than regeneration. Typically, spent media can be disposed of in a non-hazardous landfill.
- In general, the backwash waste from the adsorption process represents 0.5 to 2 percent of the treated flow volume. It is economical to discharge the waste to sewer, if sewer discharge is an option at the proposed site. To avoid overloading the sewer system during discharge, the backwash waste can be stored and equalized in a backwash waste equalization tank.
- Discharge of residuals to the sanitary sewer is not acceptable unless specifically approved by the City. Developers should consult the City's public works department regarding obtaining a sewer discharge permit prior to planning for this option. The economics and adverse impacts of sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.
- When discharging un-thickened residuals is not an option, backwash residuals from the equalization tank can be thickened in gravity thickeners with or without lamella plate / tube settlers. Water recovered from the thickeners can be returned to the process. The thickened sludge can be discharged to the sewer or further treated using drying beds or mechanical dewatering equipment such as centrifuges or belt presses. The dewatered solids can be disposed of at a landfill.

7.2.2 Coagulation/Filtration Treatment Technology

A coagulation/filtration treatment facility generally consists of coagulant addition, optional pH adjustment chemicals, mixing through an inline static mixer or rapid mix/flocculation process, granular media filters, disinfection chemicals, finished water storage, finished water pumping, and optional residual handling facility. The coagulation/filtration treatment technology basis of design is included in Table WT.47. The coagulation/filtration process flow diagram is included in Figure WT.15. An implementation package for coagulation-filtration technology is also included in Appendix E.

Table WT.47 Coagulation Filtration Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	80	When iron:arsenic>20:1, verify with media supplier with specific water quality
Treatment Water Loss(3)	%	5	3 ~ 7
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	636	Example
Flow Bypassed for Blending (4)	gpm	26	Example
Flow Rate to the Final Blended Stream(3)	gpm	662	Example
Treated Flow Percentage (4)	%	96	Example
Coagulation			
Chemical for Coagulation		Ferric Chloride	
Coagulant Dose	mg/L	10	5 - 15 ppm
Rapid Mixing Velocity Gradient	1/s	500	500-1,000
Flocculation			
Type of Flocculator		Three Stage	Two or three stage
Retention Time	min	20	0 – 30
1st Stage Velocity Gradient	1/s	90 - 30	
2nd Stage Velocity Gradient	1/s	60 - 20	
3rd Stage Velocity Gradient	1/s	30 - 10	
Granular Media Filters			
Filter Media	-	Dual Media (anthracite and sand)	Mono or dual media
Surface Loading Rate	gpm/sf	6	5 ~ 8
Required Surface Area	sf	106	
Filter Diameter	feet	8	4 ~ 12
Surface Area of each Filter	sf	50	
Number of Duty Filters	-	3	
Total Surface Area in Operation	sf	151	Change filter size to optimize the total
Number of Standby Filters	-	1	1 minimum
Total Number of Filters	-	4	

Table WT.47 Coagulation Filtration Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Media Bed Depth	feet	3	2 ~ 4 feet, 18-24 inches of anthracite and 6-12 inches of sand, proprietary medias are also available
Total Media Volume	cf	452	
Anthracite Effective Size	mm	1	
Sand Effective Size	mm	0.5	
Uniform Coefficient		1.4 or less	
Depth of Bed to Effective Size of Media Ratio L/D		> 1,000	
Filter Backwash			
Backwash Frequency	-	Once every 24 hours	Once every 24 to 48 hours
Type of Backwash		Water and Air Scouring	
Backwash Rate	gpm/sf	18	10 ~ 30(5)
Backwash Flow Rate	gpm	900	Backwash 1 filter at a time
Backwash Duration	minutes	15	10 ~ 20
Backwash Waste Volume	gallons	15,000	
Recommended Residuals Handling		Sewer Discharge, if permitted. See Note (6) if sewer discharge is not permitted.	
Optional Backwash Equalization Tank			
Backwash EQ Tank Volume	gallons	40.500	Sized for three backwashes
Backwash EQ Tank Diameter	feet	20	
Backwash EQ Tank Height	feet	22	Include 2 feet freeboard
Number of Backwash EQ	ea	1	
Optional Thickener			
Type of Thickener		Gravity thickener with or without plate / tube settler	
Design Surface Loading Rate	gpm/sf	0.4	
Design Solids Loading Rate	lb/day/sf	10	
Estimated Sizes	sf	40	
Estimated Diameter	feet	10	
Side Water Depth	feet	12	
Number of Thickener	ea	1	

Table WT.47 Coagulation Filtration Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Thickened Sludge Concentration	%	5	3 - 5%
Optional Mechanical Dewatering			
Type of Dewatering		Centrifuge Dewatering	
Number of Centrifuges	ea	1 duty plus 1 standby	Or use sewer discharge as backup
Centrifuge Capacity	gpm	100	Run time < 8 hrs a day
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Type of System	-	Sewer Discharge, if permitted. See Note (6) if sewer discharge is not permitted.	

Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

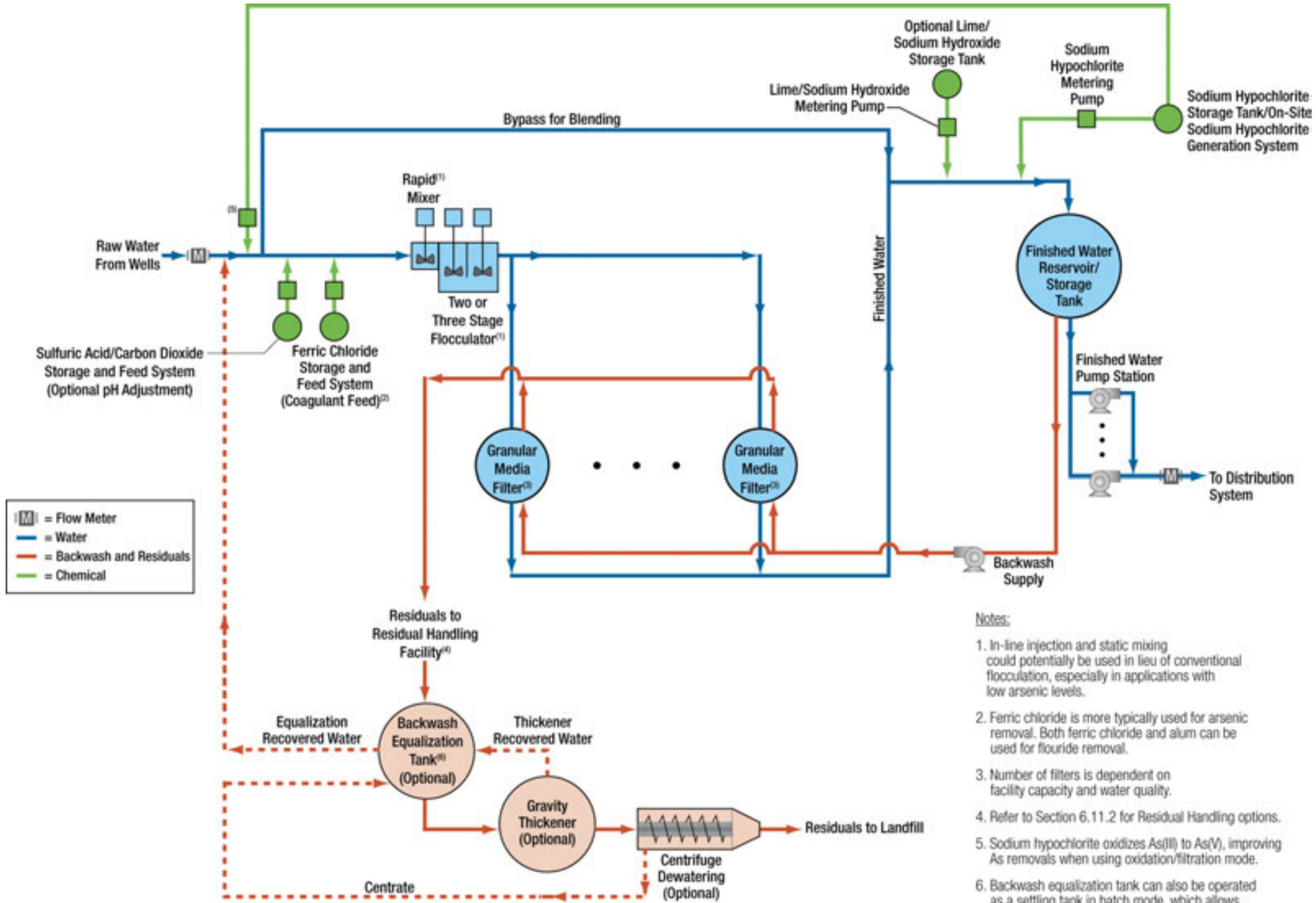
(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality and site-specific considerations.

(3) Flow rates assume backwash water is not recycled.

(4) The allowable blending ratio depends on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(5) Backwash flow rate depends on media type.

(6) If sewer discharge is not permitted, the following residuals handling alternatives are recommended. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. In-line injection and static mixing could potentially be used in lieu of conventional flocculation, especially in applications with low arsenic levels.
2. Ferric chloride is more typically used for arsenic removal. Both ferric chloride and alum can be used for flouride removal.
3. Number of filters is dependent on facility capacity and water quality.
4. Refer to Section 6.11.2 for Residual Handling options.
5. Sodium hypochlorite oxidizes As(III) to As(V), improving As removals when using oxidation/filtration mode.
6. Backwash equalization tank can also be operated as a settling tank in batch mode, which allows deletion of the gravity thickener.

COAGULATION FILTRATION PROCESS FLOW DIAGRAM

FIGURE WT.15

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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7.2.2.1 Coagulation-/Filtration Design Considerations

The following list includes design considerations associated with coagulation/filtration technology. This list should be reviewed when initially considering coagulation/filtration technologies as well as during the preliminary and final design of any coagulation/filtration treatment facilities.

- Parameters that can impact the coagulation/filtration process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, fluoride, sulfate, iron, manganese, TOC, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- The coagulation/flocculation process involves the addition of large volumes of chemicals (aluminum salts, iron salts, polymer, PACL, etc.) and produces a large volume of residuals (5 percent of the treated flow).
- Typically, the coagulation/flocculation process utilizes rapid and gentle mixing to initiate the formation of floc.
- The coagulation/flocculation process should be designed to provide proper mixing energies. The mixers should be variable speed type to allow process optimization. Insufficient mixing may not produce flocs large enough to be captured by the downstream filtration process. Excessive mixing may break the flocs and impact the removal efficiency.
- Static in-line mixing may be used in lieu of rapid mix and flocculation processes when sufficient mixing can be achieved. Static mixing must be properly designed and proven to be effective for the application to be considered an acceptable alternative. An in-line static mixer requires less maintenance than mechanical mixing, but will have limited turn-down.
- Particles are removed through either direct filtration or sedimentation and filtration (granular media or membrane filtration). For groundwater applications (low turbidity and low TOC water), coagulation / flocculation followed by granular media filtration provides sufficient and reliable treatment economically.
- Both ferric and alum are effective coagulants for arsenic removal. Below a pH of approximately 7, arsenic removal with alum or ferric sulfate/chloride is similar. Above a pH of 7, removals with alum decrease dramatically (at a pH of 7.8, alum removal efficiency is about 40 percent).
- Additional process optimization can be achieved, if necessary, through enhanced coagulation by means of increasing coagulant doses, adjusting the pH, and optimization of coagulant type. For example, systems may need to lower pH or add more coagulant to achieve higher removals.

- Coagulation can be used to remove multiple contaminants, including iron, manganese, arsenic, and fluoride. Coagulation can reduce fluoride at high concentrations (from 15 ppm down to 5 ppm). However, it may not reduce fluoride to levels less than 2 ppm. It can be used as an economic pretreatment to reduce adsorption, ion exchange, and RO costs.
- Coagulation/filtration and oxidation/filtration are best available technologies (BAT) for arsenic treatment as identified in the Safe Drinking Water Act. To obtain high arsenic removals, the iron to arsenic ratio must be at least 20:1.
- Coagulation/filtration using alum as a coagulant is a best available technology (BAT) for fluoride treatment as identified in the Safe Drinking Water Act.
- Coagulation is a cost-effective way to reduce high concentrations of arsenic and fluoride. However, the product arsenic and fluoride may not be as low as IX and AA product water. For such applications, consider using coagulation as a pretreatment followed by a polishing (smaller) adsorption or IX.
- Compared to adsorption and ion exchange, coagulation and granular media filtration is typically more economical, especially for large facilities.
- Coagulation and filtration facilities can utilize concrete tanks or metal pressure vessels. Utilizing pressure vessels may promote more efficient hydraulics and help to reduce energy consumption.
- Coagulant type and dosage can be easily determined and optimized using jar testing equipment. Consider performing such routine testing during preliminary design and throughout the operational phase.
- The residuals from coagulation / flocculation are relatively easy to treat. For a small facility, it may be more economical to discharge the waste to sewer if sewer discharge is an option at the proposed site. To avoid overloading the sewer system during the discharge, the backwash waste can be stored and equalized in a backwash waste equalization tank.
- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the economics of alternative treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.
- For a large facility, or when discharging un-thickened residuals is not an option, backwash residuals from the equalization tank can be thickened in a backwash settling tank or in gravity thickeners with or without lamella plate / tube settlers (non-mechanical residuals handling). Water recovered from the thickeners can be returned to the process. The thickened sludge can be discharged to the sewer or further treated using drying beds or mechanical dewatering equipment such as centrifuges or plate and frame press. The dewatered solids can be disposed of in a landfill.

- When actual source water quality and site-specific conditions are available, evaluate the feasibility and economics of different residuals treatment (sewer discharge, non-mechanical residuals handling and mechanical residuals handling) and water recovery options.

7.2.3 Ion Exchange Treatment Technology

An ion exchange treatment facility generally consists of prefilters, optional pH adjustment chemicals, ion exchange vessels, disinfection chemicals, finished water storage, finished water pumping, and regeneration system. The ion exchange treatment technology basis of design is included in Table WT.48. The ion exchange process flow diagram is included in Figure WT.16. An implementation package for ion exchange technology is also included in Appendix G.

Table WT.48 Ion Exchange Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	95	When sulfate < 50 mg/L, verify with media supplier based on specific water quality
Treatment Water Loss	%	2	2 - 3
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	535.7	Example
Flow Bypassed Treatment	gpm	147.6	Example
Flow Rate to the Final Blended Stream	gpm	683.3	Example
Treated Flow Percentage	%	78.4	Example
Prefiltration			
Type of Filters	-	Bag Filters / Cartridge Filters 20 micrometers nominal pore size	
Number of Filters	-	1 per train	
Size of Filters	gpm	350	
Ion Exchange Vessels			
Synthetic Resin Type		Strong Base / Weak Base Anion Exchange Resin	Strong base preferred for As treatment

Table WT.48 Ion Exchange Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Recommended Regenerant Solution		Sodium Chloride Solution	OH- or Cl- Solution; other solution may be required depending on resin selection and water quality
Required Empty Bed Contact Time (EBCT)	minutes	5	2 ~ 10; Depend on water quality and resin selection.
Total Media Volume Required	cf	358	
Media Bed Depth	feet	4	3 ~ 6
Required Surface Area	sf	90	
Surface Loading Rate	gpm/sf	6	3 - 10
Number of Duty Trains	ea	2	
Number of Standby Train(s)	ea	1	
Total Number of Trains	ea	3	
Surface Area per train	sf	45	
Vessel Diameter	feet	8	2 ~ 12
Actual Total Surface Area in Service	sf	101	
Actual Total Volume in Service	cf	402	
Regeneration			
Regeneration Frequency	-	300 ~ 60,000 Bed Volume	Check with Media Supplier. Dependent on resin type and water quality
Volume of Regenerant Solution per Regeneration		3	3 ~ 5 Bed Volume
Regeneration Volume	gallons	3,348	
Regeneration Waste Tank Volume	gallons	13,393	Sized for four regenerations; dependent on water quality
Regeneration Waste Tank Diameter	feet	8	
Regeneration Waste Tank Height	feet	36	
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality

Table WT.48 Ion Exchange Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Backwash and Rinse Water	-	Sewer Discharge with Equalization, if permitted. If not, see Note (4)	
Regeneration Wastes	-	May be a hazardous waste. Requires expensive volume reduction and concentration treatment. The concentrated brine may be disposed of only in permitted landfills.	
Replaced Resins	-	May be a hazardous waste and must be disposed of in permitted landfill.	

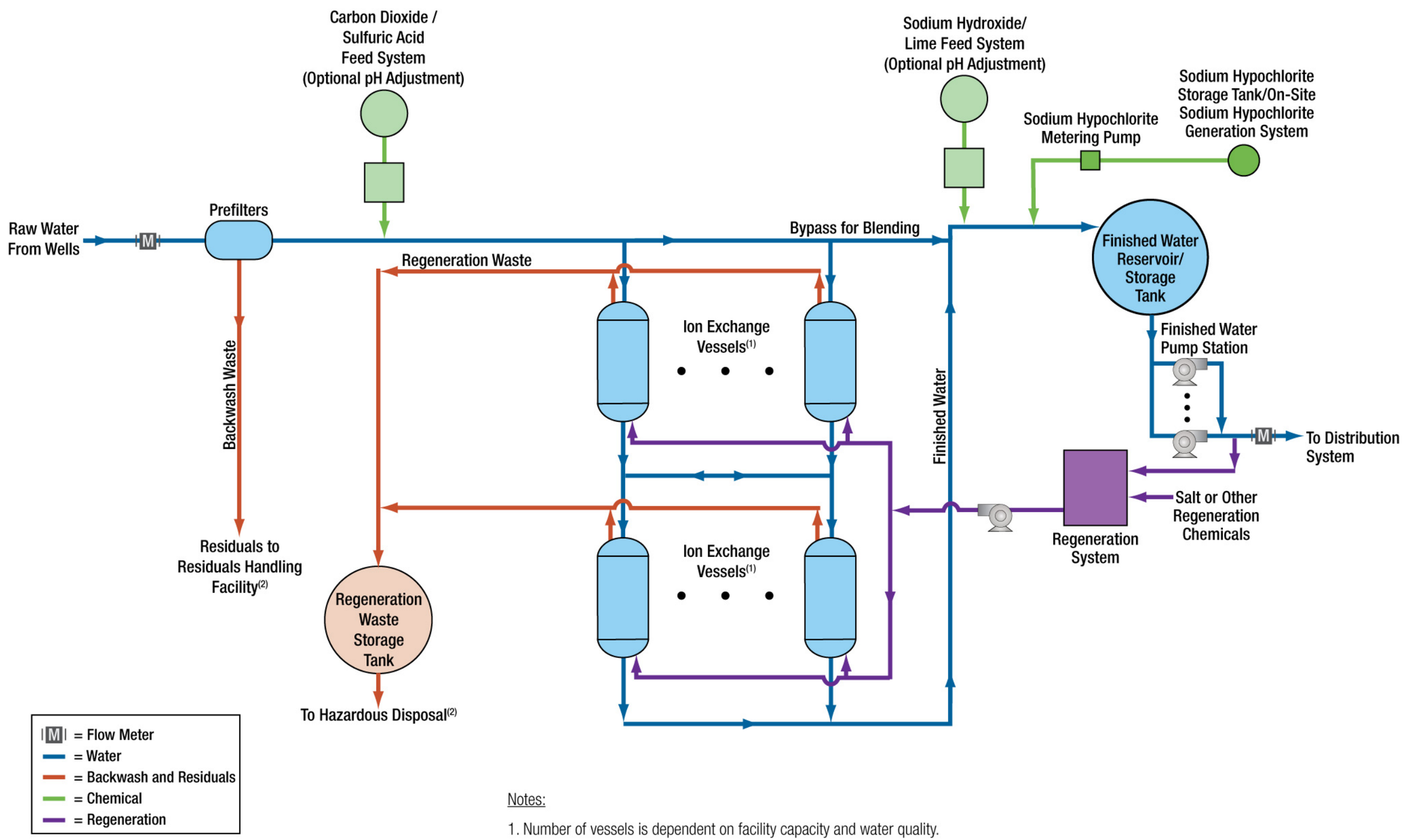
Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection, and site-specific considerations.

(3) The media disposal frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(4) If sewer discharge is not permitted, the following residuals handling alternatives are recommended for the backwash and rinse water. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. Number of vessels is dependent on facility capacity and water quality.
2. Refer to Section 6.11.2 for Residual Handling options.

ION EXCHANGE PROCESS FLOW DIAGRAM

FIGURE WT.16

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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7.2.3.1 Ion Exchange Design Considerations

The following list includes design considerations associated with ion exchange technology. This list should be reviewed when initially considering ion exchange technology as well as during the preliminary and final design of any ion exchange treatment facilities.

- Parameters that can impact the ion exchange process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, silica, nitrate, calcium, magnesium, vandium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities on process optimization and cost reduction.
- When specific water quality data is available, the design engineer should consult with the resin supplier to select the optimal ion exchange resins. Bench and pilot testing may be required for complicated applications.
- Anion exchange resins include two classes: Weak-base anion (WBA) and strong-base anion (SBA). SBA resins are typically used for arsenic removal because they tend to be more effective over a larger pH range than WBA resins.
- Investigate the impact of feed water pH on media life and the cost: benefit ratio of pH adjustment. Most SBA resins do not remove uncharged As (III) when pH is under 9.0.
- SBA anion exchange resins remove contaminants based on their selectivity sequence. The process is very selective and should be closely evaluated based on actual source water quality.
- High sulfate (> 150 mg/L) and TDS levels (> 500 mg/L) can significantly reduce arsenic removal efficiency.
- High Fe (III) in feed water can affect arsenic removal by forming Fe (III)-arsenic complexes, which cannot be removed by IX resins.
- Depending on water quality, removing arsenic, nitrate, or fluoride may require different types of resin.
- Ion exchange is a best available technology (BAT) for arsenic, nitrate, and fluoride treatment as identified in the Safe Drinking Water Act.
- Concentration profiles in an IX column can result in chromatographic peaking, where more competitive ions such as SO_4^{2-} elute adsorbed $HAsO_4^{2-}$ from the resin and result in high effluent arsenic concentrations.
- Consider the feasibilities and economics of different vessel design configurations (e.g., single vessels versus lead-lag).
- Consider oxidation. Most SBA does not remove uncharged As (III) when pH is under 9.0. Although most groundwater sources in the area contain arsenic (V), providing the flexibility to feed the primary disinfectant (e.g., sodium hypochlorite) chemical for pre-oxidation is recommended. This improves the system reliability and product water

quality at minimal additional costs. However, excessive oxidant (> 0.1 mg/L free chlorine) may degrade the resin.

- Ion exchange resins need to be regenerated with a high concentration sodium chloride or other solution. In general, the regeneration waste from the ion exchange process represents 2 to 3 percent of the treated flow volume. Disposal of the regeneration waste is difficult. The regeneration waste contains high TDS and high concentrations of target contaminants. If containing a high level of arsenic, the waste may be considered hazardous. For small facilities, diluting the waste and discharging to the sewer may be an option, but would require permitting coordination.
- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the economics of alternative treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.

7.2.4 NF/RO Treatment Technology

An NF/RO treatment facility generally consists of strainers, prefilters, optional pH adjustment chemicals, scale inhibitor chemicals, NF/RO membrane systems, disinfection chemicals, finished water storage, and finished water pumping. The NF/RO treatment technology basis of design is included in Table WT.49. The NF/RO process flow diagram is included in Figure WT.17. An implementation package for NF/RO technology is also included in Appendix H.

Table WT.49 NF/RO Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	99	When sulfate < 50 mg/L, verify with media supplier based on specific water quality
Recovery Rate	%	85	Assume no concentrate management
Treatment Water Loss	%	15	
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	Gpm	514.1	Example
Flow Bypassed Treatment	Gpm	102.8	Example
Flow Rate to the Final Blended Stream	Gpm	616.9	Example
Treated Flow Percentage	%	83.3	Example

Table WT.49 NF/RO Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Prefiltration			
Type of Prefilters	-	Cartridge Filters - 5 micrometers nominal pore size. Optional Sand Strainer.	
Number of Prefilters	-	1 per train	
Target Feed Water SDI		≤ 3	
Membrane			
Design Flux	gfd	15	Detailed array design pending water quality information
Number of Stages	ea	2	2 or 3
Elements per Vessel	ea	7	7 for two-stage; 6 for three-stage
Array Design		4:2	4:2:1 for three stage
Design Recovery	%	85	80 to 85%
Potential Membrane Elements		Hydranautics ESPA2, Koch TFC-HR, Toray TM-720, Woongjin RE	Dependent on water quality data
Estimated Cleaning Interval		4 to 6 months	
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Fouling Control	-	King Lee Y2K Antiscalant	KingLee Pretreat Plus or Y2K; Avista Vitec 3000 & 4000; Professional Water Technologies Spectra Guard
Chemical Post Treatment			
Type of Treatment		Degasifier Tower	
Loading Rate per Degasifier	gpm/sf	18	15 to 20
Air / Water Loading	scfm/gpm	3	
Air Differential (inlet - outlet)	in water	4	
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm

Table WT.49 NF/RO Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Residuals			
Concentrate Disposal	-	Sewer Discharge, if permitted. If sewer discharge is not permitted, concentrate management and disposal options can be cost prohibitive.	

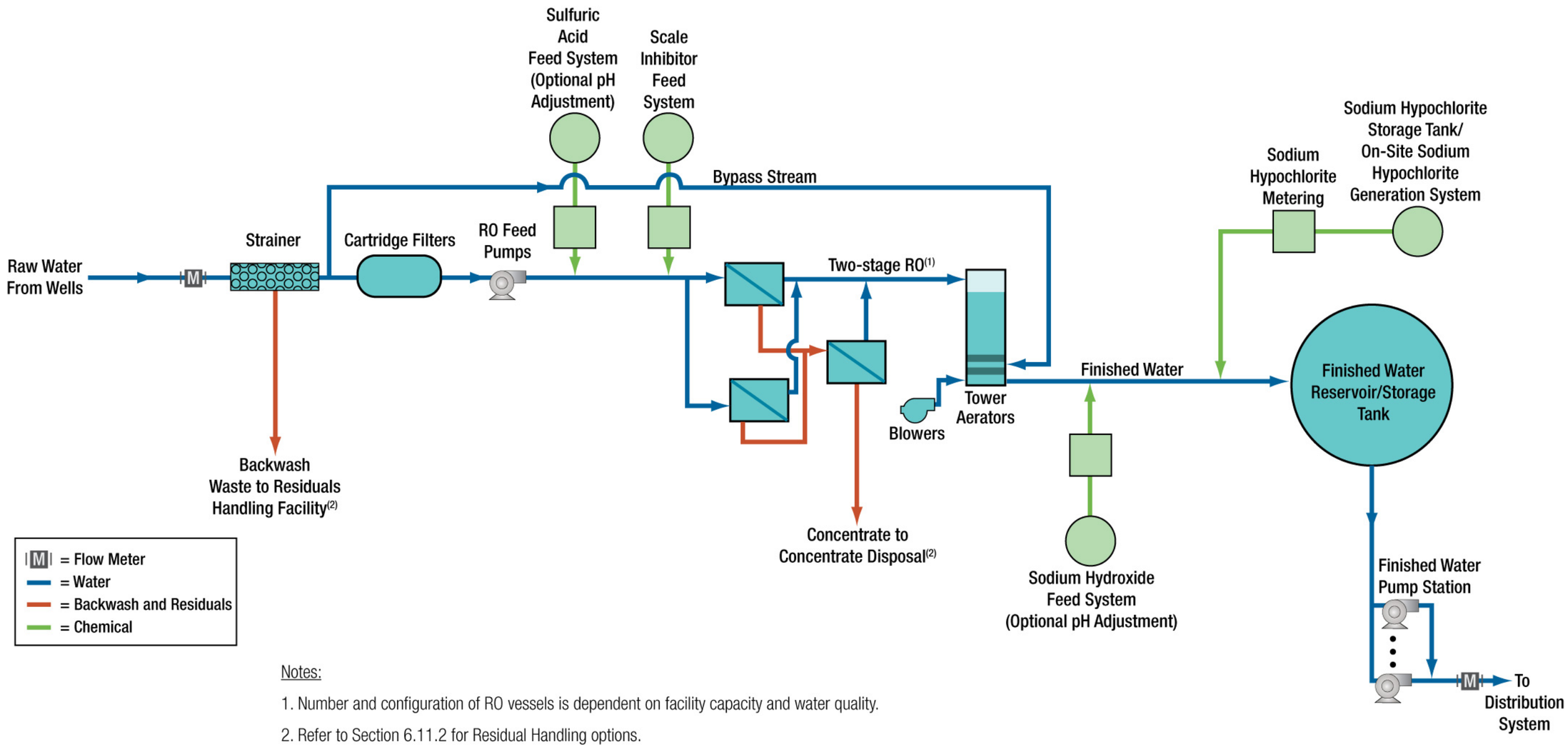
Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection, and site-specific considerations.

(3) The membrane replacement frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(4) Recovery rates for nitrate and fluoride vary significantly depending on membrane selection. Recovery can be 90% or higher for RO membranes but is typically lower for NF membranes.



Notes:

1. Number and configuration of RO vessels is dependent on facility capacity and water quality.
2. Refer to Section 6.11.2 for Residual Handling options.

NANOFILTRATION/REVERSE OSMOSIS PROCESS FLOW DIAGRAM

FIGURE WT.17

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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7.2.4.1 NF/RO Design Considerations

The following list includes design considerations associated with NF/RO technology. This list should be reviewed when initially considering NF/RO technologies as well as during the preliminary and final design of any NF/RO treatment facilities.

- Parameters that can impact the membrane process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, silica, barium, calcium, magnesium, nitrate, vandium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- The membrane design flux and the allowable blending ratios cannot be determined without actual water qualities. The analysis above presented an example which must be updated when the specific water quality data are available.
- When specific water quality data is available, the design engineer should consult with the membrane supplier to finalize the selection of membrane products. Perform membrane modeling evaluations and optimize the array design. Pilot testing may be required for complicated applications. Pending the finalization of membrane selection, NF/RO are generally considered as the same process. In fact, NF membranes have lower salt rejection than RO membranes and are slightly less efficient in removing mono-valent ions such as sodium, chloride, fluoride, and nitrate.
- A conventional oxidation process is not recommended. Excessive oxidant (> 0.5 mg/L free chlorine) may degrade membranes. High Fe (III) and manganese in the feed water can foul the membranes and reduce membrane life. If water containing iron or manganese will uptake more than 5 mg/L of oxygen, or has been chlorinated, Fe^{2+} (ferrous) is converted into Fe^{3+} (ferric), which forms insoluble colloidal hydroxide particles that may foul RO/NF membranes.
- NF/RO can remove multiple contaminants through one process, including inorganics (TDS, arsenic, nitrate, and fluoride) as well as organics and pathogens.
- RO is a best available technology (BAT) for arsenic, nitrate, and fluoride treatment as identified in the Safe Drinking Water Act.
- Depending on the water quality and the blending ratio, post-treatment may or may not be necessary.
- NF/RO has very low fouling concerns for groundwater application at 85 percent recovery. Membranes may require cleaning in place every six months.
- The process may lose up to 15 percent water as concentrate (or brine). If sewer discharge is not an option, brine management can be cost prohibitive. Sewer disposal may be a short-term solution especially for a small facility, but requires a pretreatment

permit and will impact the downstream wastewater treatment plant APP permit. Brine disposal via sewer could also increase the reclaimed water salinity and reduce its reuse potential.

- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated by the City on a case-by-case basis with consideration for the economics of residual treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.

7.2.5 Disinfection Facilities

Disinfection is required regardless of which primary treatment technology is selected. Disinfection using bulk sodium hypochlorite is the most favorable disinfection alternative, as identified in SurpriseTree™ Water. Onsite generation of sodium hypochlorite is the next most favorable disinfection alternative. Bulk sodium hypochlorite and on-site generated sodium hypochlorite should be evaluated for site-specific conditions and market conditions at the time of the associated project. When designing the disinfection facility, consider using the sodium hypochlorite selected for primary and residual disinfection for use as the pre-oxidant as well.

A disinfection system basis of design is included in Table WT.50.

Table WT.50 Disinfection System Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Design Flows	mgd	1	1 ~ 10
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 – 4
Characteristics		Liquid, 0.8% solution	

Notes:
1. Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.
2. Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection, and site-specific considerations.

8.0 SUMMARY AND CONCLUSIONS

This Water Technology Assessment Report was completed to provide the City:

- Provide the foundation for uniformity in approach to future City of Surprise water treatment facilities and infrastructure.
- Provide a mechanism to obtain consensus from all sectors and levels of City management on City water treatment and infrastructure policy.
- Provide technically feasible, cost-effective, and reliable approaches to meet the regulatory requirements for water treatment facilities and infrastructure.
- Establish a position which enhances the City's control over the planning and implementation process for its future water and treatment facilities and infrastructure.

It was critical that the City establish reasonable policies and defensible design criteria and guidelines, which promote the timely and cost-effective construction of new water supply facilities. The project provides the City of Surprise with a series of documents that provide design guidelines and standards for future water and wastewater facilities and infrastructure for the community.

The Drinking Water Technology Assessment identifies and discusses technologies for treating the City's future groundwater supplies. Current, proposed, and future regulations were reviewed and Water Quality Standards were established based on input from City staff and developer representatives. The City of Surprise Water Quality Standards establish treatment standards for all future water supply facilities within the City. Arsenic, nitrate, and fluoride were identified as CoC for the City's groundwater sources. Viable water treatment technologies were reviewed and recommendations were made regarding the most appropriate/applicable treatment processes to address the established CoC.

The water quality of future wells within the City limits is unknown. Therefore, a customized tool called SurpriseTree™ Water was created for the City to compare water treatment technologies. This tool allows the City to input future well water quality and site-specific information to assist in identifying the best alternative for treatment. All treatment processes recommended meet the City's Water Quality Standards and residual disposal requirements.

Based on general ranking results from the SurpriseTree™ Water Model, the most favorable treatment technologies identified to address the City's CoC (arsenic, nitrate, and fluoride) include:

- Adsorption
- Coagulation filtration
- Ion exchange
- NF/RO

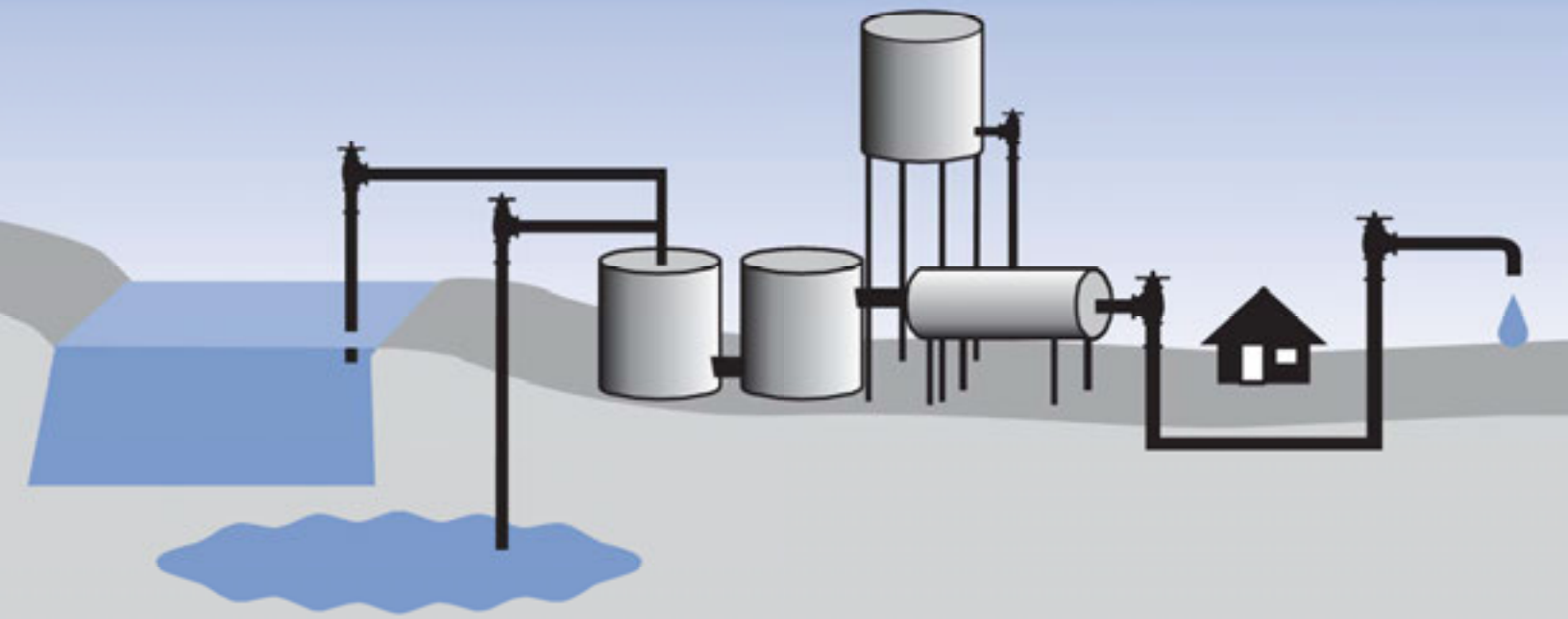
Bulk sodium hypochlorite and onsite-generated sodium hypochlorite are the most favorable disinfection alternatives, as identified by the SurpriseTree™ Water Model. Residual handling alternatives should bear evaluation based on their applicability for each of the primary water treatment processes.

This project also includes a Wastewater Technology Assessment Report and Water and Wastewater Facility Guidelines. Refer to Wastewater Technology Assessment Report (Carollo Engineers 2011) for an assessment of wastewater treatment technologies for the City of Surprise. Refer to Water and Wastewater Facility Guidelines Volumes I, II, III (Carollo Engineers 2011) for guidelines associated with the design of water and wastewater treatment support facilities.

EPA ARSENIC TREATMENT TECHNOLOGY EVALUATION HANDBOOK FOR SMALL SYSTEMS

United States
Environmental Protection
Agency

Arsenic Treatment Technology Evaluation Handbook for Small Systems



Office of Water (4606M)
EPA 816-R-03-014
July 2003
www.epa.gov/safewater

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The decision trees contained in this document were current when the handbook was published in 2003. They are still relevant and can provide a simple guide for selecting an arsenic treatment.

However, EPA has slightly modified the trees since publication to reflect changes in regulation and arsenic treatment technologies. To visit the revised trees, visit http://www.arsenictradeshow.com

The trees are intended for use as an iterative tool. Users can work their way through the trees a number of times, modifying preferences and system specific circumstances. There may not be a single solution. Further cost evaluation and assessment of other considerations such as labor commitments, residual disposal, and available space, may be necessary.

Disclaimer

The information in this document has been subjected to the Agency's peer and administrative reviews and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute an endcrsement or recommendation of use.

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Executive Summary

In January 2001, the U.S. Environmental Protection Agency (USEPA) published a final Arsenic Rule in the Federal Register. This rule established a revised maximum contaminant level (MCL) for arsenic at 0.010 mg/L. All community and non-transient, non-community (NTNC) water systems, regardless of size, will be required to achieve compliance with this rule by January 2006.

This technical handbook is intended to help small drinking water systems make treatment decisions to comply with the revised arsenic rule. A "small" system is defined as a system serving 10,000 or fewer people. Average water demand for these size systems is normally less than 1.4 million gallons per day (MGD).

Provided below is a checklist of activities that should normally take place in order to comply with the new Arsenic Rule. Many of the items on this checklist refer to a section in this handbook that may help in completing the activities.

Arsenic Mitigation Checklist

1. Monitor arsenic concentration at each entry point to the distribution system (see Section 1.3.2).
2. Determine compliance status. This may require quarterly monitoring. See Section 1.3.2 for details on Arsenic Rule compliance.
3. Determine if a non-treatment mitigation strategy such as source abandonment or blending can be implemented. See Sections 2.1.1 through 2.1.3 for more detail and Decision Tree 1, *Non-Treatment Alternatives*.
4. Measure water quality parameters. See Section 3.1.1 for more detail on water quality parameters that are used in selecting a treatment method.
   - Arsenic, Total
   - Arsenate [As(V)]
   - Arsenite [As(III)]
   - Chloride
   - Fluoride
   - Iron
   - Manganese
   - Nitrate
   - Nitrite
   - Orthophosphate
   - pH
   - Silica
   - Sulfate
   - Total Dissolved Solids (TDS)
   - Total Organic Carbon (TOC)
5. Determine the treatment evaluation criteria. See Section 3.1.2 for more detail on parameters that are used in selecting a treatment method.
   - Existing Treatment Processes
   - Target Finished Water Arsenic Concentration

- Technically Based Local Limits (TBLLs) for Arsenic and TDS
- Domestic Waste Discharge Method
- Land Availability
- Labor Commitment
- Acceptable Percent Water Loss
- Maximum Source Flowrate
- Average Source Flowrate
- State or primacy agency requirements that are more stringent than those of the USEPA.

6. Select a mitigation strategy using the decision trees provided in Section 3.2. These trees lead to the following mitigation strategies.
    - Non-Treatment & Treatment Minimization Strategies
        - Source Abandonment
        - Seasonal Use
        - Blending Before Entry to Distribution System
        - Sidestream Treatment
    - Enhance Existing Treatment Processes
        - Enhanced Coagulation/Filtration
        - Enhanced Lime Softening
        - Iron/Manganese Filtration
    - Treatment (Full Stream or Sidestream)
        - Ion Exchange
        - Activated Alumina
        - Iron Based Sorbents
        - Coagulation-Assisted Microfiltration (CMF)
        - Coagulation-Assisted Direct Filtration (CADF)
        - Oxidation/Filtration
    - Point-of-Use Treatment Program
        - Activated Alumina
        - Iron Based Sorbent
        - Reverse Osmosis
7. Estimate planning-level capital and operations and maintenance (O&M) costs for the mitigation strategy using the costs curves provided in Section 4. Include costs for arsenic removal and waste handling. If this planning level cost is not within a range that is financially possible, consider using different preferences in the decision trees.
8. Evaluate design considerations for the mitigation strategy. See Section 2.5 for enhancing existing treatment processes and Sections 6 through 8 for the design of new treatment processes.

9. Pilot the mitigation strategy. Although not explicitly discussed in this Handbook, piloting the mitigation strategy is a normal procedure to optimize treatment variables and avoid implementing a strategy that will not work for unforeseen reasons. For many small systems, piloting may be performed by the vendor and result in a guarantee from the vendor that the system will perform.
10. Develop a construction-level cost estimate and plan.
11. Implement the mitigation strategy.
12. Monitor arsenic concentration at each entry point to the distribution system to ensure that the arsenic levels are now in compliance with the Arsenic Rule – assumes centralized treatment approach, not point-of-use treatment.

Table ES-1 provides a summary of information about the different alternatives for arsenic mitigation found in this Handbook. Please note that systems are not limited to using these technologies.

Table ES-1. Arsenic Treatment Technologies Summary Comparison. (1 of 2)

Factors	Sorption Processes			Membrane Processes
	Ion Exchange	Activated Alumina [A]	Iron Based Sorbents	Reverse Osmosis
	IX	AA	IBS	RO
USEPA BAT [B]	Yes	Yes	No [C]	Yes
USEPA SSCT [B]	Yes	Yes	No [C]	Yes
System Size [B,D]	25-10,000	25-10,000	25-10,000	501-10,000
SSCT for POU [B]	No	Yes	No [C]	Yes
POU System Size [B,D]	-	25-10,000	25-10,000	25 -10,000
Removal Efficiency	95% [E]	95% [E]	up to 98% [E]	> 95% [E]
Total Water Loss	1-2%	1-2%	1- 2%	15-75%
Pre-Oxidation Required [F]	Yes	Yes	Yes [O]	Likely [H]
Optimal Water Quality Conditions	pH 6.5 - 9 [E] < 5 mg/L NO_3^- [I] < 50 mg/L SO_4^{2-} [J] < 500 mg/L TDS [K] < 0.3 NTU Turbidity	pH 5.5 - 6 [I] pH 6 - 8.3 [L] < 250 mg/L Cl^- [I] < 2 mg/L F^- [I] < 360 mg/L SO_4^{2-} [K] < 30 mg/L Silica [M] < 0.5 mg/L Fe^{+3} [I] < 0.05 mg/L Mn^{+2} [I] < 1,000 mg/L TDS [K] < 4 mg/L TOC [K] < 0.3 NTU Turbidity	pH 6 - 8.5 < 1 mg/L PO_4^{-3} [N] < 0.3 NTU Turbidity	No Particulates
Operator Skill Required	High	Low [A]	Low	Medium
Waste Generated	Spent Resin, Spent Brine, Backwash Water	Spent Media, Backwash Water	Spent Media, Backwash Water	Reject Water
Other Considerations	Possible pre & post pH adjustment. Pre-filtration required. Potentially hazardous brine waste. Nitrate peaking. Carbonate peaking affects pH.	Possible pre & post pH adjustment. Pre-filtration may be required. Modified AA available.	Media may be very expensive. [O] Pre-filtration may be required.	High water loss (15-75% of feed water)
Centralized Cost	Medium	Medium	Medium	High
POU Cost	-	Medium	Medium	Medium

[A] Activated alumina is assumed to operate in a non-regenerated mode.
[B] USEPA, 2002a.
[C] IBS's track record in the US was not established enough to be considered as Best Available Technology (BAT) or Small System Compliance Technology (SSCT) at the time the rule was promulgated.
[D] Affordable for systems with the given number of people served.
[E] USEPA, 2000.
[F] Pre-oxidation only required for As(III).
[O] Some iron based sorbents may catalyze the As(III) to As(V) oxidation and therefore would not require a pre-oxidation step.
[H] RO will remove As(III), but its efficiency is not consistent and pre-oxidaton will increase removal efficiency.
[I] AwwaRF, 2002.
[J] Kempic, 2002.
[K] Wang, 2000.
[L] AA can be used economically at higher pHs, but with a significant decrease in the capacity of the media.
[M] Clifford, 2001.
[N] Tumlo, 2002.
[O] With increased domestic use, IBS cost will significantly decrease.

Table ES-1. Arsenic Treatment Technologies Summary Comparison. (2 of 2)

Factors	Precipitative Processes				
	Enhanced Lime Softening	Enhanced (Conventional) Coagulation Filtration	Coagulation-Assisted Micro-Filtration	Coagulation-Assisted Direct Filtration	Oxidation Filtration
	LS	CF	CMF	CADF	OxFilt
USEPA BAT [B]	Yes	Yes	No	Yes	Yes
USEPA SSCT [B]	No	No	Yes	Yes	Yes
System Size [B,D]	25-10,000	25-10,000	500-10,000	500-10,000	25-10,000
SSCT for POU [B]	No	No	No	No	No
POU System Size [B,D]	-	-	-	-	-
Removal Efficiency	90% [E]	95% (w/ $FeCl_3$) [E] < 90% (w/ Alum) [E]	90% [E]	90% [E]	50-90% [E]
Total Water Loss	0%	0%	5%	1-2%	1-2%
Pre-Oxidation Required [F]	Yes	Yes	Yes	Yes	Yes
Optimal Water Quality Conditions	pH 10.5 - 11 [I] > 5 mg/L Fe^{+3} [I]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 >0.3 mg/L Fe Fe:As Ratio > 20:1
Operator Skill Required	High	High	High	High	Medium
Waste Generated	Backwash Water, Sludge (high volume)	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge
Other Considerations	Treated water requires pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	None.
Centralized Cost	Low [G]	Low [G]	High	Medium	Medium
POU Cost	N/A	N/A	N/A	N/A	N/A

[B] USEPA, 2002a.
[D] Affordable for systems with the given number of people served.
[E] Depends on arsenic and iron concentrations.
[F] Pre-oxidation only required for As(III).
[I] AwwaRF, 2002.
[F] Fields, et al., 2002a.
[G] Costs for enhanced LS and enhanced CF are based on modification of an existing technology. Most small systems will not have this technology in place.

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List of Acronyms and Abbreviations

AA	Activated Alumina
Al	Aluminum
ANSI	American National Standards Institute
As	Arsenic
As(III)	Valence +3 Arsenic (found in Arsenite ion, AsO_3^{-3})
As(V)	Valence +5 Arsenic (found in Arsenate ion, AsO_4^{-3})
AsO_3^{-3}	Arsenite ion
AsO_4^{-3}	Arsenate ion
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BAT	Best Available Technology
BV	Bed Volume
cft	Cubic feet
Ca^{+2}	Calcium
$CaCO_3$	Calcium Carbonate
CADF	Coagulation-Assisted Direct Filtration
CCI	Construction Cost Index
CF	Enhanced (Conventional) Coagulation/Filtration
Cl^-	Chloride
Cl_2	Chlorine
CMF	Coagulation-Assisted Microfiltration
CO_3^{-2}	Carbonate
CT	Disinfectant Concentration Times Contact Time
CWA	Clean Water Act of 1987
DBP	Disinfection By-Product
DBPR	Disinfectants/Disinfection By-Products Rule
DO	Dissolved Oxygen
EBCT	Empty Bed Contact Time
ENR	Engineering News Record
F^-	Fluoride
Fe, Fe^{+2}, Fe^{+3}	Iron
$FeCl_3$	Ferric Chloride
$Fe(OH)_3$	Ferric Hydroxide
ft	Feet
FTW	Filter-To-Waste
g	Gram
gal	Gallon
GFH	Granular Ferric Hydroxide
gpd	Gallons per Day
gph	Gallons per Hour

gpm	Gallons per Minute
hr	Hour
H^+	Hydronium, Hydrogen ion
$H_2AsO_3^-$	Monovalent Arsenite Ion
$H_2AsO_4^-$	Monovalent Arsenate Ion
H_2O	Water
H_2S	Hydrogen Sulfide
H_2SO_4	Sulfuric Acid
H_3AsO_3	Arsenite Molecule
H_3AsO_4	Arsenate Molecule
HAA5	Haloacetic Acid
$HAsO_3^{-2}$	Divalent Arsenite Ion
$HAsO_4^{-2}$	Divalent Arsenate Ion
HCl	Hydrochloric Acid
HOCl	Hypochlorous Acid
HS^-	Hydrogen Sulfide Ion
IBS	Iron Based Sorbents
in.	Inches
IESWTR	Interim Enhanced Surface Water Treatment Rule
IX	Ion Exchange
kg	kilogram
kWh	Kilowatt Hour
L	Liter
LACSL	Land Application Clean Sludge Limit
lb(s)	Pound(s)
LCR	Lead and Copper Rule
LS	Lime Softening
LT1ESWTR	Long Term-1 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MF	Micro-Filtration
mg	Milligram
Mg	Magnesium
MGD	Million Gallons per Day
min.	Minute
mL	Milliliter
mm	Millimeter
Mn, Mn^{+2}	Manganese
MnO_2	Manganese Dioxide
MnO_4^-	Permanganate
MSHA	Mine Safety and Health Administration
MTZ	Mass Transfer Zone
N	Nitrogen
NaCl	Sodium Chloride
NaOCl	Sodium Hypochlorite
NaOH	Sodium Hydroxide

NIOSH	National Institute for Occupational Safety and Health
NIPDWRs	National Interim Primary Drinking Water Regulations
NO_2^-	Nitrite
NO_3^-	Nitrate
NOM	Natural Organic Matter
NPDES	National Pollutant Discharge Elimination System
NPDWRs	National Primary Drinking Water Regulations
NTNC	Non-Transient, Non-Community
NTU	Nephelometric Turbidity Units
O_2	Oxygen
O_3	Ozone
O&M	Operations and Maintenance
OCl^-	Hypochlorite
OH^-	Hydroxide
PFLT	Paint Filter Liquids Test
pH	Negative Log of Hydrogen Ion Concentration
PO_4^{-3}	Phosphate, Orthophosphate
POE	Point-of-Entry
POTW	Publicly Owned Treatment Works
POU	Point-of-Use
psi	Pounds per Square Inch
RCRA	Resource Conservation and Recovery Act
RO	Reverse Osmosis
S^0	Sulfur, zero valence
SBA	Strong Base Anion exchange resin
scf	Standard Cubic Feet
scfm	Standard Cubic Feet per Minute
SDWA	Safe Drinking Water Act
sft	Square Feet
$Si(OH)_3O^-$	Silicate Ion
SO_4^{2-}	Sulfate
SSCT	Small System Compliance Technologies
SWTR	Surface Water Treatment Rule
TBLL	Technically Based Local Limit
TC	Toxicity Characteristic
TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TTHM	Total Trihalomethanes
TOC	Total Organic Carbon
UFC	Uniform Fire Code
USEPA	United States Environmental Protection Agency
UV	Ultra-Violet
WET	Waste Extraction Test
wt%	Weight Percent
y	Year

Equation Nomenclature

Symbol	Definition	Units
BV_e	Number of Bed Volumes to Exhaustion	-
$C_{As,j}$	Arsenic Concentration of Source j	mg/L
$C_{As,B}$	Arsenic Concentration of Blended Stream	mg/L
C_{Cl_2}	Chlorine Concentration	lbs Cl_2/gal
C_{FeCl_3}	Ferric Chloride Stock Solution Concentration	wt%
C_i	Concentration of Species *i* in the Feed Stream	mg/L
C_k	Arsenic Concentration Entering System During Quarter k	mg/L
C_{MCL}	Arsenic MCL	mg/L
C_{MnO_4}	Permanganate Stock Solution Concentration	mg/L
$C_{R,i}$	Concentration of Species *i* in the Retentate	mg/L
C_{RAA}	Running Annual Average Arsenic Concentration	mg/L
C_{TDS}	Concentration of Total Dissolved Solids	g/L
$CCI_{Current}$	Construction Cost Index for the Current Year	-
CCI_{1998}	Construction Cost Index for 1998	-
D	Column Diameter	ft
D_{Cl_2}	Ultimate Chlorine Demand	mg/L as Cl_2
D_{MnO_4}	Ultimate Permanganate Demand	mg/L as Mn
D_{O_2}	Ultimate Oxygen Demand	mg/L
D_{O_3}	Ultimate Ozone Demand	mg/L
E	Overall Rejection Rate	%
E_S	Individual Stage Contaminant Rejection Rate	%
EBCT	Empty Bed Contact Time	minutes
F	Freeboard Allowance	%
G_{BW}	Backwash Flux	gpm/sft
G_R	Regeneration Flux	gpm/sft
HLR	Hydraulic Loading Rate	gpm/sft
H	Column Height	ft
h_j	Height of Media Layer *j*	ft
i	Annual Inflation Rate	%
M_{Brine}	Brine Molarity	mole/L
M_{Cl_2}	Chlorine Mass Flow	lb/day of Cl_2

Symbol	Definition	Units
M_{O_3}	Ozone Mass Flow	g/hr of O_3
n	Number of Stages	-
n_P	Number of Parallel Treatment Trains	-
P_{1998}	Year 1998 Cost	$
$P_{Current}$	Current Cost	$
Q	Design Flow Rate	gpm
Q_j	Flowrate of Source j	gpm
Q_B	Flowrate of Blended Stream	gpm
Q_{BW}	Backwash Flowrate	gpm
Q_{Cl_2}	Hypochlorite Metering Pump Rate	gph
Q_{FeCl_3}	Ferric Chloride Metering Pump Rate	mL/min
Q_{MnO_4}	Permanganate Metering Pump Rate	gph
Q_S	Flowrate to be Split off and Treated	gpm
t	Storage Time	days
t_{BW}	Backwash Duration	minutes
t_{FTW}	Filter-To-Waste Duration	minutes
t_R	Regeneration Duration	minutes
V	Storage Volume	gal
V_{WW}	Volume of Wastewater	gal
W_j	Weight of Media *j*	lbs
$Y_{Current}$	Current Year	-
Z	Depth of Media	ft
β	Individual Stage Water Recovery Rate	%
δ_{Cl_2}	Chlorine Dose	mg/L as Cl_2
δ_{FeCl_3}	Ferric Chloride Dose	mg/L
δ_{MnO_4}	Permanganate Dose	mg/L as Mn
δ_{O_2}	Oxygen Dose	mg/L
δ_{O_3}	Ozone Dose	mg/L
ε	Arsenic Rejection Rate	%
ρ_{FeCl_3}	Density of Ferric Chloride	kg/L
ρ_j	Bulk Density of Media *j*	lbs/cft
σ	Safety Margin	%
τ	Optimal Filter Run Time	hr
ω	Treatment Water Loss	%

Section 1
Background

1.1 Purpose of this Handbook

This Handbook is intended to serve as a resource for small municipal drinking water systems that may be affected by provisions of the Arsenic Rule. A "small" system is defined as a system serving 10,000 or fewer people. Average water demand for these size systems is normally less than 1.4 million gallons per day (MGD). Please note that the USEPA statutes and regulations described in this document contain legally binding requirements. The recommendations provided in this handbook do not substitute for those statutes or regulations, nor is this document a regulation itself. The approaches described in this handbook are strictly voluntary and do not impose legally-binding requirements on USEPA, states, local or tribal governments, or members of the public, and may not apply to a particular situation based upon the circumstances. Although the USEPA strongly recommends the approach outlined in this document, state and local decision makers are free to adopt approaches that differ from this handbook or to evaluate and choose technologies that are not discussed here. Interested parties are free to raise questions and objections about the appropriateness of the application of this handbook. Any USEPA decisions regarding a particular system will be made based on the applicable statutes and regulations. The USEPA may review and update this handbook as necessary and appropriate.

1.2 How to Use this Handbook

This Handbook includes general arsenic treatment information, cost evaluation tools, and design considerations for specific treatment technologies. The Handbook is organized to enable the utility to make educated decisions about the most appropriate treatment approach(es) to address arsenic concerns prior to getting involved in detailed design considerations. The utility should read Sections 1 through 3 in sequence, then use the treatment selection guidance provided in Section 3 to determine the most appropriate cost and design considerations sections (Sections 4 through 8).

Section 1 provides background information on the Arsenic Rule, waste disposal regulation, and arsenic chemistry that is useful in understanding the remainder of the Handbook.

Section 2 provides descriptions and background information for established arsenic mitigation strategies, with emphasis on those that are most technically and financially suitable for small systems. The utility should use this section to gather background information on the various arsenic mitigation strategies and determine the flowrate to be treated if treatment is selected as the mitigation strategy.

Section 3 describes the considerations required to make an informed treatment method selection. Decision trees are provided to guide the utility to the most applicable mitigation or treatment strat-

egy. The selected process is the one that has the highest chance of achieving the most cost effective solution for the particular water source, given the parameters used in the decision making process.

Section 4 enables the utility to quickly estimate the planning-level costs for the selected treatment process. This section is intended for those utilities that have identified the need to install new arsenic treatment. Based on the cost estimate, the utility can then decide if the selected treatment process is economically feasible. If it is not, the utility can repeat the decision trees and apply different preferences. It is important to recognize that the cost curves provided are for planning-level considerations only and should not be used as the primary decision-making tools.

Section 5 presents pre-oxidation alternatives and design calculations. This section is relevant to those utilities that have selected a treatment alternative and do not currently employ oxidation at the source(s) with arsenic concerns.

Sections 6-8 are intended for those utilities that have identified the need to install new arsenic treatment technologies. These sections provide design information on each of the primary arsenic treatment technologies.

After the selected mitigation strategy has been reviewed, the utility should evaluate the cost and constraints of the mitigation strategy. For strategies that involve modification of an existing process, a test should be run. For strategies that involve a new process, a pilot plant test should be run. After the tests have been performed and the results analyzed, the utility should re-evaluate whether the strategy will reduce the arsenic concentration below the Maximum Contaminant Level (MCL).

1.3 Regulatory Direction

1.3.1 The Arsenic Rule

The former arsenic MCL was 0.05 mg/L, as established under the 1975 National Interim Primary Drinking Water Regulations (NIPDWRs). As part of the 1996 Safe Drinking Water Act (SDWA) Amendments, the United States Environmental Protection Agency (USEPA) was directed to conduct health effects and cost/benefit research to finalize a new arsenic standard.

In June 2000, the USEPA proposed a revised arsenic MCL of 0.005 mg/L, and requested public comment on alternative MCLs of 0.003, 0.010, and 0.020 mg/L. The USEPA published a final rule in the Federal Register in January 2001 (USEPA, 2001). This rule established a revised arsenic MCL of 0.010 mg/L, and identified the following as Best Available Technologies (BATs) for achieving compliance with this regulatory level:

- Ion Exchange (IX)
- Activated Alumina (AA)
- Oxidation/Filtration
- Reverse Osmosis (RO)

- Electrodialysis Reversal
- Enhanced Coagulation/Filtration
- Enhanced Lime Softening

The following are listed in the final rule and the *Implementation Guidance for the Arsenic Rule* (USEPA, 2002a) as Small System Compliance Technologies (SSCT).

- IX
- AA, centralized and point-of-use (POU)
- RO, centralized and POU
- Electrodialysis Reversal
- Oxidation/Filtration
- Coagulation/Filtration, Enhanced Coagulation/Filtration, and Coagulation-Assisted Microfiltration (CMF)
- Lime Softening (LS) and Enhanced Lime Softening

This regulation applies to all community water systems and non-transient, non-community (NTNC) water systems, regardless of size. Please note that systems are not required to use these technologies.

Compliance with the Arsenic Rule will be required by January 2006. The running annual average arsenic level must be at or below 0.010 mg/L at each entry point to the distribution system. However, POU treatment can be instituted instead of centralized treatment. Analytical results for arsenic are rounded to the nearest 0.001 mg/L for reporting and compliance determination.

1.3.2 Health Effects

Motivation to reduce the arsenic MCL is driven by the findings of health effects research. Over the past several years, numerous toxicological and epidemiological studies have been conducted to ascertain health risks associated with low-level exposure to As(V) ingestion.

Ingestion of inorganic arsenic can result in both cancer and non-cancer health effects (NRC, 1999). Arsenic interferes with a number of essential physiological activities, including the actions of enzymes, essential cations, and transcriptional events in cells (NRC, 1999). The USEPA has classified arsenic as a Class A human carcinogen. Chronic exposure to low arsenic levels (less than 0.05 mg/L) has been linked to health complications, including cancer of the skin, kidney, lung, and bladder, as well as other diseases of the skin, neurological, and cardiovascular system (USEPA, 2000).

The primary mode of exposure is ingestion of water containing arsenic. Dermal absorption of arsenic is minimal; therefore, hand washing and bathing do not pose a known risk to human health.

1.3.3 Other Drinking Water Regulations

In an attempt to comply with one drinking water regulation, it is possible to compromise treatment performance or compliance with other drinking water regulations. Therefore, in an effort to conform with the Arsenic Rule, community water systems should be cognizant of potential system-wide, regulatory, and operational impacts. In particular, compliance with the following regulations should be considered.

- Lead and Copper Rule (LCR)
- Surface Water Rules (SWTR, IESWTR, LT1ESWTR)
- Disinfectants/Disinfection By-Products Rule (DBPR)

Many of the arsenic treatment technologies require pH adjustment for optimization of performance. Figure 11 provides a summary of the optimal pH ranges for several arsenic treatment technologies. Sorption and coagulation processes are particularly sensitive to pH, and function most effectively at the lower end of the natural pH range. However, use of AA at a natural pH may be a cost effective option for many small water systems.

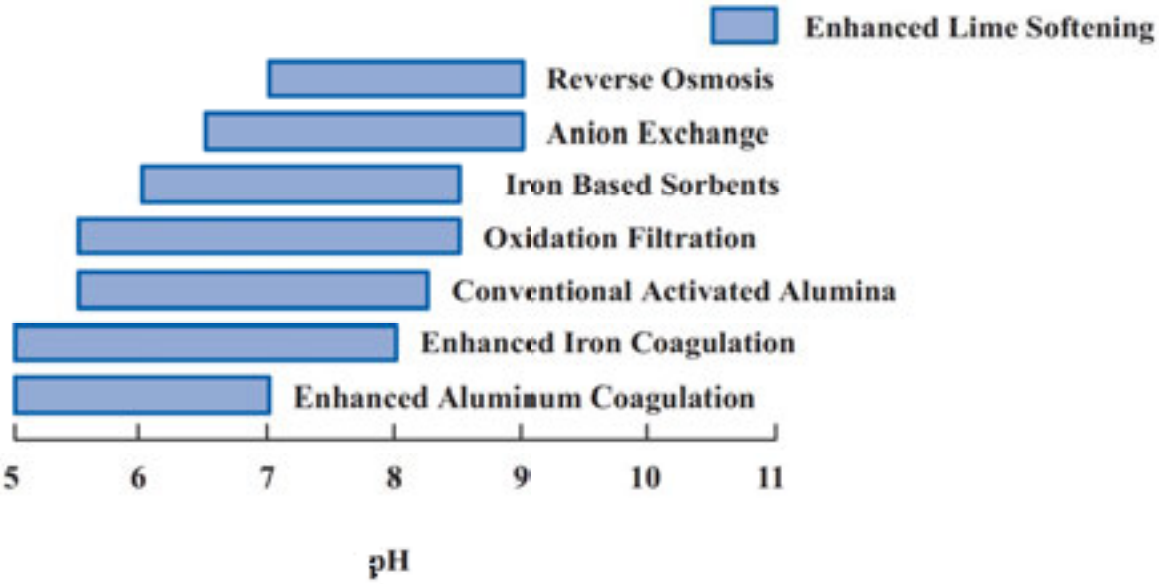

Figure 1-1. Optimal pH Ranges for Arsenic Treatment Technologies.

In addition to affecting arsenic treatability, pH also can have a significant effect on disinfection, coagulation, and chemical solubility/precipitation within the distribution system and in plumbing systems (LCR).

Lead and Copper Rule

Lead and copper in tap water is primarily due to corrosion of plumbing system components within buildings, including copper pipes, lead-based solder used to join segments of copper pipe, and faucets made from brass. Alkalinity and pH play a critical role in providing passivation protection from corrosion. In general, the optimum pH range for minimizing corrosion of lead and copper is 7.59.0. Therefore, post-treatment pH adjustment is recommended for many of the treatment techniques provided in Figure 11.

Surface Water Rules (SWTR, IESTWR, LT1ESWTR)

Disinfection efficacy is also related to pH if chlorine is used. When pre-chlorinating, the biocidal potential of chlorine is enhanced as the pH is reduced. Therefore, utilities that are currently required to meet a CT (disinfectant concentration times contact time) standard should receive disinfection benefit from pH reduction at the head of the treatment process. Post-treatment pH adjustment for corrosion control should be conducted after CT requirements are met.

Coagulation and flocculation processes are also related to pH. The formation of floc is improved as the pH is reduced, and optimized within the range of 5-8. However, iron and aluminum-based coagulants also consume alkalinity, thereby decreasing the buffering capacity of the water.

Disinfectants/Disinfection By-Products Rule (DBPR)

Chlorine reacts with natural organic matter (NOM) to form halogenated disinfection by-products, such as total trihalomethanes (TTHM) and haloacetic acids (HAA5). Therefore, incorporating pre-chlorination to convert As(III) to As(V) could increase the occurrence of these regulated chemicals. However, as most arsenic in surface water is already oxidized to As(V), chlorination may not be necessary in surface water, where disinfection byproducts are of the most concern. The Stage 1 DBPR[1] establishes running annual average MCLs of 0.080 mg/L and 0.060 mg/L for TTHM and HAA5, respectively.

The Stage 2 DBPR, scheduled for proposal in early 2003, augments the Stage 1 DBPR to reduce health risks from DBP exposure.

1.3.4 Waste Disposal Regulations

Waste disposal is an important consideration in the treatment selection process. Arsenic removal technologies produce several different types of waste, including sludges, brine streams, backwash slurries, and spent media. These wastes have the potential for being classified as hazardous and can pose disposal problems. Table 1-1 provides a summary of the available waste disposal options and associated criteria. These are further discussed in the following paragraphs. In addition, specific waste disposal considerations for each technology are discussed in Section 2.

[1] The Stage 1 DBPR became effective for surface water systems and groundwater systems under the direct influence of surface water serving at least 10,000 people in January 2002. The rule will take effect for all groundwater systems, and surface water systems and groundwater systems under the direct influence of surface water systems serving less than 10,000 people in January 2004.

Table 1-1. Waste Disposal Options.	
Waste Type	**Disposal Method (Criteria)**
Liquid	• Direct Discharge to Surface Water (CWA, NPDES) • Indirect Discharge to POTW (TBLLs) • On-Site Sewerage (POU systems) • Infiltration to Ground Water • Evaporation Ponds • Recycle/Reuse • Ocean Discharge
Solid (sludge, media)	• Land Application • Municipal Solid Waste Landfill (PFLT, TCLP, WET in California) • Hazardous Waste Landfill (PFLT)

Liquid waste streams must have lower concentrations than the Toxicity Characteristic (TC) in order for the waste to be classified as non-hazardous. The arsenic TC is 5.0 mg/L. Those liquid waste streams that contain more than 5.0 mg/L of arsenic would therefore be classified as a hazardous waste. Many of the arsenic removal technologies also remove other constituents (e.g., chromium). The waste stream must be analyzed for these other substances that may be in concentrations above their respective TCs. Because of Resource Conservation and Recovery Act (RCRA) requirements and cost implications, on-site treatment or off-site disposal of hazardous waste is likely to be infeasible for small water systems. Indirect discharge may be an option since wastes that pass through a sewer system to a Publicly Owned Treatment Works (POTW) are exempt from RCRA regulation once the waste mixes with wastewater from the sewer. Utilities considering indirect discharge should work with the POTW to determine if the arsenic waste levels would be acceptable to a revised Technically Based Local Limit (TBLL). (The TBLL would be revised because the arsenic treatment will change the arsenic background at the POTW).

Solids waste streams are subject to the Toxicity Characteristic Leaching Procedure (TCLP). This test is used to simulate the potential for leaching in a landfill setting. The TCLP leachate must be lower than any of the TC values in order for the waste to be classified as non-hazardous.

There are five realistic methods for the disposal of arsenic waste streams.

Landfill Disposal

Historically, municipal solid waste landfills have been commonly used for the disposal of non-hazardous solid wastes emanating from treatment processes. However, the hazard potential of arsenic may limit the feasibility of this alternative.

Dewatered sludge and spent media can be disposed in a municipal solid waste landfill if the waste passes both the Paint Filter Liquids Test (PFLT) and the TCLP. The PFLT is used to verify there is no free liquid residual associated with the waste. However, if the TCLP extract contains arsenic or any other contaminant (e.g., chromium) above the TC, the waste

residuals must be disposed in a designated and licensed hazardous waste landfill. These landfills are strictly regulated under RCRA and have extensive monitoring and operational guidelines. As such, the costs of disposal are relatively high. As with municipal solid waste landfill disposal, waste sludges must not contain free liquid residuals.

A critical element of hazardous waste disposal is the cradle-to-grave concept. The party responsible for generating the hazardous waste retains liability and responsibility for the fate and transport of the waste.

Direct Discharge to Surface Waters

Direct discharge refers to the disposal of liquid waste streams to nearby surface waters, which act to dilute and disperse the waste by-products. The primary advantage of direct discharge is reduced capital and operations and maintenance (O&M) costs due to the elimination of residuals treatment. The feasibility of this disposal method is subject to provisions of the National Pollution Discharge Elimination System (NPDES) and state anti-degradation regulation. The allowable discharge is a function of the ability of the receiving water to assimilate the arsenic without exceeding water quality criteria established under the Clean Water Act (CWA) or state regulation. Different water quality criteria exist depending on the classification of the receiving water. For specific NPDES conditions and limits, the appropriate NPDES permitting agency should be contacted, because the conditions and limits can vary according to the receiving stream's particular characteristics.

Indirect Discharge

The discharge of liquid waste streams to a POTW is a potential disposal alternative. In this case, the waste stream will be subject to TBLLs established regionally by sewer authorities as part of the POTW's Industrial Pretreatment Program. TBLLs are established in order to protect POTW operation, assure compliance with NPDES permits, and prevent an unacceptable level of accumulation of contaminants in the process sludge and biosolids. The arsenic limit is usually on the order of 0.05 to 0.1 mg/L. The TBLLs are computed for each POTW to take into account the background levels of contaminants in the municipal wastewater. The background level will change because of the drinking water treatment process, which may lead to revised TBLLs. The revised TBLL would be used to determine if the liquid waste stream could be discharged to the POTW.

Land Application

Land application of concentrated sludge may be allowed under certain conditions depending on the state law and regulations. Some states do not allow land application of solid residuals. Sewage sludge (also called "biosolids") containing <41 mg As/kg biosolids can be land-applied with no restrictions. Biosolids with arsenic concentrations between 41 and 75 mg/kg can be land-applied, but must track arsenic accumulation. The lifetime arsenic accumulation limit is 41 kg As per hectare of land. Federal part 503 land application limits are only applicable in states that have adopted these limits for water plant residuals or in cases where these residuals are mixed with sewage sludge.

On-Site Sewerage

Liquid waste streams from RO POU devices should be suitable for disposal in an on-site sewerage or septic system. Figure 1-2 illustrates a typical flow diagram for RO POU water treatment and on-site waste disposal.

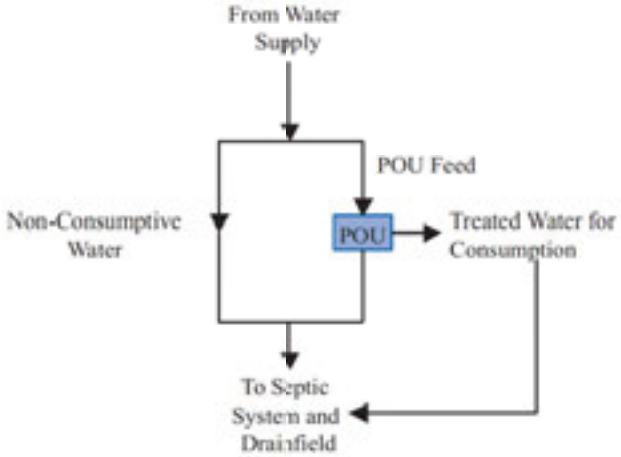

Figure 1-2. Flow Diagram for RO POU.

Arsenic is concentrated in the RO retentate during normal process operation. However, eventually this retentate is combined with other domestic wastewater in the septic tank. Because the amount of water consumed is small relative to the total flow entering the dwelling, the concentration of arsenic in the *blended* wastewater is nearly identical to that in the influent stream.

1.4 Arsenic Chemistry

Arsenic is introduced into the aquatic environment from both natural and manmade sources. Typically, however, arsenic occurrence in water is caused by the weathering and dissolution of arsenic-bearing rocks, minerals, and ores. Although arsenic exists in both organic and inorganic forms, the inorganic forms are more prevalent in water and are considered more toxic. Therefore, the focus of this Handbook is on inorganic arsenic.

Total inorganic arsenic is the sum of particulate and soluble arsenic. A 0.45-micron filter can generally remove particulate arsenic.

Soluble, inorganic arsenic exists in either one of two valence states depending on local oxidation-reduction conditions. Typically groundwater has anoxic conditions and arsenic is found in its arsenite or reduced trivalent form [As(III)]. Surface water generally has aerobic conditions and arsenic is found in its arsenate or oxidized pentavalent form [As(V)].

Both arsenite and arsenate exist in four different species. The speciation of these molecules changes by dissociation and is pH dependent. The kinetics of dissociation for each are nearly instantaneous. The pH dependencies of arsenite and arsenate are depicted in Figure 1-3 and Figure 1-4, respec-

tively. The species shown in bold are those that are most likely to be removed by the techniques discussed in this handbook.

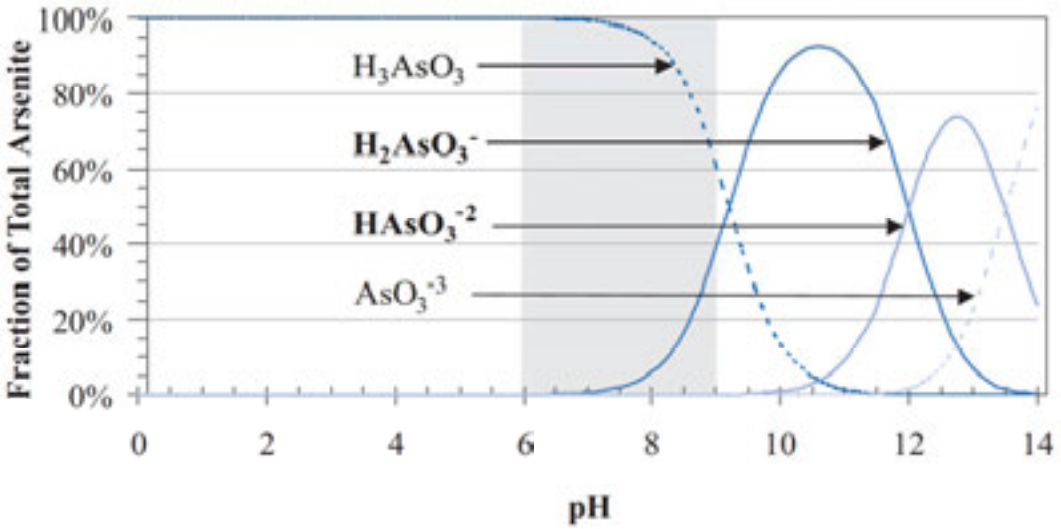

Figure 1-3. Dissociation of Arsenite [As(III)].

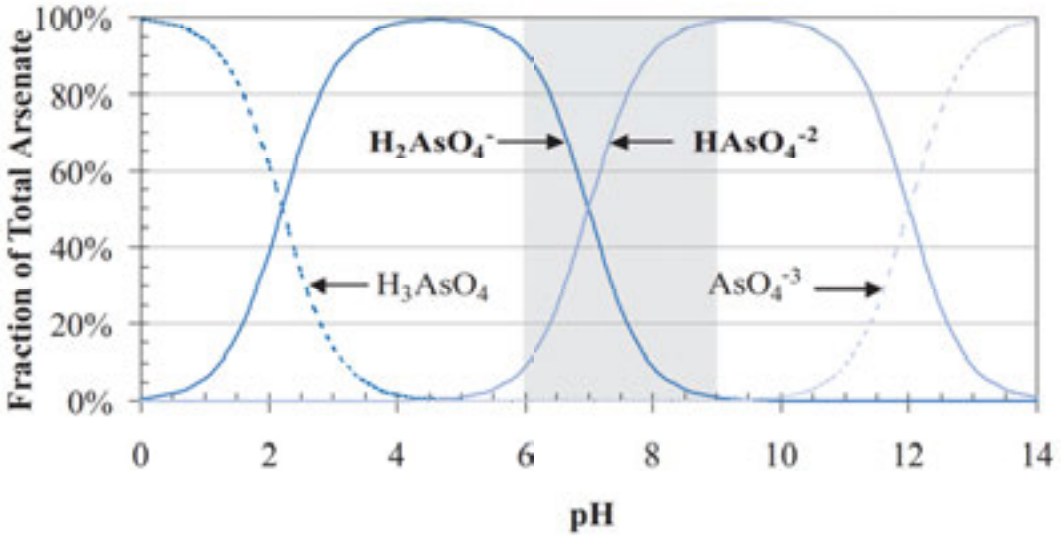

Figure 1-4. Dissociation of Arsenate [As(V)].

Chemical speciation is a critical element of arsenic treatability. Negative surface charges facilitate removal by adsorption, anion exchange, and co-precipitative processes. Since the net charge of arsenite [As(III)] is neutral at natural pH levels (6-9), this form is not easily removed. However, the net molecular charge of arsenate [As(V)] is negative (-1 or -2) at natural pH levels, enabling it to be removed with greater efficiency. Conversion to As(V) is a critical element of most arsenic treatment processes. This conversion can be accomplished by adding an oxidizing agent such as chlorine or permanganate. Selection of the most appropriate oxidation technology should be based on several considerations, including cost, integration with existing treatment, disinfection requirements, and secondary effects. This is discussed further in Section 2.2.

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Section 2
Arsenic Mitigation Strategies

2.1 Description of Arsenic Mitigation Strategies

Problematic arsenic levels in drinking water can be mitigated in several different ways. This Handbook will address the following mitigation strategies:

- Abandonment - The total abandonment of the problematic source(s) and subsequent switch to other source(s) within the system or purchase from a neighboring system.
- Seasonal Use - Switching the problematic source(s) from full-time used to seasonal or peaking use only with subsequent blending with other full-time source(s).
- Blending - The combination of multiple water sources to produce a stream with an arsenic concentration below the MCL.
- Sidestream Treatment - The treatment of a portion of the high arsenic water stream and subsequent blending back with the untreated portion of the stream to produce water that meets the MCL.
- Treatment – The processing of all or part of a water stream to reduce the arsenic concentration to below the MCL.
  - Wellhead Treatment – Treatment is located at the wellhead location before the water is mixed with water from other sources.
  - Centralized Treatment – Water from several sources is piped to a centralized location for treatment before the water enters the distribution system.
  - POU Treatment – Treatment devices are located at the Point-Of-Use within the building or home and treat only the water intended for direct consumption, typically at a single tap.

There are three primary categories of available treatment processes.

- Sorption Treatment Processes
  - IX [2]
  - AA [2,3]
  - Iron Based Sorbents (IBS)[4]
- Membrane Treatment Processes
  - RO [2,3]
  - Precipitation/Filtration Processes

[2] Technologies that have been designated as small system compliance technologies (SSCT) for centralized or wellhead treatment.

[3] Technologies that have been designated as SSCT for POU treatment.

[4] Due to limited performance research at the time the rule was promulgated, IBS was not designated as a BAT or a SSCT by the USEPA.

- Enhanced Conventional Gravity Coagulation/Filtration [2 above]
- CMF [2 above]
- Coagulation-Assisted Direct Filtration (CADF) [2 above]
- Oxidation/Filtration [2 above]
- Enhanced Lime Softening [2 above]

The selection of the most appropriate mitigation strategy should be based on feasibility issues, system constraints, and costs.

2.1.1 Abandonment

Perhaps the simplest approach for remedying a high arsenic source is abandonment of the high arsenic water source and procurement of a new source that meets the arsenic MCL. This option is most realistic for utilities with multiple water sources where at least one source can be relied upon for producing water with arsenic below the MCL. There may, however, be other constraints to switching primary sources, such as inadequate treatment capacity or water rights. Many small systems do not have the flexibility to switch to a source with a lower arsenic concentration. In this particular case, the utility has two options: (1) locate or install a new source, or (2) purchase water from a nearby system if an interconnection exists. New source installations may or may not be more costly than treatment. It should also be noted that drilling a new source may not be the best option if the aquifer has consistently high levels of arsenic. The utility should check with other systems in the area before drilling.

2.1.2 Seasonal Use

Another option is to switch a high arsenic water source from full-time production to seasonal or peaking use only. When used, it would be blended with low arsenic water sources before entry to the distribution system. This is allowed at the federal level, as long as the running annual average at the entry point to the distribution system does not exceed the MCL. Individual state requirements may preclude this option.

The running annual average can be calculated by adding the four most recent quarterly arsenic concentrations together and dividing by 4 as seen in the following equation.

$$C_{RAA} = \frac{C_1 + C_2 + C_3 + C_4}{4} \qquad \text{Eqn. 2-1}$$

Where:

C_{RAA} = Running Annual Average Arsenic Concentration Entering System,
C_1 = Arsenic Concentration Entering System During the Quarter 1,
C_2 = Arsenic Concentration Entering System During the Quarter 2,
C_3 = Arsenic Concentration Entering System During the Quarter 3, and
C_4 = Arsenic Concentration Entering System During the Quarter 4.

An example of this is shown in Figure 2-1. Well 1 is the only source for the first and second quarters of year and has an arsenic concentration of 0.003 mg/L. Well 2 is used in conjunction with Well 1 for the third and fourth quarters of the year and the combined output from Wells 1 and 2 has an arsenic concentraticn of 0.014 mg/L. The running annual average is calculated below as 0.009 mg/L and complies with the federal Arsenic Rule.

$$C_{RAA} = \frac{0.003 + 0.003 + 0.014 + 0.014}{4} = 0.0085 \text{ mg/L} \quad \Rightarrow \quad 0.009 \text{ mg/L}$$

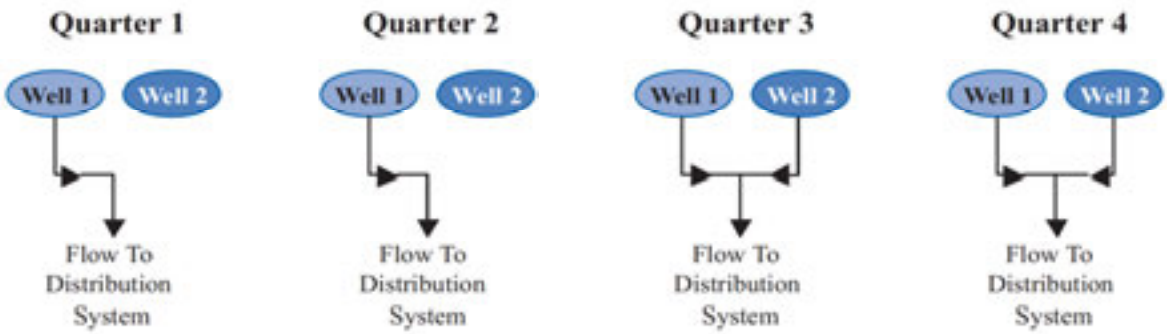

Figure 2-1. Example of Seasonal High Arsenic Source Use.

2.1.3 Blending

The revised arsenic MCL must be met at all entry points to the distribution system. Therefore, blending is a viable mitigation strategy for conservative inorganic substances and should be considered by systems that utilize multiple sources. Blending involves mixing waters from two or more different sources prior to entering the distribution system. The purpose of blending is to eliminate the need for treatment.

Stand-alone blending shown in Figure 2-2 is only a consideration when a water system has multiple sources, one (or more) with arsenic levels above the MCL, and one (or more) with arsenic levels below the MCL. Also, the wells with low arsenic levels must be reliable on a continuous basis.

Each stream in the blending process shcuild have a flow measurement to insure that the streams are blended in a ratio that produces an arsenic concentration that meets the MCL requirement. Flow measurement is shown in the following figure and an "F" inscribed in a circle.

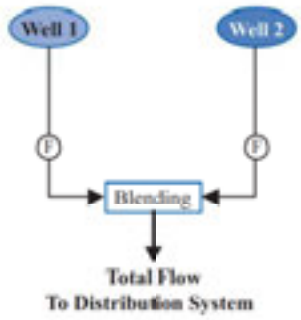

Figure 2-2. Blending.

The concentration of the blended stream ($C_{As,B}$) can be calculated using the following formula.

$$C_{As,B} = \frac{Q_1 \cdot C_{As,1} + Q_2 \cdot C_{As,2}}{Q_1 + Q_2} \qquad \text{Eqn. 2-2}$$

Where:

$C_{As,B}$ = Arsenic Concentration of Blended Stream (mg/L),
$C_{As,1}$ = Arsenic Concentration of Well 1 (mg/L),
$C_{As,2}$ = Arsenic Concentration of Well 2 (mg/L),
Q_1 = Flowrate of Well 1 (gpm), and
Q_2 = Flowrate of Well 2 (gpm).

For example, suppose that water from Wells 1 and 2 in Figure 2-2 contain arsenic concentrations of 0.015 mg/L and 0.006 mg/L, respectively, with flowrates of 700 gpm and 2,450 gpm, respectively. The blended stream's arsenic concentration will then be 0.008 mg/L, which meets the MCL, and is calculated as follows:

$$C_{As,B} = \frac{700\ \text{gpm} \cdot 0.015\ \text{mg/L} + 2{,}450\ \text{gpm} \cdot 0.006\ \text{mg/L}}{700\ \text{gpm} + 2{,}450\ \text{gpm}} = 0.008\ \text{mg/L}$$

The following equation can be used to determine the required flowrate from the low arsenic source (Q2) that, when blended with flow from the high arsenic source (Q1), will produce water with an arsenic concentration a safe margin below the MCL.

$$Q_2 = Q_1 \cdot \left(\frac{[1-\sigma] \cdot C_{MCL} - C_{As,1}}{C_{As,2} - [1-\sigma] \cdot C_{MCL}} \right) \qquad \text{Eqn. 2-3}$$

Where:

Q_1 = Flowrate of Well 1 (gpm) {high arsenic source},
Q_2 = Flowrate of Well 2 (gpm) {low arsenic source},
$C_{As,1}$ = Arsenic Concentration of Well 1 (mg/L) {high arsenic source},
$C_{As,2}$ = Arsenic Concentration of Well 2 (mg/L) {low arsenic source},
C_{MCL} = Arsenic MCL (mg/L), and
s = Safety Margin (% expressed as a decimal).

For example, suppose that water from Wells 1 and 2 in Figure 2-2 contain arsenic concentrations of 0.015 mg/L and 0.006 mg/L, respectively. Assuming that the utility wants to provide a 20% safety margin (i.e., produce water with 0.008 mg/L of arsenic) and the maximum flowrate from Well 1 is 700 gpm, the minimum required flowrate from Well 2 is 2,450 gpm and is calculated as follows:

$$Q_2 = 700\ \text{gpm} \cdot \left(\frac{[1-0.2] \cdot 0.010\ \text{mg/L} - 0.015\ \text{mg/L}}{0.006\ \text{mg/L} - [1-0.2] \cdot 0.010\ \text{mg/L}} \right) = 2{,}450\ \text{gpm}$$

2.1.4 Treatment

If a treatment method is used to mitigate the arsenic problem from multiple sources, the utility will need to decide between wellhead treatment and centralized treatment. Wellhead treatment treats the water from each well at or near the wellhead. For systems with multiple wells, this could result in multiple treatment facilities. If possible, piping high arsenic water from multiple sources to a single, centralized treatment facility may be more economical. Some factors to take into account would be:

- the proximity of wells to be treated to each other,
- feasibility of piping the sources to a central location,
- availability of land and power at the treatment site(s), and
- labor requirements for multiple sites rather than a single site.

Some treatment processes (e.g., RO) may have significant water losses associated with them. Water loss is incoming water that does not exit the system as treated water. Water losses frequently occur as a stream used to dispose of waste. Typical treatment efficiencies and water losses for processes operated under normal conditions are provided in Table 2-1.

Table 2-1. Typical Treatment Efficiencies and Water Losses.		
Treatment	**As(V) Removal Efficiency**	**Water Loss**
Sorption Processes		
Ion Exchange	95% [1]	1-2%
Activated Alumina (Throw-Away Media)	95% [1]	1-2%
Iron Based Sorbents	Up to 98% [1]	1-2%
Iron and Manganese Removal Processes		
Oxidation/Filtration (Greensand)	50-90% [2]	≤2%
Membrane Processes		
Reverse Osmosis	>95% [1]	15-50% [1]
Precipitative Processes		
Coagulation Assisted Microfiltration	90% [1]	5%
Enhanced Coagulation/Filtration		
With Alum	<90% [1]	1-2%
With Ferric Chloride	95% [1]	
Enhanced Lime Softening	90% [1]	1-2%

[1] USEPA, 2000.

[2] Depends on arsenic and iron concentrations

2.1.5 Sidestream Treatment

The treatment and blending strategies can be combined in a variety of ways as illustrated in Figure 2-3 through Figure 2-5.

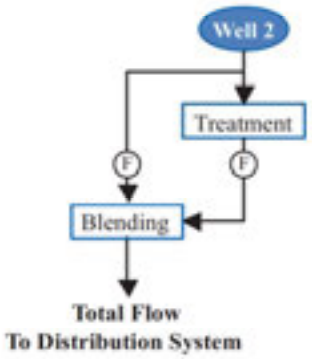

Figure 2-3. Sidestream Treatment.

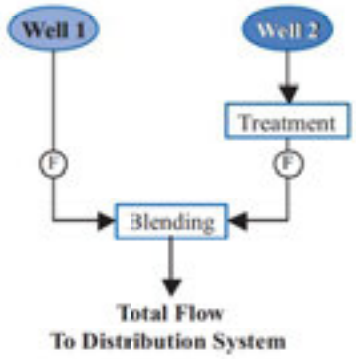

Figure 2-4. Treatment and Blending.

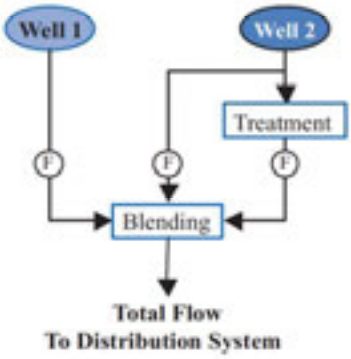

Figure 2-5. Sidestream Treatment and Blending.

Sidestream treatment, Figure 2-3, involves splitting the source flow, treating one stream, and then blending it with the untreated stream prior to distribution. Sidestream treatment is feasible when a water source exceeds the revised MCL by a relatively small margin. This approach is viable because most arsenic treatment processes (operated under optimal conditions) can achieve at least 80% arsenic removal and, in many cases, this high level of

performance is not needed to meet the MCL. Any utility considering treatment should consider sidestream treatment as a method to reduce the overall level and cost of the treatment required.

In the simple case of sidestream treatment from a single source, as in Figure 2-6, the flowrate of the split stream requiring treatment can be calculated using Equation 2-4. If the treatment process is RO, as in Figure 2-7, the flowrate of the split stream requiring treatment can be calculated using Equation 2-5. RO requires a more complex equation because RO has a continuous stream of water lost during operation and this water is not available for blending. In all the other treatments, when the water loss occurs (e.g., the backwash of a column or filter) no treated water is available for blending so no blending occurs. (Under these circumstances, the untreated water flow to the distribution is also halted.) For all the treatment methods, the resulting blended treated flowrate can be calculated using Equation 2-6.

$$Q_S = Q_1 \left(\frac{C_1 - (1-\sigma) \cdot C_{MCL}}{\varepsilon C_1} \right) \qquad \text{Eqn. 2-4}$$

$$Q_S = Q_1 \left(\frac{C_1 - (1-\sigma) \cdot C_{MCL}}{C_1 [1 - (1-\omega)(1-\varepsilon)] - \omega \cdot (1-\sigma) \cdot C_{MCL}} \right) \qquad \text{Eqn. 2-5}$$

$$Q_B = Q_1 - \omega Q_S \qquad \text{Eqn. 2-6}$$

The variable for the equations are:

Q_S = Flowrate to Split Off for Treatment (gpm),
Q_B = Flowrate of the Final Blended Stream (gpm),
Q_1 = Source 1 Flowrate (gpm),
C_1 = Arsenic Concentration of the Source (mg/L),
C_{MCL} = Arsenic MCL (mg/L),
σ = Safety Margin (% expressed as a decimal),
ω = Treatment Water Loss (% expressed as a decimal), and
ε = Arsenic Rejection Rate (% expressed as a decimal).

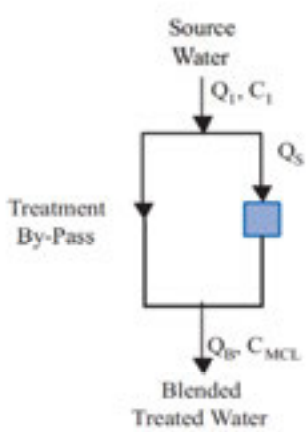

Figure 2-6. Sidestream Treatment.

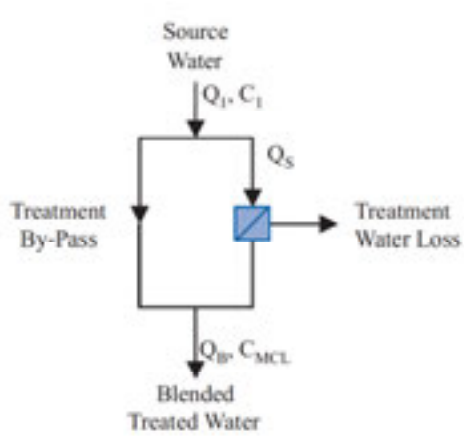

Figure 2-7. Sidestream Treatment for RO.

For example, suppose a water utility operates a single well at a maximum flowrate (Q_1) of 500 gpm. The well water contains (C_1) 0 012 mg/L of arsenic. Further, assume that utility wants to provide a 20% safety margin (σ) on the arsenic MCL (C_{MCL}) of 0.010 mg/L (i.e., produce water with 0.008 mg/L of arsenic). The utility has selected a RO process that has demonstrated an arsenic removal efficiency (ε) of 95% at a water loss (ω) of 40%. Using Equation 2-5, 237 gpm of the well's flow (or approximately 47%) should be split and sent to the RO treatment unit. The final (blended) flowrate is 405 gpm, as determined using Equation 26.

$$Q_S = (500\ \text{gpm}) \cdot \left(\frac{0.012\,\text{mg/L} - [1-0.2] \cdot 0.010\,\text{mg/L}}{0.012\,\text{mg/L}\,[1-(1-0.4)(1-0.95)] - 0.4 \cdot [1-0.2] \cdot 0.010\,\text{mg/L}} \right) = 237\ \text{gpm}$$

$$Q_B = (500\,\text{gpm}) - 0.4 \cdot (237\ \text{gpm}) = 405\ \text{gpm}$$

2.2 Pre-Oxidation Processes

Reduced inorganic As(III) (arsenite) should be converted to As(V) (arsenate) to facilitate removal. **This step is critical for achieving optimal performance of all unit processes described in this Handbook.** Conversion to As(V) can be accomplished by providing an oxidizing agent at the head of any proposed arsenic removal process. Chlorine, permanganate, ozone, and Filox-R™ [5] are highly effective for this purpose. Chlorine dioxide and monochloramine are ineffective in oxidizing As(III). Ultraviolet (UV) light, by itself, is also ineffective. However, if the water is spiked with sulfite, UV photo-oxidation shows promise for As(III) conversion (Ghurye and Clifford, 2001). Based on these considerations, only chlorine, permanganate, ozone, and Filox-R™ are discussed further in this Handbook.

Table 2-2 provides a summary of the benefits and drawbacks associated with the use of several oxidation technologies. The choice of oxidation method should be based primarily on the arsenic treatment technology to be employed (as described in Section 3), and secondarily on factors provided in Table 2-2. Many small water systems employ chlorine disinfection, either alone or as part of a larger treatment process. In most of these instances, the existing chlorination process can be optimized to provide concurrent As(III) oxidation.

[5] Filox is a registered trademark of Matt-Son, Inc., Barrington, IL. Filox-R is a trademark of Matt-Son, Inc., Barrington, IL.

Table 2-2. Comparison of Oxidizing Agents.

Oxidant	Benefits	Drawbacks
Chlorine	• Low relative cost ($0.50/lb.) • Primary disinfection capability • Secondary disinfectant residual • MnO_2 media regenerant • Oxidizes arsenic in less than 1 minute	• Formation of disinfection by-products • Membrane fouling • Special handling and storage requirements
Permanganate	• Unreactive with membranes • No formation of disinfection by-products • MnO_2 media regenerant? • Oxidizes arsenic in less than 1 minute	• High relative cost ($1.35/lb.) • No primary disinfection capability • Formation of MnO_2 particulates • Pink Water • Difficult to handle • An additional oxidant may be required for secondary disinfection
Ozone	• No chemical storage or handling required • Primary disinfection capability • No chemical by-products left in water • Oxidizes arsenic in less than 1 minute in the absence of interfering reductants	• Sulfide and TOC interfere with conversion and increase the required contact time and ozone dose for oxidation • An additional oxidant may be required for secondary disinfection
Solid Phase Oxidants (Filox R™)	• No chemical storage or handling required • No chemical by-products left in water • Oxidizes arsenic with an EBCT of 1.5 minutes in the absence of interfering reductants	• Backwashing required • Backwash waste is generated • Requires dissolved oxygen to work • No primary disinfection capability • An additional oxidant may be required for secondary disinfection • Iron, manganese, sulfide, and TOC increase the contact time and dissolved oxygen concentration required for oxidation

2.2.1 Chlorine

Issues associated with pre-chlorination are: (1) sensitivity of the treatment process to chlorine; (2) disinfection by-product (DBP) formation potential; (3) code requirements associated with chemical storage and handling; and (4) operator safety. Chlorine can be added either as a gas or as liquid hypochlorite, although chlorine gas may not be appropriate for small systems. For new chlorine feed installations, these alternatives should be evaluated with respect to capital and operating costs, O&M requirements, code restrictions, containment requirements, footprint, and safety concerns, among other issues. Gas feed is typically conducted with either 150-pound cylinders or 2,000-pound (1-ton) containers, depending on the rate of chlorine consumption. Small systems normally use the 150-pound cylinders. Liquid hypochlorite can either be generated on-site (0.8% strength), or purchased as commercial strength (5¼ or 12½%) liquid hypochlorite.

The stoichiometric oxidant demand is 0.95 mg of chlorine (as Cl_2) per mg of As(III). The oxidation-reduction reaction for chlorine (as hypochlorite) is provided in the following equation.

$$H_3AsO_3 + OCl^- \rightarrow H_2AsO_4^- + H^+ + Cl^- \qquad \text{Eqn. 2-7}$$

The ability of chlorine to convert As(III) to As(V) was found to be relatively independent of pH in the range 6.3 – 8.3. Based on laboratory oxidation studies (Ghurye and Clifford, 2001), chlorine applied in a stoichiometric excess of 3 times was capable of converting over 95% of As(III) to As(V) within 42 seconds. Dissolved iron, manganese, and total organic carbon (TOC) had no significant effects on the conversion time. However, sulfide in 1 and 2 mg/L concentrations increased the conversion time to 60 seconds.

The stoichiometric oxidant demands and the oxidation-reduction reactions for chlorine (as hypochlorite) to oxidize iron, manganese, and sulfide are provided below.

Stoichiometric ratio for oxidation of Fe(II) is 0.64 mg Cl_2 per mg Fe^{2+}.

$$2Fe^{2+} + OCl^- + 5H_2O \rightarrow 2Fe(OH)_3 + Cl^- + 4H^+ \qquad \text{Eqn. 2-8}$$

Stoichiometric ratio for oxidation of Mn(II) is 1.29 mg Cl_2 per mg Mn^{2+}.

$$Mn^{2+} + OCl^- + H^2O \rightarrow MnO_2 + Cl^- + 2H^+ \qquad \text{Eqn. 2-9}$$

Stoichiometric ratio for oxidation of sulfide is 2.21 mg Cl_2 per mg HS^-.

$$HS^- + OCl^- \rightarrow S^0 + Cl^- + OH^- \qquad \text{Eqn. 2-10}$$

Information on the design of a chlorination system can be found in Section 5.1, *Chlorine Pre-Oxidation Design Considerations*.

2.2.2 Permanganate

Permanganate is a powerful oxidizing agent that is commonly used in iron and manganese removal processes. Potassium permanganate exists in solid, granular form and is readily soluble in water (60 g/L at room temperature). Most applications involve metering of a permanganate solution.

The stoichiometric oxidant demand is 1.06 mg of permanganate per mg of As(III). The oxidation-reduction reaction for permanganate is provided in the following equation.

$$3H_3AsO_3 + 2MnO_4^- \rightarrow 3H_2AsO_4^- + H^+ + 2MnO_2 + H_2O \qquad \text{Eqn. 2-11}$$

The ability of permanganate to convert As(III) to As(V) was found to be relatively independent of pH in the range 6.3 – 8.3. Based on laboratory oxidation studies (Ghurye and

Clifford, 2001), permanganate applied in a stoichiometric excess of 3 times was capable of converting over 95% of As(III) to As(V) within 36 seconds. Dissolved iron, manganese, and TOC had no significant effects on the conversion time. However, sulfide in 1 and 2 mg/L concentrations increased the conversion time to 54 seconds.

The stoichiometric oxidant demands and the oxidation-reduction reactions for permanganate to oxidize iron, manganese, and sulfide are provided below.

Stoichiometric ratio for the oxidation of Fe(II) is 0.71 mg MnO_4^- per mg Fe^{2+}.

$$3Fe^{2+} + MnO_4^- + 7H_2O \rightarrow 3Fe(OH)_3 + MnO_2 + 5H^+ \qquad \text{Eqn. 2-12}$$

Stoichiometric ratio for oxidation of Mn(II) is 1.44 mg MnO_4^- per mg Mn^{2+}.

$$3Mn^{2+} + 2MnO_4^- + 2H_2O \rightarrow 5MnO_2 + 4H^+ \qquad \text{Eqn. 2-13}$$

Stoichiometric ratio for oxidation of sulfide is 2.48 mg MnO_4^- per mg HS^-.

$$3HS^- + 2MnO_4^- + 5H^+ \rightarrow 3S^0 + 2MnO_2 + 4H_2O \qquad \text{Eqn. 2-14}$$

The use of permanganate has several disadvantages.

Firstly, it is difficult to handle. It comes as a powder, is very corrosive, and stains nearly everything purple. The second drawback is the formation of manganese particulates (MnO_2). To prevent the accumulation of these deposits in the distribution system, they must be removed via filtration. A third drawback is that, because permanganate is not used as a secondary disinfectant, another oxidant may be required for secondary disinfection. Additionally, if a secondary disinfectant is not used in the distribution system when a POU treatment strategy is implemented, anoxic conditions could develop in the distribution system causing the As(V) to reduce back to As(III). This would decrease the effectiveness of the POU devices and increase the cost of the treatment.

Information on the design of a permanganate system can be found in Section 5.2, *Permanganate Pre-Oxidation Design Considerations*.

2.2.3 Ozone

Ozone is the most powerful and rapid-acting oxidizer produced. It is created by exposing oxygen, either in air or pure oxygen, to high energy such as an electric discharge field (i.e., corona discharge) or to UV radiation. This causes the oxygen molecules to react to form an unstable configuration of three oxygen atoms – the oxygen molecule contains only two. Because of its instability, ozone is very reactive and is a very efficient oxidant. The only by-product from oxidation with ozone is oxygen, which is dissolved in aqueous systems. But because of ozone's highly reactive nature, it will quickly self-react and revert back to oxygen if in high concentrations or not used within short periods of time. Therefore, if ozone is used as an oxidant, it must be produced on site.

The stoichiometric oxidant demand is 0.64 mg of ozone per mg of As(III). The oxidation-reduction reaction for ozone is provided in the following equation.

$$H_3AsO_3 + O_3 \rightarrow H_2AsO_4^- + H^+ + O_2 \qquad \text{Eqn. 2-15}$$

The ability of ozone to convert As(III) to As(V) was found to be relatively independent of pH in the range 6.3 – 8.3. Based on laboratory oxidation studies (Ghurye and Clifford, 2001), ozone applied in a stoichiometric excess of 3 times was capable of converting over 95% of As(III) to As(V) within 18 seconds. Dissolved iron, manganese, and TOC had no significant effects on the conversion time. However, sulfide in 1 and 2 mg/L concentrations increased the conversion time to 54 and 132 seconds, respectively.

The stoichiometric oxidant demands and the oxidation-reduction reactions for ozone to oxidize iron, manganese, and sulfide are provided below.

Stoichiometric ratio for the oxidation of Fe(II) is 0.43 mg O_3 per mg Fe^{2+}.

$$2Fe^{2+} + O_3 + 5H_2O \rightarrow 2Fe(OH)_3 + O_2 + 4H^+ \qquad \text{Eqn. 2-16}$$

Stoichiometric ratio for oxidation of Mn(II) is 0.88 mg O_3 per mg Mn^{2+}.

$$Mn^{2+} + O_3 + H_2O \rightarrow MnO_2 + O_2 + 2H^+ \qquad \text{Eqn. 2-17}$$

Stoichiometric ratio for oxidation of sulfide is 1.50 mg O_3 per mg HS^-.

$$HS^- + O_3 + H^+ \rightarrow S^0 + O_2 + H_2O \qquad \text{Eqn. 2-18}$$

The primary drawback to the use of ozone is that, because ozone does not provide a secondary disinfectant, another oxidant may be required for secondary disinfection. Additionally, if a secondary disinfectant is not used in the distribution system when a POU treatment strategy is implemented, anoxic conditions could develop in the distribution system causing the As(V) to reduce back to As(III). This would decrease the effectiveness of the POU devices and increase the cost of the treatment.

Information on the design of an ozonation system can be found in Section 5.3, *Ozone Pre-Oxidation Design Considerations*.

2.2.4 Solid Phase Oxidants (Filox-R™)

Filox-R™ is a granular manganese dioxide media that can catalyze the oxidation of As(III) to As(V) (Ghurye and Clifford, 2001). This media catalytically oxidizes As(III) to As(V) using dissolved oxygen in the water. The Filox-R™ media also tends to adsorb some of the arsenic. New media can adsorb as much as 26% of the arsenic. Once the media's capacity is exhausted, the media will no longer remove arsenic but will continue to oxidize it.

The stoichiometric oxidant demand is 0.21 mg of oxygen per mg of As(III). The oxidation-reduction reaction for oxygen is provided in the following equation.

$$2H_3AsO_3 + O_{2(aq)} \rightarrow 2H_2AsO_4^- + 2H^+ \qquad \text{Eqn. 2-19}$$

Based on laboratory oxidation studies (Ghurye and Clifford, 2001) with an empty bed contact time (EBCT) of 1.5 minutes, Filox-R™ was capable of converting over 98.7% of As(III) to As(V). Decreasing the pH from 8.3 to 6.0 increased the conversion to 100%. Dissolved iron, manganese, hydrogen sulfide, and total organic carbon (TOC) were found to interfere with arsenic oxidation when the dissolved oxygen (DO) concentration was low (0.1 mg/L) and the EBCT was low (1.5 minutes). Either increasing the DO concentration (to 8.2 mg/L) or increasing the EBCT (to 6 minutes), eliminated the effects of these interfering reductants.

Filox-R™ also has the ability to remove iron, manganese, hydrogen sulfide. The stoichiometric oxidant demands and the oxidation-reduction reactions for oxygen to oxidize iron, manganese, and sulfide are provided below.

Stoichiometric ratio for the oxidation of Fe(II) is 0.43 mg O_2 per mg Fe^{2+}.

$$4Fe^{2+} + 3O_2 + 6H_2O + 2e^- \rightarrow 4Fe(OH)_3 \qquad \text{Eqn. 2-20}$$

Stoichiometric ratio for oxidation of Mn(II) is 0.58 mg O_2 per mg Mn^{2+}.

$$Mn^{2+} + O_2 + 2e- \rightarrow MnO_2 \qquad \text{Eqn. 2-21}$$

Stoichiometric ratio for oxidation of sulfide is 0.48 mg O_2 per mg HS^-.

$$2HS^- + O_2 + 2H^+ \rightarrow 2S^0 + 2H_2O \qquad \text{Eqn. 2-22}$$

The primary drawback to the use of a solid phase oxidant is that, because the solid phase oxidant does not provide a secondary disinfectant, another oxidant may be required for secondary disinfection. Additionally, if a secondary disinfectant is not used in the distribution system when a POU treatment strategy is implemented, anoxic conditions could develop in the distribution system causing the As(V) to reduce back to As(III). This would decrease the effectiveness of the POU devices and increase the cost of the treatment.

Information on the design of a solid phase oxidant system can be found in Section 5.4, *Solid Phase Oxidant Pre-Oxidation Design Considerations*.

2.3 Sorption Treatment Processes

The following three forms of sorption treatment are addressed: (1) ion exchange, (2) adsorption to AA media, and (3) adsorption on IBS media.

2.3.1 Ion Exchange

Ion exchange is a physical-chemical process in which ions are swapped between a solution phase and solid resin phase. The solid resin is typically an elastic three-dimensional hydrocarbon network containing a large number of ionizable groups electrostatically bound to the resin. These groups are exchanged for ions of similar charge in solution that have a stronger exchange affinity (i.e., selectivity) for the resin. In drinking water treatment, this technology is commonly used for POE softening and nitrate removal.

Arsenic removal is accomplished by continuously passing water under pressure through one or more columns packed with exchange resin. Figure 2-8 shows a typical process flow diagram for ion exchange. As(V) can be removed through the use of strong-base anion exchange resin (SBA) in either chloride or hydroxide form. These resins are insensitive to pH in the range 6.5 to 9.0 (USEPA, 2000; reference to Clifford et al., 1998). The following paragraphs discuss factors that affect IX system efficiency and economics.

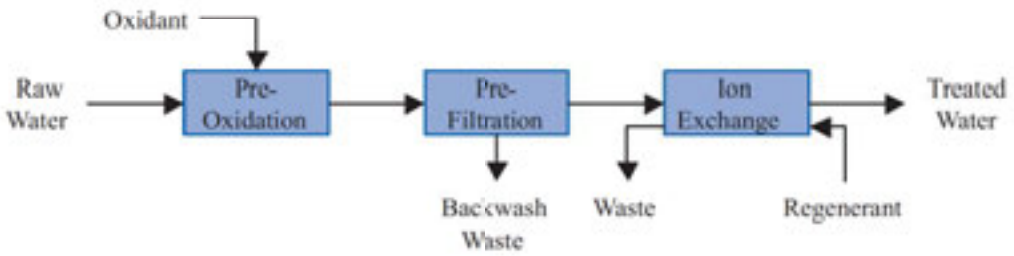

Figure 2-8. Ion Exchange Process Flow Diagram.

The exchange affinity of various ions is a function of the net surface charge. Therefore, the efficiency of the IX process for As(V) removal depends strongly on the solution pH and the concentration of other anions, most notably sulfates and nitrates. These and other anions compete for sites on the exchange resin according to the following selectivity sequence (Clifford, 1999).

$$SO_4^{2-} > \mathbf{HAsO_4^{2-}} > NO^{3-}, CO_3^{2-} > NO^{2-} > Cl^-$$

High levels of total dissolved solids (TDS) can adversely affect the performance of an IX system. In general, the IX process is not an economically viable treatment technology if source water contains over 500 mg/L of TDS (Wang et al., 2000) or over 50 mg/L of sulfate (SO42-) (Kempic, 2002). Figure 2-9 illustrates the effect of sulfate ions on the performance of IX media. Although this relationship will not be exactly the same for all waters, it does provide a general indication of the impact of sulfates on IX treatment. Additionally, small amounts of iron may form a soluble complex with arsenic and carry it out of the column.

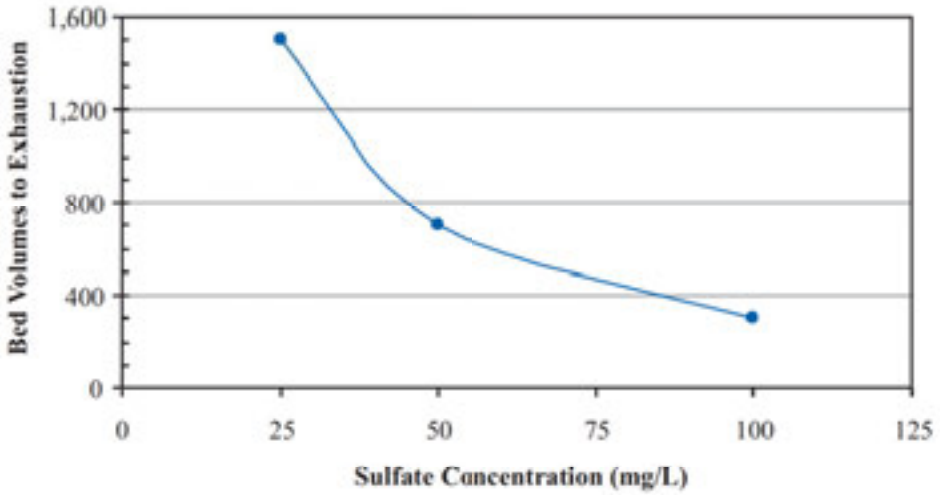

Figure 2-9. Effect of Sulfate on Ion Exchange Performance (Clifford, 1999).

One of the primary concerns related to IX treatment is the phenomenon known as chromatographic peaking, which can cause As(V) and nitrate levels in the treatment effluent to exceed those in the influent stream. This can occur if sulfates are present in the raw water and the bed is operated past exhaustion. Because sulfate is preferentially exchanged, incoming sulfate anions may displace previously sorbed As(V) and nitrate. In most groundwaters, sulfates are present in concentrations that are orders of magnitude greater than As(V). Therefore, the level of sulfates is one of the most critical factors to consider for determining the number of bed volumes that can be treated. A useful technique for avoiding chromatographic peaking is to perform careful monitoring of the effluent stream during startup. Then, based on the analysis, determine a setpoint for the total volume treated before breakthrough occurs. This volumetric setpoint would then be used to trigger the regeneration cycle. Regular monitoring of the column effluent should be continued to insure that loss of capacity in the media does not lead to premature breakthrough. Frequently, the volumetric setpoint is based on the breakthrough of sulfate. The kinetics of breakthrough are rapid; therefore a margin of safety should be provided or a guard column should be used in series with the IX column.

Hydraulic considerations associated with IX include empty bed contact time (EBCT) and headloss. The recommended EBCT range is 15 minutes. EBCTs as low as 1.5 minutes have been shown to work in some installations. The presence of suspended solids in the feed water could gradually plug the media, thereby increasing headloss and necessitating more frequent backwashing. Therefore, pre-filtration is recommended if the source water turbidity exceeds 0.3 NTU.

Another concern is resin fouling. Resin fouling occurs when mica or mineral-scale coat the resin or when ions bond the active sites and are not removable by the standard regeneration methods. This can have a significant effect on the resins capacity as the media becomes older. Replacement of the media or reconditioning may be needed after a number of years.

Resin that has been used to exhaustion can be regenerated on-site using a four-step process: (1) backwash, (2) regeneration with brine (for chloride-form SBA) or caustic soda (for hydroxide-form SBA), (3) slow water rinse, and (4) fast water rinse. It is recommended that small systems use the chloride-form resin due to the easier chemical handling considerations for regeneration.

Single-pass regeneration of anion exchange media typically produces 45 bed volumes of brine waste (USEPA, 2000; reference to AwwaRF, 1998). In a study conducted by the USEPA (Wang et al., 2000), dissolved arsenic concentrations in spent brine ranged from 1.83 mg/L to 38.5 mg/L, with an average value of 16.5 mg/L. It is anticipated that for most sources with arsenic levels above 0.010 mg/L and sulfate levels below 50 mg/L, the spent regenerant will contain at least 5.0 mg/L of dissolved arsenic.

Liquid waste streams (less than 0.5% solids) are evaluated directly against the TC to characterize hazard potential. Those liquid waste streams that contain more than 5.0 mg/L of arsenic would be classified as hazardous waste based on TC.

Indirect discharge may be an option since wastes that pass through a sewer system to a POTW are exempt from RCRA regulation. The critical factor dictating the feasibility of this option will be TBLLs for arsenic and TDS. The background level will change because of the drinking water treatment process, which may lead to revised TBLLs. The revised TBLL would be used to determine if the liquid waste stream could be discharged to the POTW. Water systems that elect to use brine recycle will further concentrate the dissolved arsenic and solids, making it even more unlikely that the stream will meet local TBLLs.

Because of RCRA requirements and cost implications, off-site disposal of hazardous waste or on-site treatment of waste is likely to be infeasible for small water systems.

Replacement of IX media may be required over time. Based on previous studies, spent IX resin does not exceed any TC concentrations, enabling it to be disposed of in a municipal solid waste landfill. This is true regardless of whether or not the media has been regenerated prior to conducting the TCLP.

Information on the design of an IX system can be found in Section 6, *Process Design Considerations*.

2.3.2 Activated Alumina

Activated alumina is a porous, granular material with ion exchange properties. The media, aluminum trioxide, is prepared through the dehydration of aluminum hydroxide at high temperatures. AA grains have a typical diameter of 0.3 to 0.6 mm and a high surface area for sorption.

In drinking water treatment, packed-bed AA adsorption is commonly used for removal of natural organic matter and fluoride. The removal of As(V) by AA adsorption can be accom-

plished by continuously passing water under pressure through one or more beds packed with AA media. Figure 2-10 shows a typical process flow diagram for ion exchange. Dashed lines and boxes indicate optional streams and processes. The efficiency and economics of the system are contingent upon several factors, as discussed in the following paragraphs.

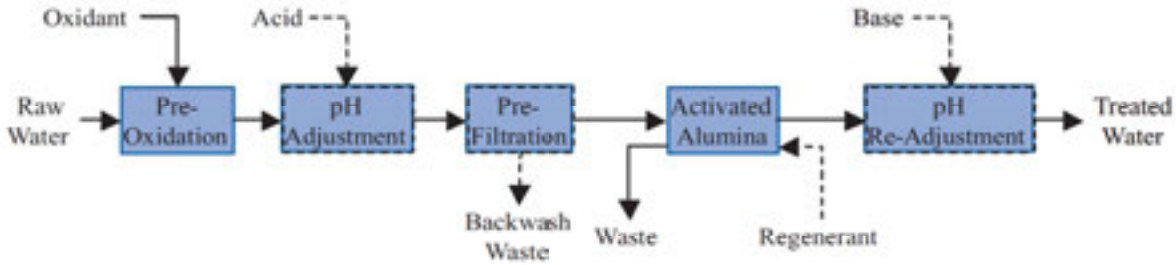

Figure 2-10. Activated Alumina Process Flow Diagram.

The level of competing ions affects the performance of AA for As(V) removal, although not in the same manner nor to the same extent as IX. The following selectivity sequence has been established for AA adsorption (USEPA, 2000):

$$OH^- > \mathbf{H_2AsO_4^-} > Si(OH)_3O^- > F^- > HSeO_3^- > TOC > SO_4^{2-} > H_3AsO_3$$

The selectivity of AA towards As(III) is poor, owing to the overall neutral molecular charge at pH levels below 9.2. Therefore, pre-oxidation of As(III) to As(V) is critical. Several different studies have established the optimum pH range as 5.5-6.0, and demonstrated greater than 98% arsenic removal under these conditions. AA column runs operated under acidic pH conditions are 5 to 20 times longer than under natural pH conditions (6.0-9.0), as depicted in Figure 2-11. However, many small utilities elect to conduct AA treatment under natural pH conditions. In these cases, the savings in capital and chemical costs required for pH adjustment and media regeneration offset the costs associated with decreased run length.

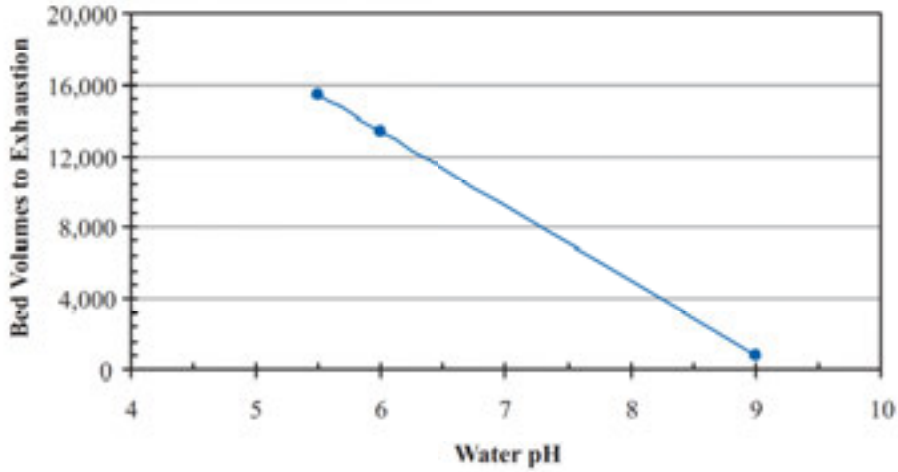

Figure 2-11. Effect of pH on Activated Alumina Performance (USEPA, 2000; original data from Hathaway and Rubel, 1987).

Several constituents can interfere with the adsorption process, either by competing for adsorption sites or clogging the media with particulate matter. These constituents, and their corresponding problematic levels, are summarized in Table 2-3.

Table 2-3. Water Quality Interferences with AA Adsorption.

Parameter	Problem Level
Chloride	250 mg/L [1]
Fluoride	2 mg/L [1]
Silica	30 mg/L [2]
Iron	0.5 mg/L [1]
Manganese	0.05 mg/L [1]
Sulfate	720 mg/L [3]
Dissolved Organic Carbon	4 mg/L [3]
Total Dissolved Solids	1,000 mg/L [3]

[1] AwwaRF (2002)
[2] Clifford (2001)
[3] Wang, et al. (2000)

Hydraulic considerations associated with AA adsorption include empty bed contact time and headloss. For most types of AA media, the recommended EBCT range is 310 minutes. The presence of suspended solids in the feed water could gradually clog the media, thereby increasing headloss. Pre-filtration is recommended for sources where the turbidity exceeds 0.3 NTU.

The technologies and market for alumina-based adsorptive media continue to expand. There are several emerging proprietary media, commonly referred to as modified AA, which contain alumina in a mixture with other substances such as iron and sulfur. In some instances, these media have greater overall adsorptive capacities, enhanced selectivity towards arsenic, and/or greater overall operational flexibility than conventional AA, thus making them more cost-effective. To account for this industry growth, the decision trees in Section 3 include a treatment alternative known as modified-AA. If this endpoint is reached, the water system should strongly consider more detailed investigation into current, innovative media. It is required by most states that all media used in water treatment be approved under NSF Standard 61.

AA media can either be regenerated on-site or disposed of and replaced with fresh media. On-site regeneration of AA media typically produces 37 to 47 bed volumes of caustic soda waste (USEPA, 2000). Because of the high pH of the regeneration process, roughly 2% of the AA media dissolves during each regeneration sequence. Therefore, the waste solution typically contains high levels of TDS, aluminum, and soluble arsenic. In most cases, this arsenic level will exceed the 5.0 mg/L TC, and the waste stream will be classified as a hazardous liquid waste. Backwashing may also be necessary to prevent cementation of the media, which can occur as a result of dissolution caused by chemical addition during regeneration. For these reasons, regeneration of AA is likely to be an infeasible option for most small water systems.

The alternative for utilities considering AA adsorption is the use of throwaway media, operated with or without pH adjustment. The savings in O&M requirements and residuals disposal may offset the cost of periodically replacing the media. For this option, systems must provide an equalization basin for backwash water (if applicable) and a staging area to store spent media prior to disposal. Throwaway AA media is expected to not exceed any TCs, enabling it to be disposed of in a municipal solid waste landfill (Wang et al., 2000). As an added convenience to small systems, media suppliers may offer a media disposal service with the purchase of their media.

Information on the design of an AA system can be found in Section 6, *Sorption Process Design Considerations*. Information on POU systems can be found in Section 8.1.1, *Adsoprtion Point-of-Use Treatment*.

2.3.3 Iron Based Sorbents

Adsorption on IBS is an emerging treatment technique for arsenic. Examples of IBS products currently available with NSF 61 approval are shown in Table 2-4. The sorption process has been described as chemisorption (Selvin et al., 2000), which is typically considered to be irreversible. It can be applied in fixed bed pressure columns, similar to those for AA. Due to limited performance research at the time the Arsenic Rule was promulgated, it was not designated as a BAT or a SSCT by the USEPA.

Table 2-4. Examples of Iron Based Sorbents. [1]

Product Name	Company	Material Type
G2	ADI International	Modified Iron
SMI III	SMI	Iron/Sulfur
GFH	U.S. Filter/General Filter Products	Granular Ferric Hydroxide
Bayoxide E 33	Bayer AG	Iron Oxide

[1] Examples are taken from Rubel 2003.

The few studies conducted with IBS media have revealed that the affinity of this media for arsenic is strong under natural pH conditions, relative to AA. This feature allows IBS to treat much higher bed volumes without the need for pH adjustment. However, similar to AA, optimal IBS performance is obtained at lower pH values. The recommended operating conditions include an EBCT of 5 minutes and a hydraulic loading rate of 5 gpm/sft.

Phosphate has been shown to compete aggressively with As(V) for adsorption sites. Each 0.5 mg/L increase in phosphate above 0.2 mg/L will reduce adsorption capacity by roughly 30% (Tumalo, 2002).

In previous studies, exhausted IBS media has not exceeded any TCs, enabling it to be disposed of in a municipal solid waste landfill (MacPhee et al., 2001). As an added convenience to small systems, media suppliers may offer a media disposal service with the purchase of their media.

Information on the design of IBS systems can be found in Section 6, *Sorption Process Design Considerations*. Information on POU systems can be found in Section 8.1.1, *Adsorption Point-of-Use Treatment*.

2.4 Membrane Treatment Processes

Membrane separation technologies are attractive arsenic treatment processes for small water systems. They can address numerous water quality problems while maintaining simplicity and ease of operation. The molecular weight cut-off of microfiltration (MF) processes necessitates the use of a coagulation stage to generate arsenic-laden floc and is therefore discussed in Section 2.5.3, *Coagulation-Assisted Microfiltration*. However, RO units have a much larger retention spectrum, and can be used as stand-alone arsenic treatment under most water quality conditions. Figure 2-12 provides a block flow diagram for a typical RO membrane process. Dashed lines indicate optional streams and processes.

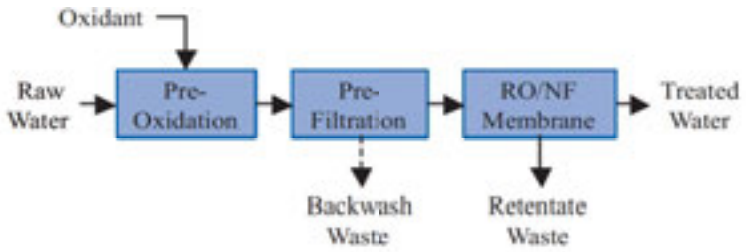

Figure 2-12. RO Membrane Process Flow Diagram.

Most RO membranes are made of cellulose acetate or polyamide composites cast into a thin film. The semi-permeable (non-porous) membrane is then constructed into a cartridge called an RO module, typically either hollow-fiber or spiral-wound.

RO is a pressure-driven membrane separation process capable of removing dissolved solutes from water by means of particle size, dielectric characteristics, and hydrophilicity/hydrophobicity. Reverse osmosis is capable of achieving over 97% removal of As(V) and 92% removal of As(III) in a single pass (NSF, 2001a; NSF 2001b). As an added benefit, RO also effectively removes several other constituents from water, including organic carbon, salts, dissolved minerals, and color. The treatment process is relatively insensitive to pH. In order to drive water across the membrane surface against natural osmotic pressure, feed water must be sufficiently pressurized with a booster pump. For drinking water treatment, typical operating pressures are between 100 and 350 psi. Water recovery is typically 60 –80%, depending on the desired purity of the treated water. In some cases, particularly POU applications, RO units are operated at tap water pressures. This results in a significantly lower water recovery.

Multiple RO units can be applied in series to improve the overall arsenic removal efficiency. Figure 2-13 illustrates a 2-stage RO treatment process. The overall rejection rate for a multi-staged RO treatment process can be calculated as:

$$E = 1-(1-E_S)^n \qquad \text{Eqn. 2-23}$$

Where:

E = Overall Rejection Rate (Treatment Efficiency),
E_S = Individual Stage Contaminant Rejection Rate, and
n = Number of Stages.

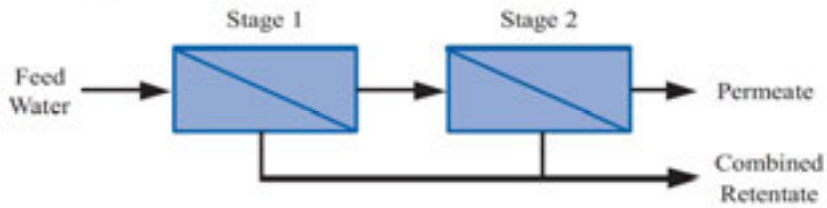

Figure 2-13. Two-Stage RO Treatment Process Schematic.

Membrane fouling can occur in the presence of NOM and various inorganic ions, most notably calcium, magnesium, silica, sulfate, chloride, and carbonate. These ions can be concentrated (in the retentate) to concentrations an order of magnitude higher than in raw water. This can lead to the formation of scale on the membrane surface, which in turn can cause a decline in arsenic rejection and water recovery. Further, the membrane surface can act as a substrate for biological growth. Membrane cleaning can restore treatment performance; however, the cleaning process is difficult and costly. The rate of membrane fouling depends on the configuration of the module and feed water quality. Most RO modules are designed for cross-flow filtration, which allows water to permeate the membrane while the retentate flow sweeps rejected salts away from the membrane surface. In many cases, pre-filtration (commonly through sand or granular activated carbon) is worthwhile. This minimizes the loading of salt precipitates and suspended solids on the membrane surface, thereby extending run length, improving system hydraulics, and reducing O&M requirements.

Some membranes, particularly those composed of polyamides, are sensitive to chlorine. Feed water should be dechlorinated (if applicable) in these instances. Another potential concern associated with RO treatment is the removal of alkalinity from water, which in turn could affect corrosion control within the distribution system. If feasible, this problem can usually be avoided by conducting sidestream treatment for arsenic removal.

Indirect discharge to a POTW or direct discharge to an on-site sewerage system (for POU systems) are considered the most viable residuals disposal option. For those systems considering indirect discharge, the retentate must meet local TBLLs for arsenic. The arsenic concentration in the retentate can be calculated using Equation 2-24.

$$C_{R,i} = \frac{C_i \cdot E_S}{1-\beta} \qquad \text{Eqn. 2-24}$$

Where:

$C_{R,i}$ = Concentration of Species *i* in the Retentate (mg/L),

C_i = Concentration of Species *i* in the Feed Stream (mg/L),

E_s = Individual Stage Contaminant Rejection Rate (% expressed as a decimal), and
β = Individual Stage Water Recovery Rate (% expressed as a decimal).

It is not anticipated that a small system will use an RO system for centralized treatment because RO systems for centralized treatment can be expensive. Therefore, no design information on centralized systems has been provided in this Handbook. However, information on RO POU systems can be found in Section 8.1.2, *Reverse Osmosis Point-of-Use Treatment*.

2.5 Precipitation/Filtration Treatment Processes

- The following four chemical precipitation processes are addressed:
- LS,
- Conventional Gravity Coagulation/Filtration,
- CMF,
- CADF, and
- Oxidation/Filtration.

Figure 2-14 provides a block flow diagram for a generic precipitation/filtration process. Dashed lines and boxes indicate optional streams and processes.

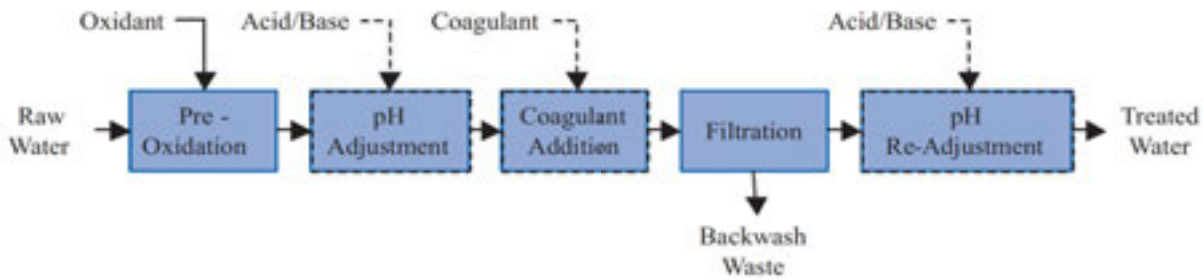

Figure 2-14. Generic Precipitation/Filtration Process Flow Diagram.

2.5.1 Enhanced Lime Softening

Lime softening is a chemical-physical treatment process used to remove calcium and magnesium cations from solution. The addition of lime increases the pH of solution, thereby causing a shift in the carbonate equilibrium and the formation of calcium carbonate and magnesium hydroxide precipitates. These precipitates are amenable to removal by clarification and filtration.

LS solely for arsenic removal is uneconomical and is generally considered cost-prohibitive. However, for water systems that use LS to reduce hardness, the process can be enhanced for arsenic removal. To remove As(V), additional lime is added to increase the pH above 10.5. In this range magnesium hydroxide precipitates and As(V) is removed by co-precipitation with it. As(V) removal by co-precipitation with calcium carbonate (i.e., below a pH of 10.5) is poor (less than 10%).

The amount of waste residual produced by LS is dependent on the hardness removed. While the total volume of waste produced from LS is typically higher than that produced by coagulation/filtration and co-precipitative processes, the arsenic concentration in the sludge is generally lower because more solids are produced. Typical solids concentrations are 1 - 4% arsenic. Prior to disposal, this waste residual will require thickening and dewatering, most likely via mechanical devices. Previous studies have indicated that typical lime sludge will not exceed TC limits, enabling it to be disposed of in a municipal solid waste landfill (Fields et al., 2000a).

Because LS is unlikely to be installed solely for arsenic removal in small systems, no design discussion is provided in this Handbook.

2.5.2 Conventional Gravity Coagulation/Filtration

Coagulation is the process of destabilizing the surface charges of colloidal and suspended matter to allow for the agglomeration of particles. This process results in the formation of large, dense floc, which is amenable to removal by clarification or filtration. The most widely used coagulants for water treatment are aluminum and ferric salts, which hydrolyze to form aluminum and iron hydroxide particulates, respectively.

Conventional gravity coagulation/filtration processes use gravity to push water through a vertical bed of granular media that retains the floc and are typically used within surface water treatment plants. They are less commonly used for treatment of groundwater supplies since these sources usually contain much lower concentrations of suspended solids, organic carbon, and pathogenic microorganisms. Installation and operation of a conventional gravity coagulation/filtration process solely for arsenic removal is uneconomical.

Coagulation/filtration processes can be optimized to remove dissolved inorganic As(V) from water. The mechanism involves the adsorption of As(V) to an aluminum or ferric hydroxide precipitate. The As(V) becomes entrapped as the particle continues to agglomerate. As(III) is not effectively removed because of its overall neutral charge under natural pH conditions. Therefore, pre-oxidation is recommended. The efficiency and economics of the system are contingent upon several factors, including the type and dosage of coagulant, mixing intensity, and pH. In general, however, optimized coagulation-filtration systems are capable of achieving over 90% removal of As(V) and producing water with less than 0.005 mg/L of As(V). Influent As(V) levels do not appear to impact the effectiveness of this treatment process.

Iron-based coagulants, including ferric sulfate and ferric chloride, are more effective at removing As(V) than their aluminum-based counterparts. This is because iron hydroxides are more stable than aluminum hydroxides in the pH range 5.5 to 8.5. A fraction of the aluminum remains as a soluble complex, which is incapable of adsorbing As(V) and can pass through the filtration stage. The optimal pH ranges for coagulation with aluminum and ferric salts are 5 to 7 and 5 to 8, respectively. At pH values above 7, the removal performance of aluminum-based coagulants drops markedly. Feed water pH should be adjusted

to the appropriate range prior to coagulant addition. Post-filtration pH adjustment may be necessary to optimize corrosion control and comply with other regulatory requirements.

Several batch studies have demonstrated that As(V) removal is positively related to coagulant dosage. However, specific dose requirements needed to meet As(V) removal objectives were contingent upon the source water quality and pH. Effective coagulant dosage ranges were 5-25 mg/L of ferric chloride and as much as 40 mg/L of alum.

Water intended for indirect discharge will be subject to TBLLs for TDS and arsenic. Dewatering can be accomplished by gravity thickening, followed by other mechanical or non-mechanical techniques. Settling basins can be used to allow settleable solids to drop out of solution via gravity, while the supernatant can be decanted and recycled to the process head. The solids can be slurried out periodically and passed through a small filter press for dewatering. The resultant sludge can be disposed of in a municipal solid waste landfill if it meets the criteria of the PFLT (no free liquid) and the TCLP. Previous studies have indicated that typical coagulation/filtration sludge will not exceed TC limits (Fields et al., 2000a).

Because conventional gravity coagulation filtration is unlikely to be installed solely for arsenic removal in small systems, no design discussion is provided in this Handbook.

2.5.3 Coagulation-Assisted Microfiltration

Coagulation-Assisted Microfiltration uses the same coagulation process described above. However, instead of the granular media filtration step, the water is forced through a semi-permeable membrane by a pressure differential. The membrane retains the As(V) laden floc formed in the coagulation step.

The use of pre-engineered CMF package plants is a realistic possibility for new installations where water quality precludes the use of sorption treatment. Due to limited full-scale application, it was not designated as a BAT by the USEPA but was listed as a SSCT in the final rule.

The membrane must be periodically backwashed to dislodge solids and restore hydraulic capacity. Backwash water is typically a high-volume, low solids (less than 1.0%) waste stream. The specific amount of solids will depend on several factors, including coagulant type, dosage, filter run length, and ambient solids concentration. Two treatment options are available for this waste stream: (1) indirect discharge, and (2) dewatering and sludge disposal (AwwaRF 2000).

Water intended for indirect discharge will be subject to TBLLs for TDS and arsenic. Dewatering can be accomplished by gravity thickening, followed by other mechanical or non-mechanical techniques. Settling basins can be used to allow settleable solids to drop out of solution via gravity, while the supernatant can be decanted and recycled to the process head. The solids can be slurried out periodically and passed through a small filter press for dewatering. The resultant sludge can be disposed of in a municipal solid waste landfill if it meets

the criteria of the PFLT (no free liquid) and the TCLP. Previous studies have indicated that typical CMF sludge will not exceed TC limits (Fields et al., 2000a).

Design of a CADF system can be found in Section 7, *Pressurized Media Filtration Process Design Considerations*.

2.5.5 Oxidation/Filtration

Oxidation/filtration refers to processes that are designed to remove naturally occurring iron and manganese from water. The processes involve the oxidation of the soluble forms of iron and manganese to their insoluble forms and then removal by filtration. If arsenic is present in the water, it can be removed via two primary mechanisms: adsorption and co-precipitation. First, soluble iron and As(III) are oxidized. The As(V) then adsorbs onto the iron hydroxide precipitates that are ultimately filtered out of solution.

Although some arsenic may be removed by adsorption/co-precipitation with manganese, iron is much more efficient for arsenic removal. The arsenic removal efficiency is strongly dependent on the initial iron concentration and the ratio of iron to arsenic. In general, the Fe:As mass ratio should be at least 20:1. These conditions customarily result in an arsenic removal efficiency of 80-95%. In some cases, it may be appropriate to add ferric coagulant to the beginning of the iron removal process to optimize arsenic removal.

The effectiveness of arsenic co-precipitation with iron is relatively independent of source water pH in the range 5.5 to 8.5. However, high levels of NOM, orthophosphates, and silicates weaken arsenic removal efficiency by competing for sorption sites on iron hydroxide precipitates (Fields et al., 2000b).

The common iron/manganese methods consist of (1) air oxidation or chemical oxidation followed by media filtration and (2) potassium permanganate oxidation followed by a greensand media filter. The latter process is commonly referred to as the greensand process. The greensand process can be operated on an intermittent regeneration (IR) basis or on a continuous feed (CF) basis. With IR operational procedure, the greensand filter is periodically regenerated with potassium permanganate following the back washing of the filter. In the CF mode, permanganate or chlorine is continuously added to the feed water ahead of greensand filter.

In the air/chemical oxidation filtration iron removal process, the iron is oxidized with either air (aeration tower) or with an oxidizing chemical, usually chlorine. Because of the limitations of air to oxidize As(III), chlorine is normally used in order for the process to be effective for arsenic removal. After the water is oxidized, it is filtered with a granular media to remove the iron hydroxide precipitates that contain the adsorbed arsenic. The effectiveness of the granular media is important because any iron particles that manage to get through the filter media will contain some arsenic.

The greensand process is a special case of pressurized granular-media filtration where the granular media, greensand, catalyzes the oxidation and precipitation of iron and manganese. In the greensand process, operated an IR basis, the water is passed through a column of greensand media, which adsorbs and catalyzes the oxidation of the iron and manganese. In order for greensand to retain its adsorption and catalytic oxidation capabilities, the media must be regenerated with permanganate or chlorine. When operated on an IR basis, the greensand filter column is taken off line and the media is soaked in a solution of permanganate. In the CF mode, permanganate or chlorine is continuously added to the feed water ahead of greensand filter where they provide continuous oxidation of the iron and As(III) and regeneration of the greensand. If the arsenic in the ground water is not already oxidized to As(V), it is recommended that CF process using chlorine or permanganate be used to provide continuous oxidation of the iron, manganese, and As(III).

Greensand is manufactured by coating glauconite with manganese dioxide. Other manganese dioxide media are also used for iron and manganese removal such as pyrolucite, Pyrolox[6], Filox-R™ [7], MTM[8], BIRM[9], and Anthrasand. Greensand and some of the other manganese dioxide media (Filox-R™) have been shown to have some arsenic adsorptive effectiveness in removing arsenic from drinking water (Hanson et al., 1999, Fields et al., 2000b, Ghurye and Clifford, 2001).

In all oxidation/filtration processes, the filter media must be periodically backwashed to dislodge solids and restore hydraulic capacity. Backwash water is typically a high-volume, low solids (less than 0.1%) waste stream. The specific amount of solids will depend on several factors, including raw water iron levels, coagulant addition (if any), filter run length, and background solids concentration. Two treatment options are available for this waste stream: (1) indirect discharge and (2) dewatering and sludge disposal.

Water intended for indirect discharge will be subject to TBLLs for TDS and arsenic. The background level will change because of the drinking water treatment process, which may lead to revised TBLLs. The revised TBLL would be used to determine if the liquid waste stream could be discharged to the POTW. Dewatering can be accomplished by gravity thickening, followed by other mechanical or non-mechanical techniques. Settling basins can be used to provide gravity clarification, while the supernatant can be decanted and recycled to the process head. The solids can be slurried out periodically and passed through a filter press for dewatering. The resultant sludge can be disposed of in a municipal solid waste landfill if it passes the PFLT (no free liquid) and the TCLP. Previous studies have indicated that typical ferric coagulation-filtration sludge will not exceed TC limits (Fields et al., 2000b).

Design of an oxidation/filtration system can be found in Section 7, *Pressurized Media Fil-*

[6] Pyrolox is a trademark of American Materials.

[7] Filox is a registered trademark of Matt-Son, Inc., Barrington, IL. Filox-R is a trademark of Matt-Son, Inc., Barrington, IL.

[8] MTM is a registered trademark of Clack Corporation, Windsor, WI.

[9] Birm is a registered trademark of Clack Corporation, Windsor, WI.

tration Process Design Considerations.

2.6 Point-of-Use Treatment

Under the final Arsenic Rule, POU devices are approved as SSCTs. However, SDWA requires that the devices be owned, controlled, and maintained by the public water utility or by an agency under contract with the water utility. Therefore, the responsibility of operating and maintaining the devices cannot be passed to the customer.

POU devices are particularly attractive for removing contaminants that pose only an ingestion risk, as is the case with arsenic. This is because a very small fraction of the total water supplied to a given household is ultimately consumed. In most cases, the POU unit is plumbed in at the kitchen sink (the device will have its own faucet).

The primary advantage of employing POU treatment in a small system is reduced capital and treatment costs, relative to centralized treatment. On the downside, however, these programs generally incur higher administrative and monitoring costs to make sure that all units are functioning properly. Previous studies have suggested that POU programs are an economically viable alternative to centralized treatment for systems serving roughly 50-500 people.

Most POU devices do not address the issue of pre-oxidation. While RO may remove As(III) to acceptable standards, sorptive processes such as AA or IBS will probably not. In this case, water systems may need to conduct centralized chlorine treatment to convert As(III) to As(V). There is also a concern that even with centralized pre-oxidation, anoxic conditions could exist in the distribution system that allow As(V) to reduce back to As(III). Depending on the extent of reduction, this could be detrimental to a POU program.

The technologies that are most amenable to POU treatment include AA, IBS, and RO. AA and RO are approved as SSCTs for POU applications (USEPA, 2002a). Although there are no IBS systems currently approved as SSCTs, there are several media currently being tested.

The primary criteria for selecting an appropriate POU treatment device are arsenic removal performance and cost. The unit must be independently certified against NSF/ANSI product standards to be used for compliance purposes.

More information on POU technologies and can be found in Section 8, *Point-of-Use Treatment*, and in USEPA's soon to be released *Guidance for Implementing a Point-of-Use or Point-of-Entry Treatment Strategy for Compliance with the Safe Drinking Water Act* (USEPA, 2002b Draft).

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Section 3
Arsenic Treatment Selection

3.1 Selection Criteria

The task of navigating through the alternative arsenic treatment technologies involves several technical considerations. Although nearly all of the unit processes previously presented could be used for arsenic reduction at an arbitrary site, some are more economically viable under specific circumstances. Optimization of existing processes is a realistic option for some utilities. Although most water systems today have been designed without the goal of arsenic removal, many current practices may accomplish incidental removal. Optimization of these processes is a realistic option. The utility should coordinate the selection and implementation process with its state drinking water program.

3.1.1 Source Water Quality

Source water quality dictates the performance of the removal processes identified in Section 2. In turn, process performance, associated O&M requirements, and residuals disposal dictate the economics of a particular treatment approach. Therefore, it is important that utilities conduct thorough up-front monitoring of water quality at all active sources to make the most informed treatment selection decision.

Tables 3-1 and 3-2 provide a summary of recommended monitoring parameters and associated analytical methods. The parameters are divided into two categories: (1) Key and (2) Other. Key parameters are those most critical to evaluating the treatment performance potential of various arsenic removal processes. These parameters should be monitored multiple times over the course of several weeks or months to capture variability in concentrations. Other parameters should be monitored at least once in order to optimize the selected arsenic treatment method.

Table 3-1. Key Water Quality Parameters to be Monitored.

Parameter	USEPA Method	Standard Method [3]	ASTM[4]
Arsenic, Total [1]	200.8 200.9	3113 B 3114 B	D2972-93B D2972-93C
Arsenite {As(III)}		3500-As B	
Arsenate {As(V)}		3500-As B	
Chloride (Cl^-) [2]	300.0	4110 B 4500-Cl^- D 4500-Cl^- B	D4327-91 D512-89B
Fluoride (F^-) [1,2]	300.0	4110 B 4500-F^- B 4500-F^- C 4500-F^- D 4500-F^- E	D4327-91 D1179-93B
Iron (Fe) [2]	200.7 200.9	3120 B 3111 B 3113 B	
Manganese (Mn) [2]	200.7 200.8 200.9	3120 B 3111 B 3113 B	
Nitrate (NO_3^-) [1]	300.0 353.2	4110 B 4500-NO_3^- F 4500-NO_3^- D 4500-NO_3^- E	D4327-91 D3867-90A D3867-90B
Nitrite (NO_2^-) [1]	300.0 353.2	4110 B 4500-NO_3^- F 4500-NO_3^- E 4500-NO_2^- B	D4327-91 D3867-90A D3867-90B
Orthophosphate (PO_4^{-3}) [1]	365.1 300.0	4500-P F 4500-P E 4110 B	D515-88A D4327-91
pH[1, 2]	150.1 150.2	4500-H^+ B	D1293-95
Silica [1]	200.7	4500-Si D 4500-Si E 4500-Si F	D859-95
Sulfate (SO_4^{-2}) [2]	300.0 375.2	4110 B 4500-SO_4^{2-} F 4500-SO_4^{2-} C 4500-SO_4^{2-} D 4500-SO_4^{2-} E	D4327-91 D516-90
Total Dissolved Solids (TDS) [2]		2540 C	
Total Organic Carbon (TOC)	415.1		

[1] USEPA Approved Methods for Drinking Water Analysis of Inorganic Chemicals and other parameters.
[2] USEPA Recommended Methods for Secondary Drinking Water Contaminants.
[3] 18th and 19th editions of Standard Methods for the Examination of Water and Wastewater, 1992 and 1995, American Water Works Association (AWWA).
[4] Annual Book of ASTM Standards, 1994 and 1996, Vols. 11.01 and 11.02, American Society for Testing and Materials (ASTM).

Table 3-2. Other Water Quality Parameters to be Monitored.			
Parameter	USEPA Method	Standard Method [3]	ASTM [4]
Alkalinity [1]		2320 B	D1067-92B
Aluminum (Al) [2]	200.7 200.8 200.9	3120 B 3113 B 3111 D	
Calcium (Ca^{+2}) [1]	200.7	3500-Ca D 3111 B 3120 B	D511-93A D511-93B
Magnesium (Mg^{+2}) [1]	200.7	3113 B 3120 B 3500-Mg E	D511-53B D511-93B
Turbidity	180.1		
Water Hardness	215.1 242.1		

[1] USEPA Approved Methods for Drinking Water Analysis of Inorganic Chemicals and other parameters.
[2] USEPA Recommended Methods for Secondary Drinking Water Contaminants.
[3] 18th and 19th editions of Standard Methods for the Examination of Water and Wastewater, 1992 and 1995, American Water Works Association (AWWA).
[4] Annual Book of ASTM Standards, 1994 and 1996, Vols. 11.01 and 11.02, American Society for Testing and Materials (ASTM).

3.1.2 Process Evaluation Basis

There are several variables, design criteria, and assumptions that should be established prior to navigating the decision trees and cost tables. These include the following:

- Existing Treatment Processes
- Target Finished Water Arsenic Concentration
- TBLLs for Arsenic and TDS
- Domestic Waste Discharge Method
- Land Availability
- Labor Commitment
- Acceptable Percent Water Loss
- Maximum Source Flowrate
- Average Source Flowrate
- State or primacy agency requirements that are more stringent than those of the USEPA.

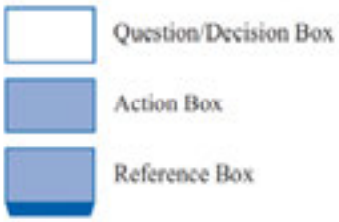
3.2 Process Selection Decision Trees

Decision trees are useful tools for narrowing the field of available treatment technologies to those that are most economical for a particular system. This is accomplished through a series of input-output blocks, which direct the utility along the path towards the best technologies. While they do not always point to a single solution, they allow the utility to rapidly eliminate some technologies that are cost-prohibitive for a specific application.

It is critical that the utility employ these decision trees, rather than the cost correlation curves, as the primary tool for selecting an arsenic mitigation strategy. These trees take into account system-specific conditions and system preferences.

The decision trees guide the utility to the technologies that are expected to work best for their particular situation. In some cases, the pathway is contingent upon a water utility's willingness to impose a particular change in their operating scheme. These decision-making scenarios were presented only for cases where it may be economically advantageous to make such a change. However, there may be other restrictions (i.e., operating labor, space) to making the operational changes in question. In other cases, there may be more than one equally viable technology. At that point, the water utility should further evaluate its preferences with respect to costs and labor commitments, and capabilities with respect to residuals disposal and facility expansion.

The decision trees employ the following labeling scheme:



The Question/Decision block requests information or utility preference in the form of a yes/no or multiple-choice question. The Action Box provides the recommended follow-up action given system-specific constraints and preferences. This box is frequently used as the stopping point for a particular branch of the decision tree. The Reference Box simply directs the utility to another portion of the decision tree.

If a utility reaches an action box pertaining to switching sources, blending, or existing treatment optimization, they should refer to Section 2 for more specific information. If a utility reaches an action box pertaining to new treatment installation, they should refer to Section 4 for cost information and Sections 6-8 for specific design considerations.

The decision trees are intended for use as an iterative tool. If a utility proceeds to a specific action box, conducts follow-up cost estimation, process optimization, and/or pilot-testing, and the results indicate that the selected strategy may be ineffective or too expensive for arsenic removal, the utility can restart the tree and modify preferences.

The following assumptions were made in the development of the decision trees:

- Optimization of existing treatment process is economically preferable over new installations.
- Construction of new conventional gravity coagulation/filtration or LS systems is not appropriate for the sole purpose of arsenic removal.
- Small water systems would opt for disposable adsorptive media rather than conduct on-site regeneration.
- Small systems would choose to not generate hazardous waste for either on-site treatment or off-site disposal.

Decision Tree Overview

Non-Treatment Alternatives

- Tree 1 Non-Treatment Alternatives

Treatment Selection

- Tree 2 Treatment Selection
  - Tree 2a Enhanced Coagulation/Filtration
  - Tree 2b Enhanced Lime Softening
  - Tree 2c Iron & Manganese Filtration

Selecting New Treatment

- Tree 3 Selecting New Treatment
  - Tree 3a Ion Exchange Processes
  - Tree 3b Sorption Processes
  - Tree 3c Filtration & Membrane Processes

Figure 3-1. Decision Tree Overview.

Tree 1
Non-Treatment Alternatives

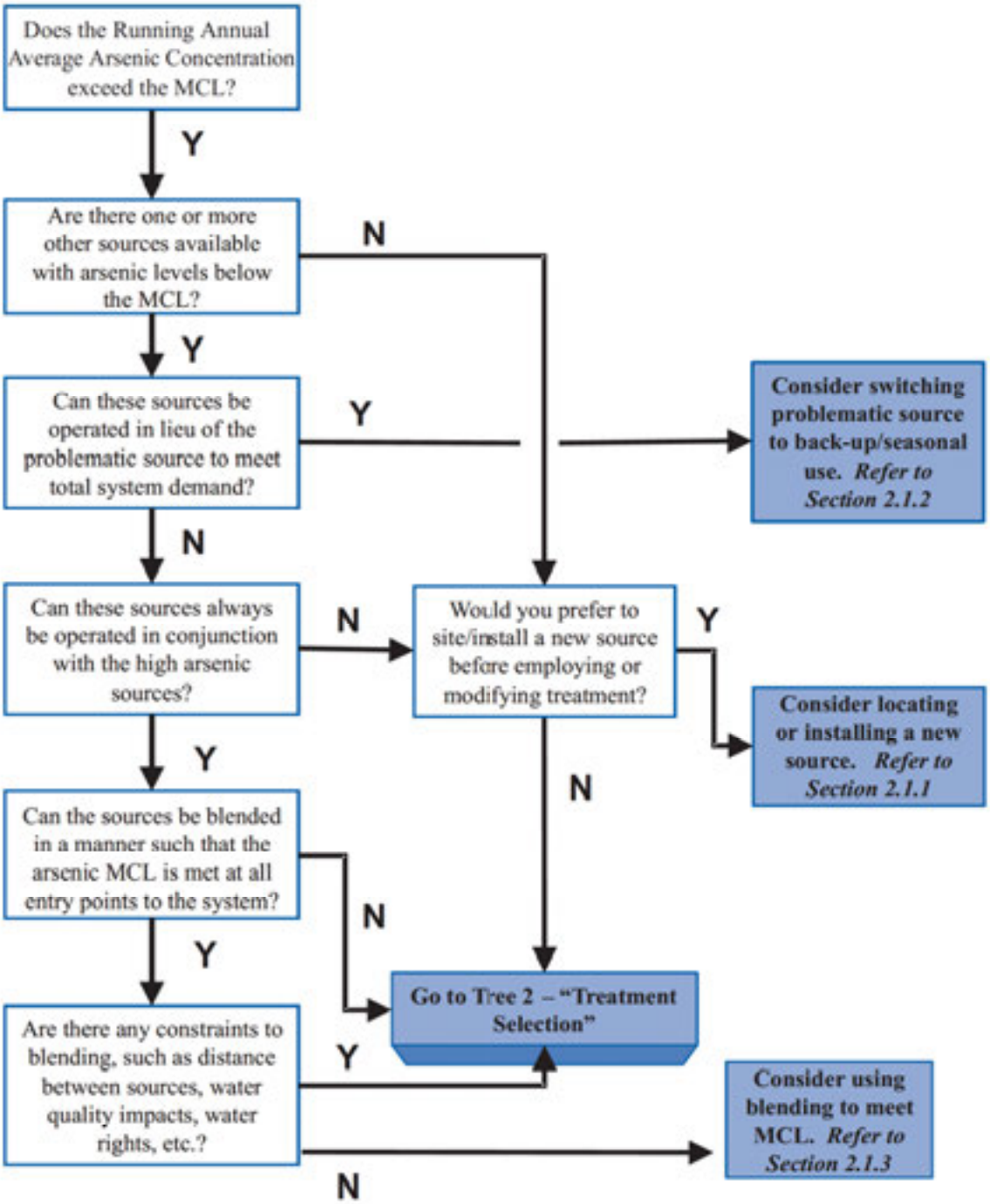


Figure 3-2. Decision Tree 1 – Non-Treatment Alternatives.

Tree 2
Treatment Selection

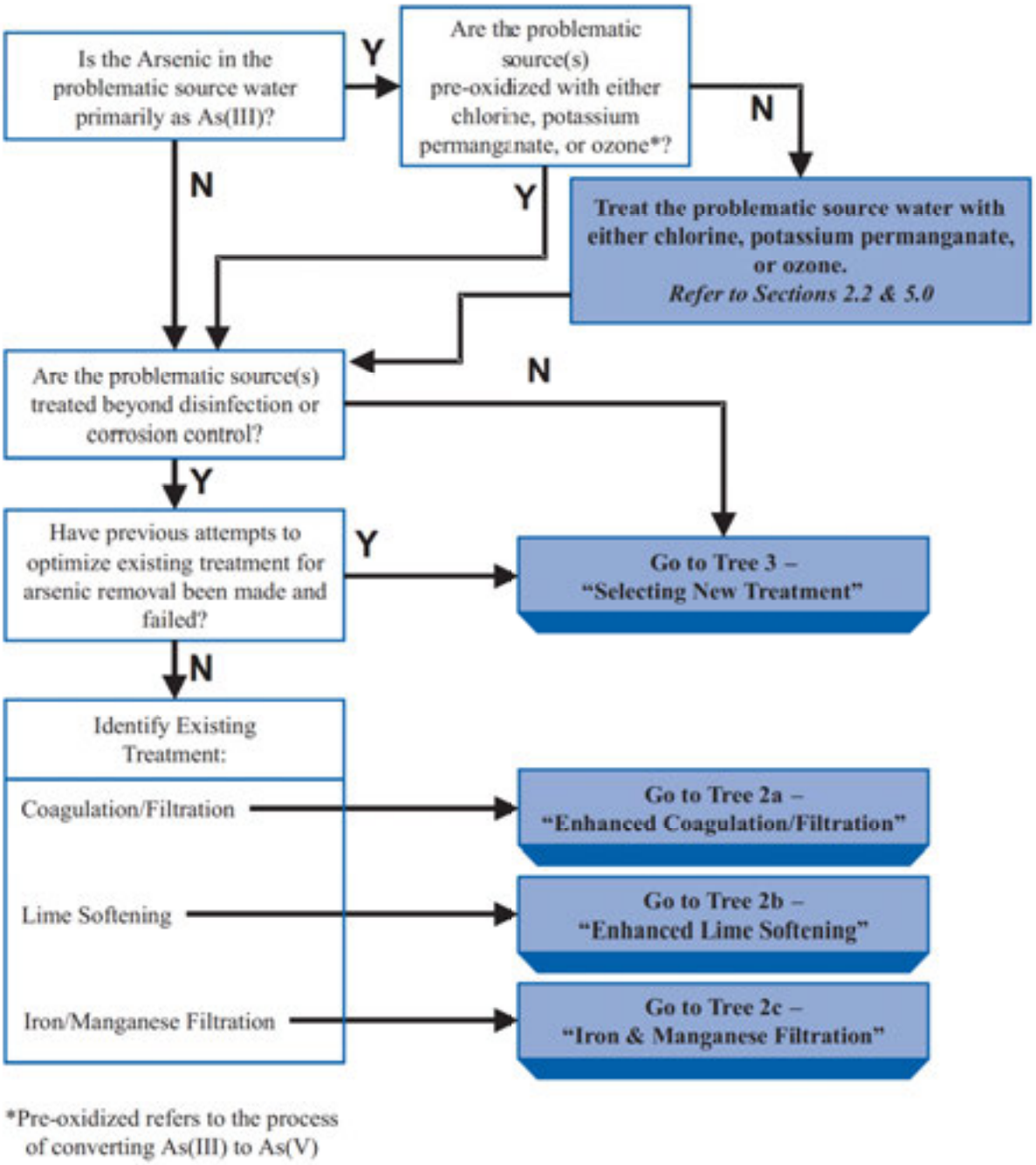


Figure 3-3. Decision Tree 2 - Treatment Selection.

Use this decision tree only after using Tree 1 "*Non-Treatment Alternatives.*"

Tree 2a
Enhanced Coagulation/Filtration

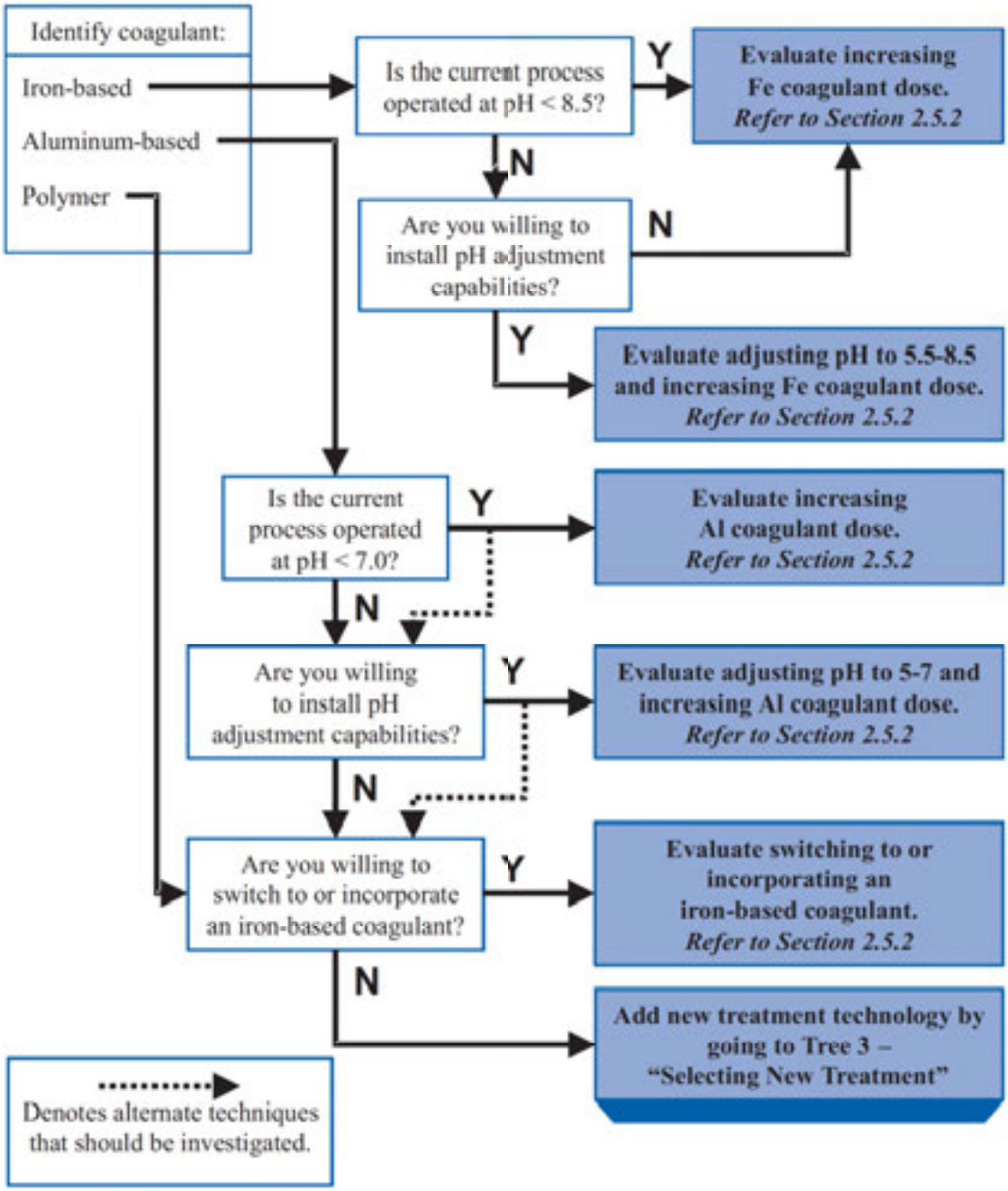


Figure 3-4. Decision Tree 2a - Enhanced Coagulation/Filtration.

Use this decision tree only after using Tree 2 "*Treatment Selection*."

Tree 2b
Enhanced Lime Softening

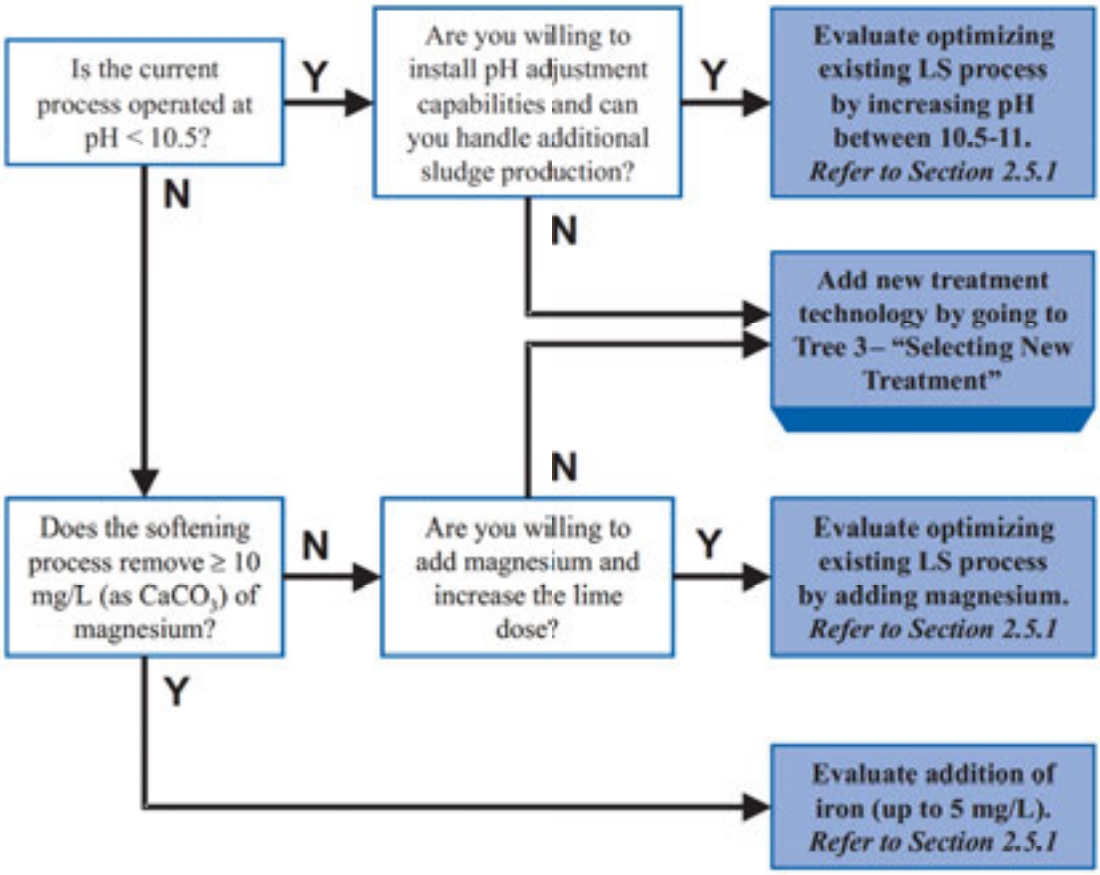


Figure 3-5. Decision Tree 2b - Enhanced Lime Softening.

Use this decision tree only after using Tree 2 "*Treatment Selection*."

Tree 2c
Iron & Manganese Filtration

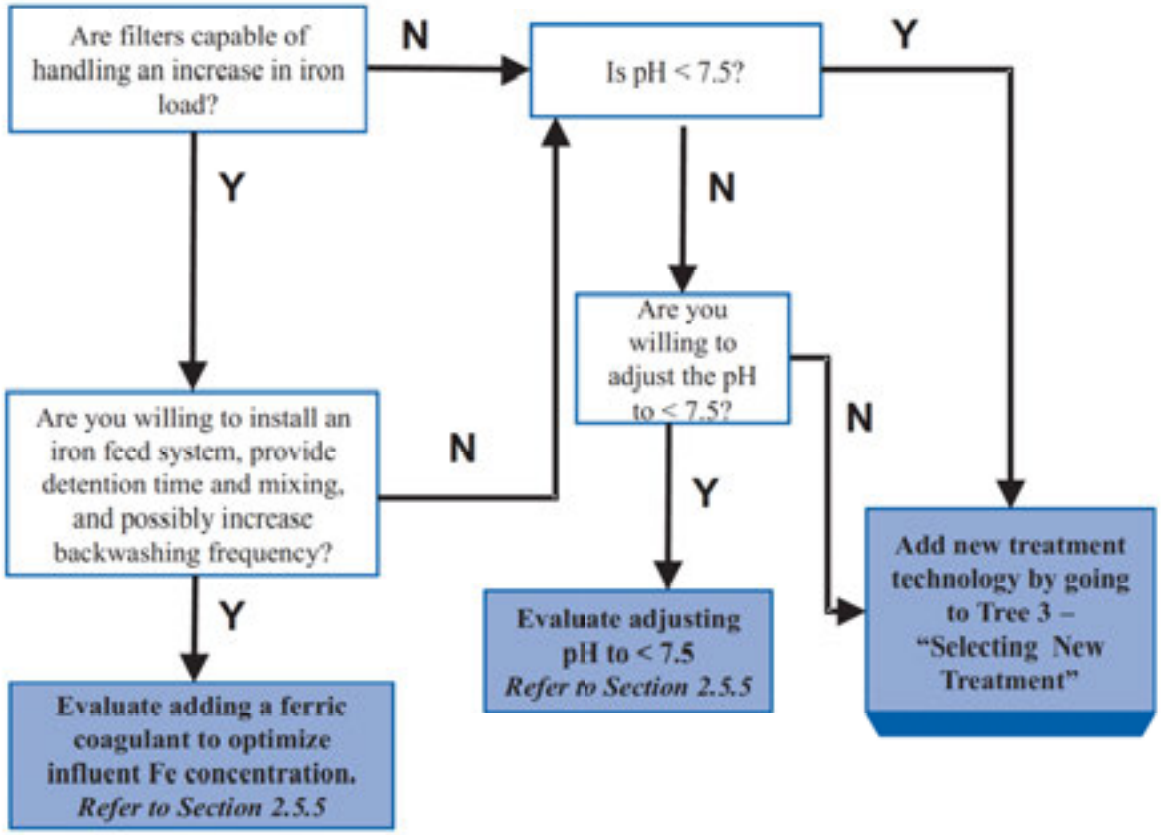


Figure 3-6. Decision Tree 2c - Iron/Manganese Filtration.

Use this decision tree only after using Tree 2 "*Treatment Selection*."

Tree 3
Selecting New Treatment

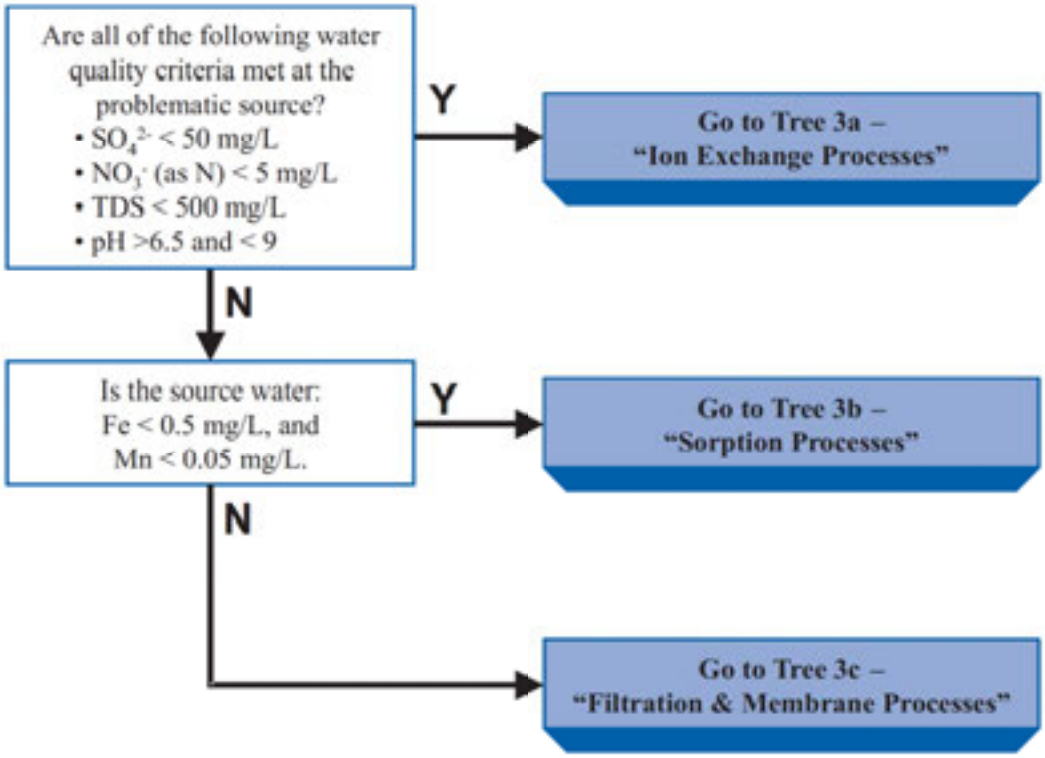
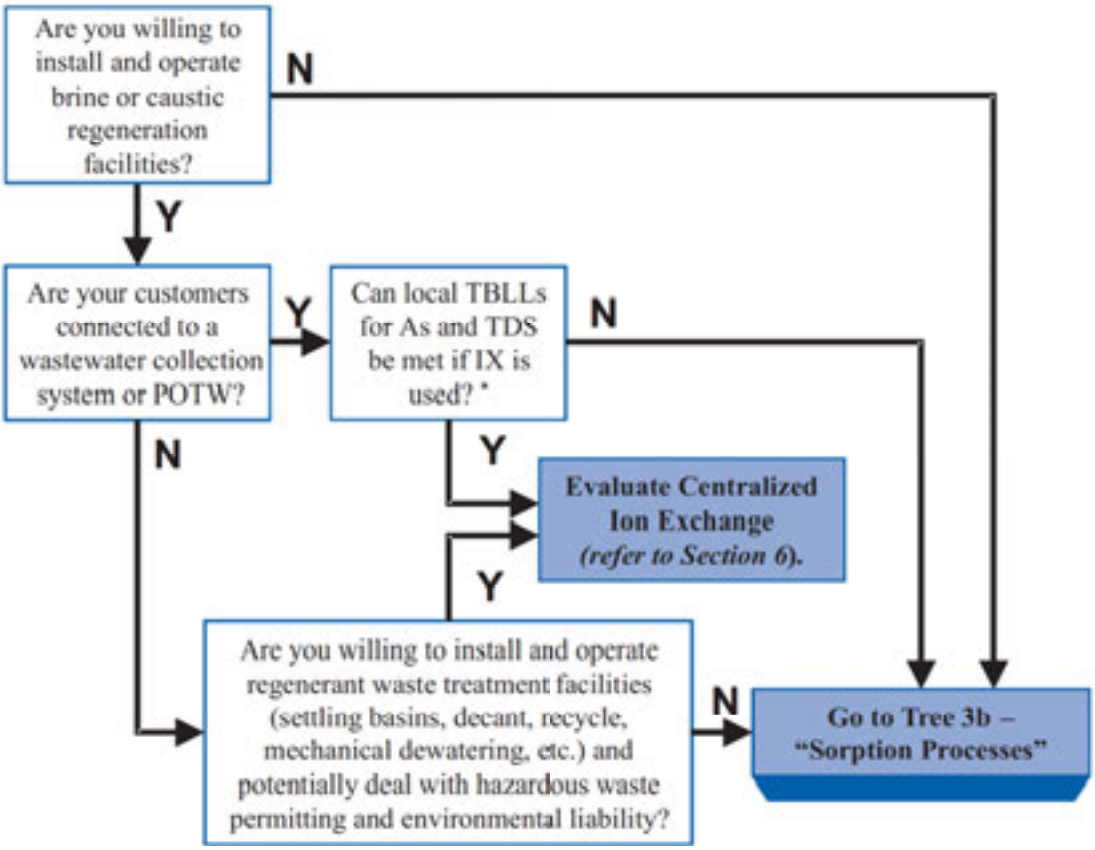


Figure 3-7. Decision Tree 3 - Selecting New Treatment.

Use this decision tree only after using Tree 2 "*Treatment Selection*."

Tree 3a
Ion Exchange Processes



* This evaluation will be complex because removal of As from drinking water will change the background As concentration for the TBLL. A revised TBLL would be used to determine if the brine stream could be discharged to the POTW. TDS may be the more critical restriction, especially in the western U.S.

Figure 3-8. Decision Tree 3a - Ion Exchange Processes.

Use this decision tree only after using Tree 3 "*Selecting New Treatment*."

Tree 3b
Sorption Processes

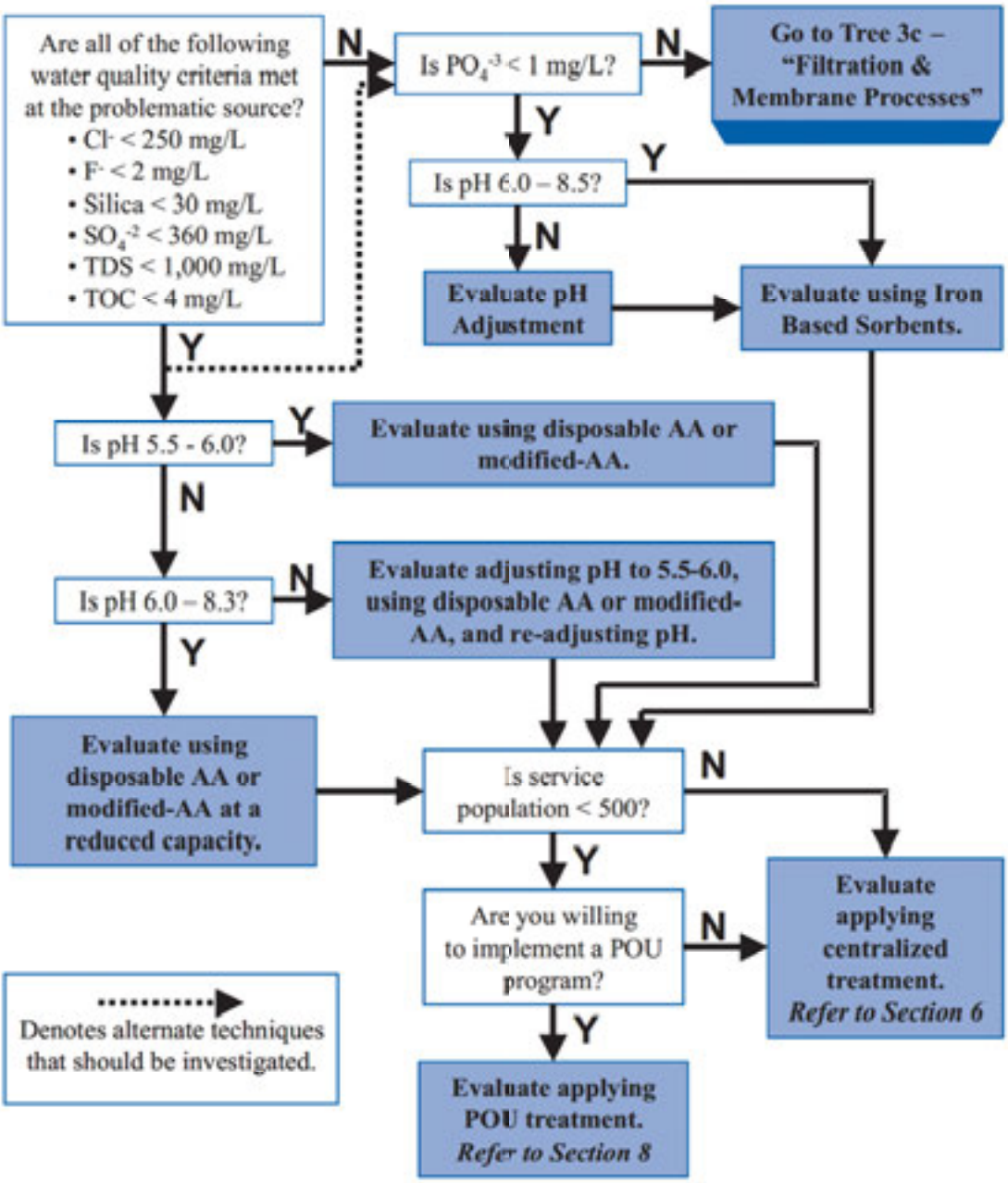


Figure 3-9. Decision Tree 3b - Sorption Processes.

Use this decision tree only after using Tree 3 "*Selecting New Treatment*."

Tree 3c
Filtration & Membrane Processes

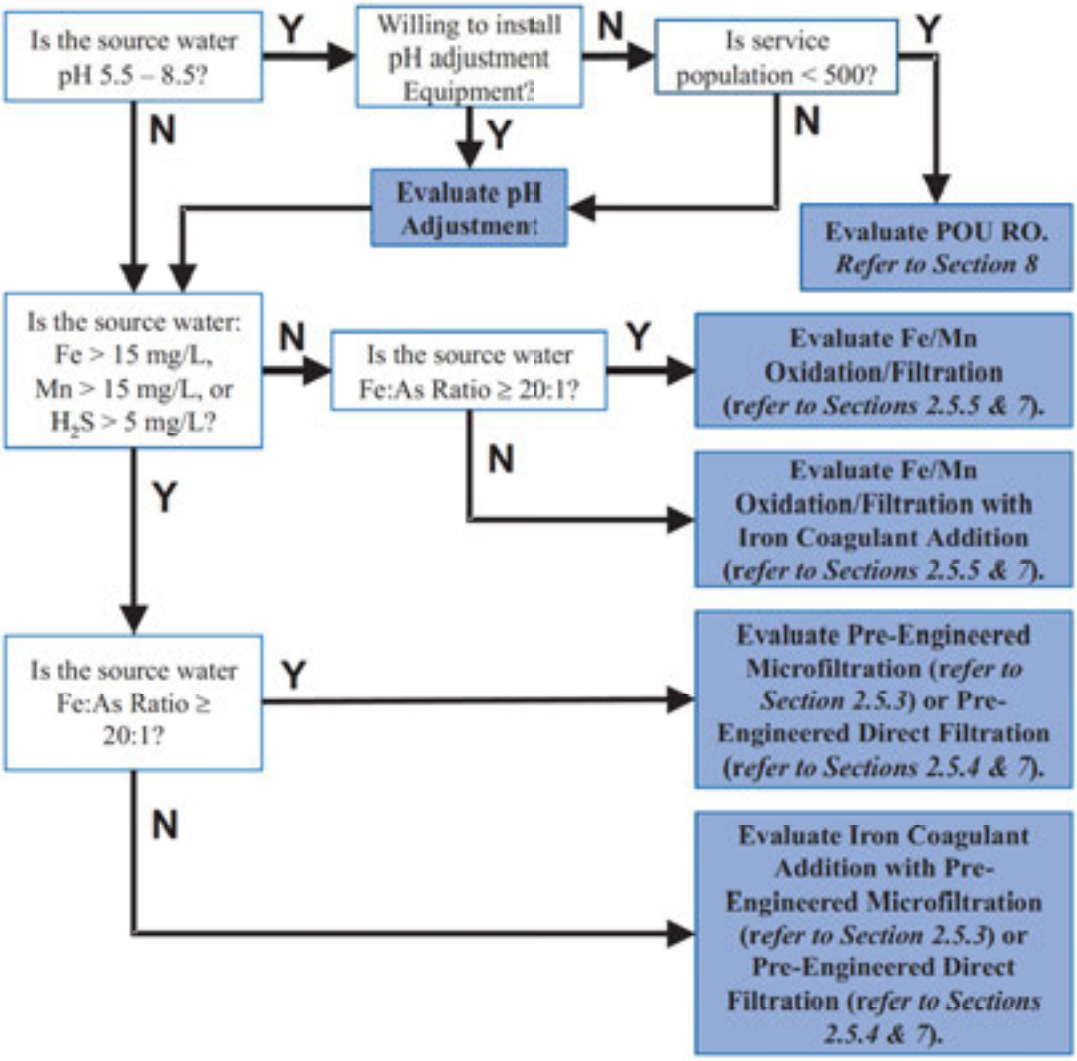


Figure 3-10. Decision Tree 3c - Filtration and Membrane Processes.

Use this decision tree only after using Tree 3 "*Selecting New Treatment*."

Table 3-3 provides a summary of information about the different alternatives for arsenic mitigation found in this Handbook.

Table 3-3. Arsenic Treatment Technologies Summary Comparison. (1 of 2)

Factors	Sorption Processes			Membrane Processes
	Ion Exchange	Activated Alumina [A]	Iron Based Sorbents	Reverse Osmosis
	IX	AA	IBS	RO
USEPA BAT [B]	Yes	Yes	No [C]	Yes
USEPA SSCT [B]	Yes	Yes	No [C]	Yes
System Size [B,D]	25-10,000	25-10,000	25-10,000	501-10,000
SSCT for POU [B]	No	Yes	No [C]	Yes
POU System Size [B,D]	-	25-10,000	25-10,000	25 -10,000
Removal Efficiency	95% [E]	95% [E]	up to 98% [E]	> 95% [E]
Total Water Loss	1-2%	1-2%	1- 2%	15-75%
Pre-Oxidation Required [F]	Yes	Yes	Yes [G]	Likely [H]
Optimal Water Quality Conditions	pH 6.5 - 9 [E] < 5 mg/L NO_3^{-} [I] < 50 mg/L SO_4^{2-} [J] < 500 mg/L TDS [K] < 0.3 NTU Turbidity	pH 5.5 - 6 [I] pH 6 - 8.3 [L] < 250 mg/L Cl^{-} [I] < 2 mg/L F^{-} [I] < 360 mg/L SO_4^{2-} [K] < 30 mg/L Silica [M] < 0.5 mg/L Fe^{+3} [I] < 0.05 mg/L Mn^{+2} [I] < 1,000 mg/L TDS [K] < 4 mg/L TOC [K] < 0.3 NTU Turbidity	pH 6 - 8.5 < 1 mg/L PO_4^{-3} [N] < 0.3 NTU Turbidity	No Particulates
Operator Skill Required	High	Low [A]	Low	Medium
Waste Generated	Spent Resin, Spent Brine, Backwash Water	Spent Media, Backwash Water	Spent Media, Backwash Water	Reject Water
Other Considerations	Possible pre & post pH adjustment. Pre-filtration required. Potentially hazardous brine waste. Nitrate peaking. Carbonate peaking affects pH.	Possible pre & post pH adjustment. Pre-filtration may be required. Modified AA available.	Media may be very expensive. [O] Pre-filtration may be required.	High water loss (15-75% of feed water)
Centralized Cost	Medium	Medium	Medium	High
POU Cost	-	Medium	Medium	Medium

[A] Activated alumina is assumed to operate in a non-regenerated mode.
[B] USEPA, 2002a.
[C] IBS's track record in the US was not established enough to be considered as Best Available Technology (BAT) or Small System Compliance Technology (SSCT) at the time the rule was promulgated.
[D] Affordable for systems with the given number of people served.
[E] USEPA, 2000.
[F] Pre-oxidation only required for As(III).
[G] Some iron based sorbents may catalyze the As(III) to As(V) oxidation and therefore would not require a pre-oxidation step.
[H] RO will remove As(III), but its efficiency is not consistent and pre-oxidaton will increase removal efficiency.
[I] AwwaRF, 2002.
[J] Kempic, 2002.
[K] Wang, 2000.
[L] AA can be used economically at higher pHs, but with a significant decrease in the capacity of the media.
[M] Clifford, 2001.
[N] Tumlo, 2002.
[O] With increased domestic use, IBS cost will significantly decrease.

Table 3-3. Arsenic Treatment Technologies Summary Comparison. (2 of 2)

Factors	Precipitative Processes				
	Enhanced Lime Softening	Enhanced (Conventional) Coagulation Filtration	Coagulation-Assisted Micro-Filtration	Coagulation-Assisted Direct Filtration	Oxidation Filtration
	LS	CF	CMF	CADF	OxFilt
USEPA BAT [B]	Yes	Yes	No	Yes	Yes
USEPA SSCT [B]	No	No	Yes	Yes	Yes
System Size [B,D]	25-10,000	25-10,000	500-10,000	500-10,000	25-10,000
SSCT for POU [B]	No	No	No	No	No
POU System Size [B,D]	-	-	-	-	-
Removal Efficiency	90% [E]	95% (w/ $FeCl_3$) [E] < 90% (w/ Alum) [E]	90% [E]	90% [E]	50-90% [E]
Total Water Loss	0%	0%	5%	1-2%	1-2%
Pre-Oxidation Required [F]	Yes	Yes	Yes	Yes	Yes
Optimal Water Quality Conditions	pH 10.5 - 11 [I] > 5 mg/L Fe^{+3} [I]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 [F]	pH 5.5 - 8.5 >0.3 mg/L Fe Fe:As Ratio > 20:1
Operator Skill Required	High	High	High	High	Medium
Waste Generated	Backwash Water, Sludge (high volume)	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge	Backwash Water, Sludge
Other Considerations	Treated water requires pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	Possible pre & post pH adjustment.	None.
Centralized Cost	Low [G]	Low [G]	High	Medium	Medium
POU Cost	N/A	N/A	N/A	N/A	N/A

[B] USEPA, 2002a.
[D] Affordable for systems with the given number of people served.
[E] Depends on arsenic and iron concentrations.
[F] Pre-oxidation only required for As(III).
[I] AwwaRF, 2002.
[F] Fields, et al., 2002a.
[G] Costs for enhanced LS and enhanced CF are based on modification of an existing technology. Most small systems will not have this technology in place.

Section 4
Planning-Level Treatment Costs

This section presents information the utility can use to calculate planning-level capital and O&M costs for the treatment method selected in Section 3. All the charts are from *Technologies and Costs for Removal of Arsenic from Drinking Water* (USEPA, 2000). This information will give the utility only a rough estimate of the selected treatment process costs so that relative costs can be evaluated. If the costs are too high, the utility is encouraged to re-evaluate the criteria used in the treatment selection process in Section 3.

It is critical that the utility employ the decision trees in Section 3, rather than the cost correlation curves provided in this section, as the primary tool for selecting an arsenic mitigation strategy. The trees take into account system-specific conditions and utility preferences. Comparing planning-level costs without consideration of the technical issues incorporated in the decision trees may lead the utility to an inappropriate technology.

The cost curves incorporate different mathematical models for different sized systems. Because of this, there are step changes between the model outputs in some of the charts. If the system being sized falls at a flowrate that lays on one of these step changes, the utility is encouraged to use an average cost number and then perform a more site specific cost evaluation.

Capital cost charts are based on the maximum flowrate for which the facility was designed (i.e., design flowrate). The design flowrate should be higher than the treated flowrate determined in Section 3. The capital costs include: process costs (including manufactured equipment, concrete, steel, electrical and instrumentation, and pipe and valves), construction costs (including site-work and excavation, subsurface considerations, standby power, contingencies, and interest during construction), engineering costs (including general contractor overhead and profit, engineering fees, and legal, fiscal, and administrative fees) and the costs associated with retrofitting, permitting, pilot testing, housing, and system redundancy (where prudent). The capital costs do not include costs associated with additional contaminants or land.

The O&M costs are based on the average flowrate that the facility is expected to treat. The O&M costs are based on the following assumptions:

- Electricity costs of $0.08/kWh,
- Diesel fuel costs of $1.25/gallon,
- Natural gas costs of $0.006/scf,
- Large systems labor costs of $40/h (or loaded labor costs of $52/h),
- Loaded labor costs for small systems of $28/h, and
- Building energy use of 102.6 kWh/sft/y.

All of the costs presented in the charts are given in year 1998 dollars. To escalate the capital cost of a technology from 1998 to the present, construction cost indexes (CCI) published by Engineering News Record (ENR) can be used in the following formula.

$$P_{Current} = P_{1998}\left(\frac{CCI_{Current}}{CCI_{1998}}\right) \qquad \text{Eqn. 4-1}$$

Where:

$P_{Current}$ = Present Cost,
P_{1998} = Year 1998 Cost (from the charts),
$CCI_{Current}$ = Construction Cost Index Value for the current year, and
CCI_{1998} = Construction Cost Index Value for 1998.

For example, a greensand filtration system is designed to handle 1 MGD. Values taken from the figures and their equations are:

- 1998 Capital Cost is $587,584 (Figure 4-21)
- 1998 Waste Disposal Capital Cost is $3,955 (Figure 4-23)

The annual average 20-cities ENR CCI for 1998 and for November 2002 are 5,920.44 and 6,578.03, respectively. Therefore, the total capital cost for this facility can be estimated for the year 2002 using Equation 4-1 as follows:

$$P_{Capital,2002} = (\$587{,}584 + \$3{,}955)\left(\frac{6{,}578.03}{5{,}920.44}\right) = \$657{,}242$$

The O&M costs presented in the Handbook are 1998 costs and can be escalated to the current year's costs using the formula below. This formula can also be used in place of the CCI equation, although it is less accurate.

$$P_{Current} = P_{1998}(1+i)^{(Y_{Current}-1998)} \qquad \text{Eqn. 4-2}$$

Where:

$P_{Current}$ = Current Cost,
P_{1998} = Year 1998 Cost (from the charts),
i = Annual rate of inflation (currently ~ 2.5% - 3%), and
$Y_{Current}$ = Current Year.

Using the same example of a 1 MGD greensand filtration system, the values taken from the figures and their equations are:

- 1998 O&M cost is $66,314/y (Figure 4-22)
- 1998 Waste Disposal O&M cost is $8,678/y (Figure 4-24)

Assuming an annual inflation rate of 2.5%, the O&M can be estimated for the year 2002 using Equation 4-2 as follows:

$$P_{O\&M,2002} = (\$66{,}314 + \$8{,}678)(1 + 0.025)^{(2002-1998)} = \$82{,}777$$

Additionally, the USEPA has a cost model for estimating the costs of processes using sorptive media. This cost model, titled *Cost Estimating Program for Arsenic Removal by Small Drinking Water Facilities*, can be found on the USEPA's website.

4.1 Pre-Oxidation System Costs Using Chlorine

Costs presented in the following charts make the following assumptions:

- A new chlorination system is installed.
- A dose of 1.5 mg/L of free chlorine is added to the treated flow.
- Systems use 15% sodium hypochlorite feed stock and are designed to handle dosages as high as 10 mg/L.

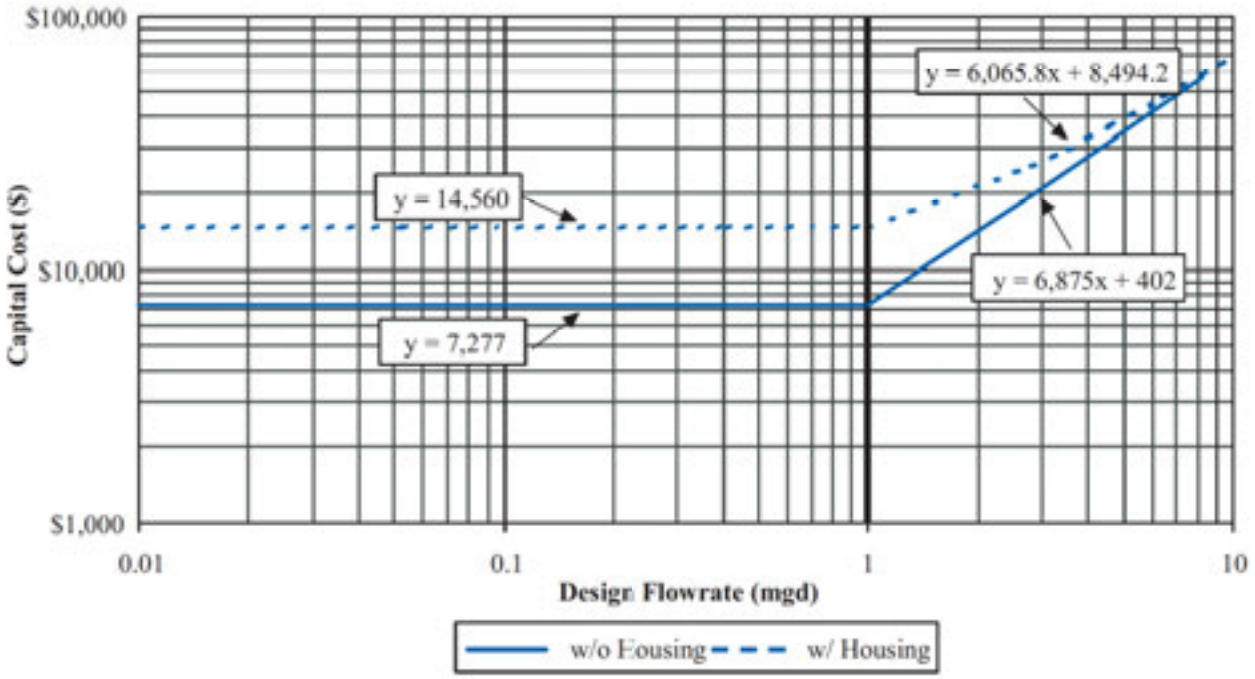


Figure 4-1. Chlorination Capital Costs.

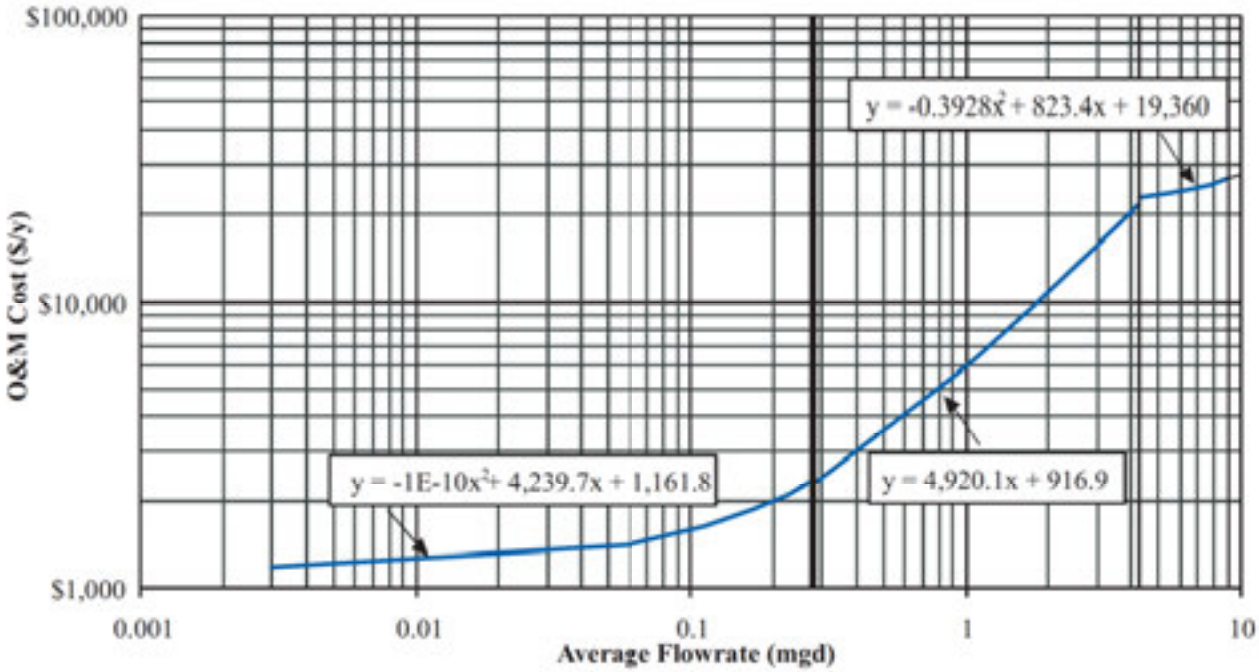


Figure 4-2. Chlorination O&M Costs.

4.2 Ion Exchange System Costs

Costs presented in the following charts make the following assumptions:

- A new IX system is installed.
- Capital Cost Design Assumptions:
  - Pre-oxidation is required but not included in these costs.
  - Cost includes a redundant column to allow the system to operate during regeneration.
- O&M Cost Design Assumptions:
  - Run length when sulfate is at or below 20 mg/L is 1500 bed volumes (BV).
  - Run length when the sulfate is between 20 and 50 mg/L is 700 BV.
  - Labor rate for small systems is $28/hour. The loaded labor rate for large systems is $52/hour.
- Waste is discharged to a POTW (i.e., indirect discharge).

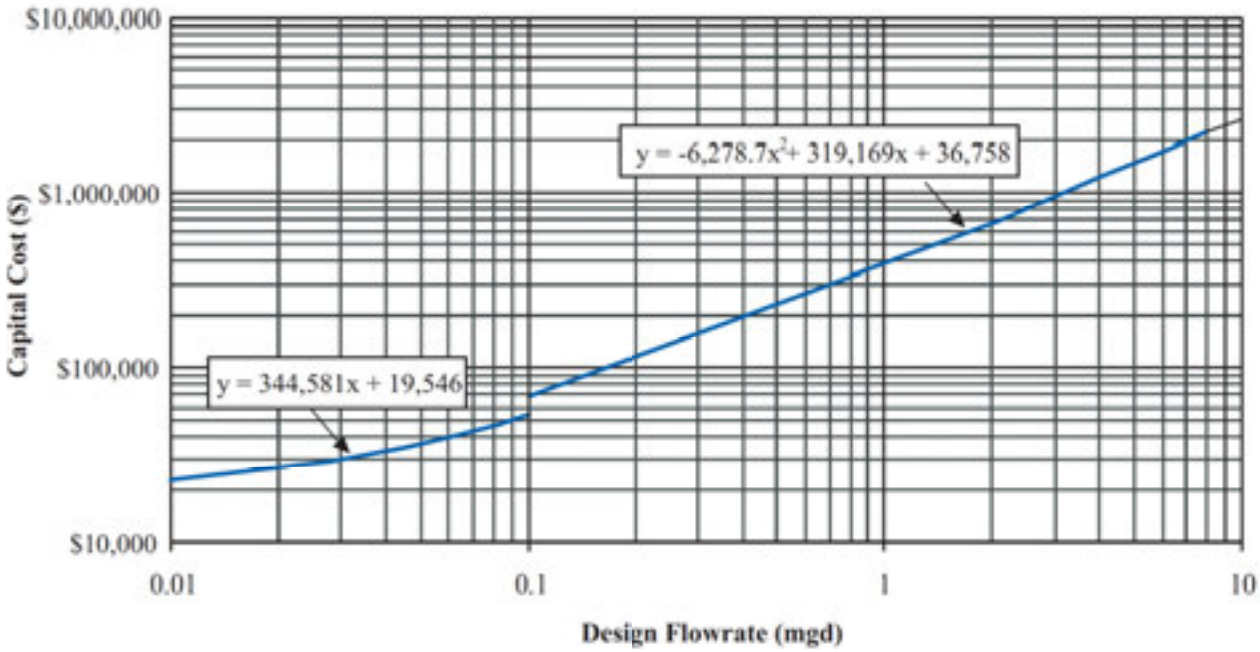


Figure 4-3. Ion Exchange (<20 mg/L SO_4^{2-}) Capital Costs.

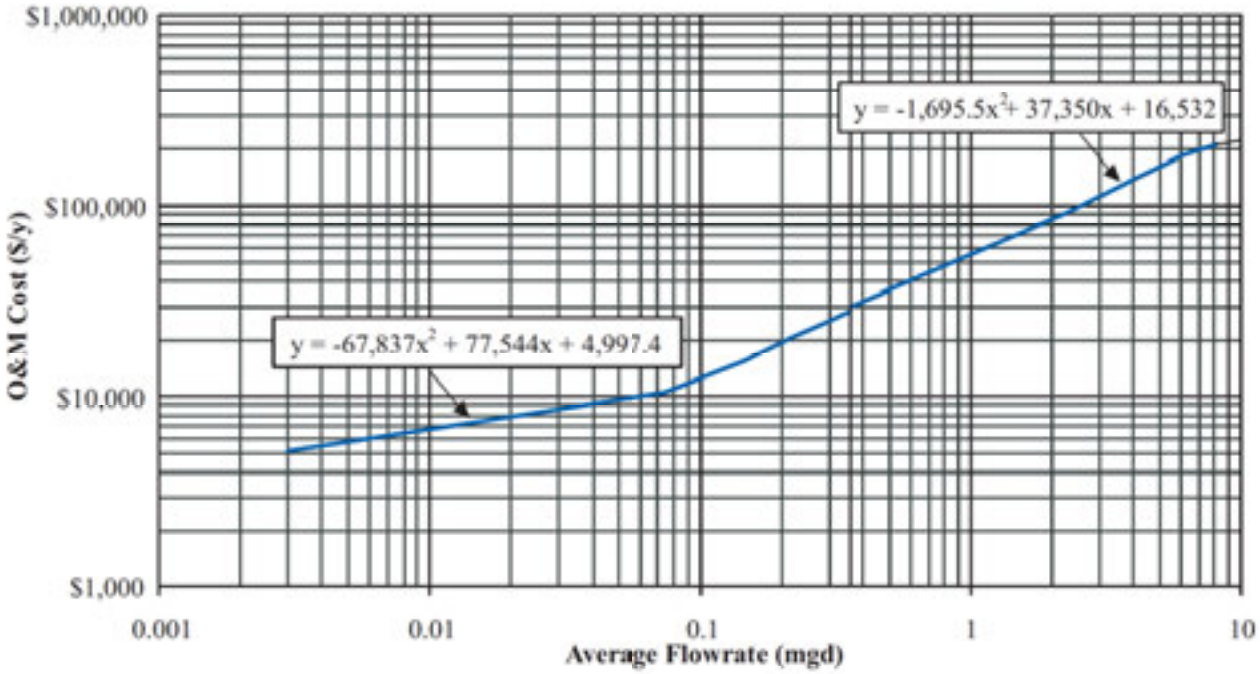


Figure 4-4. Ion Exchange (<20 mg/L SO_4^{2-}) O&M Costs.

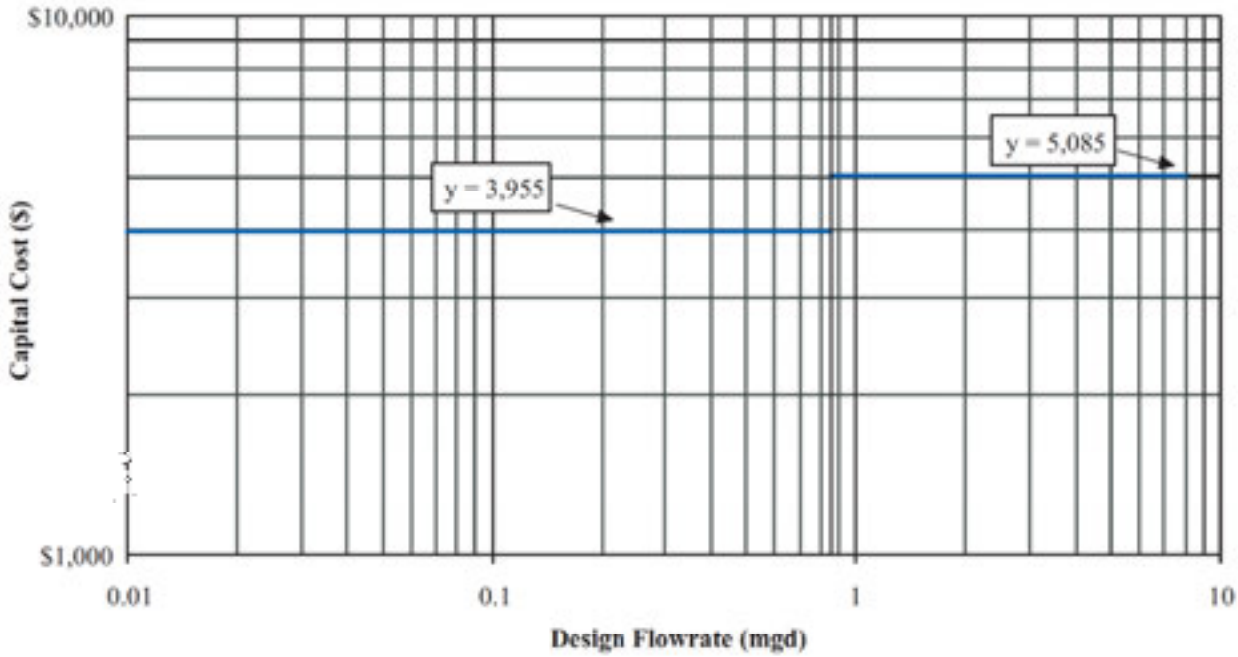


Figure 4-5. Ion Exchange (<20 mg/L SO_4^{2-}) Waste Disposal Capital Costs.

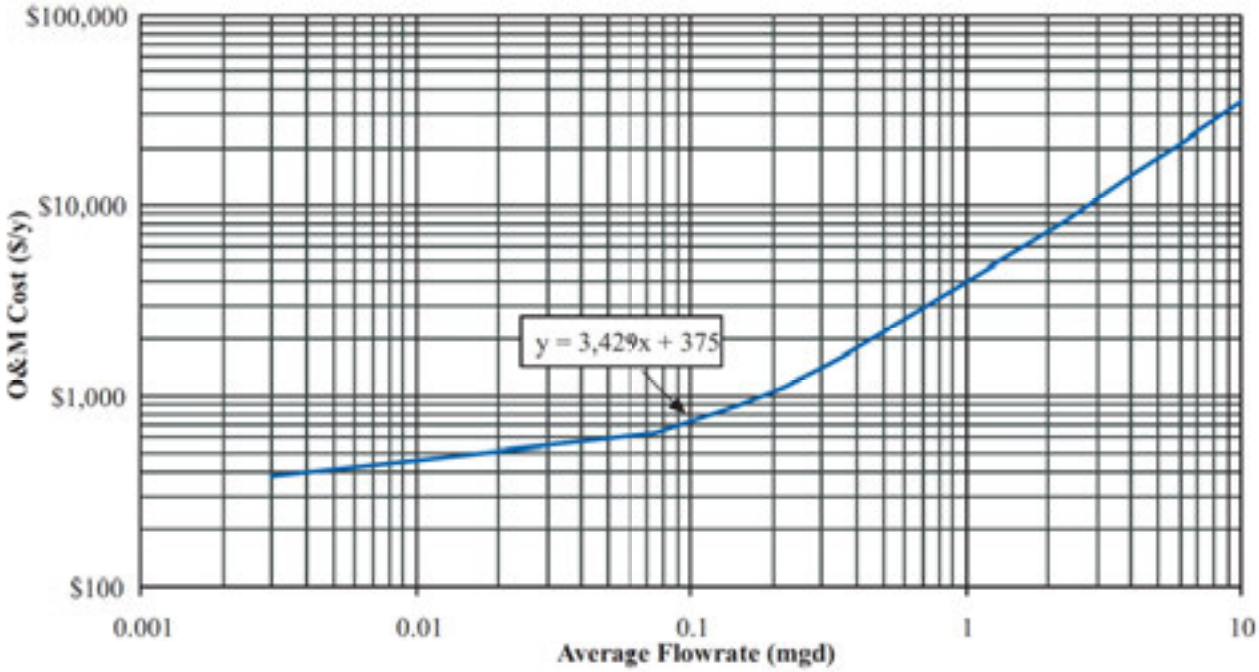


Figure 4-6. Ion Exchange (<20 mg/L SO_4^{2-}) Waste Disposal O&M Costs.

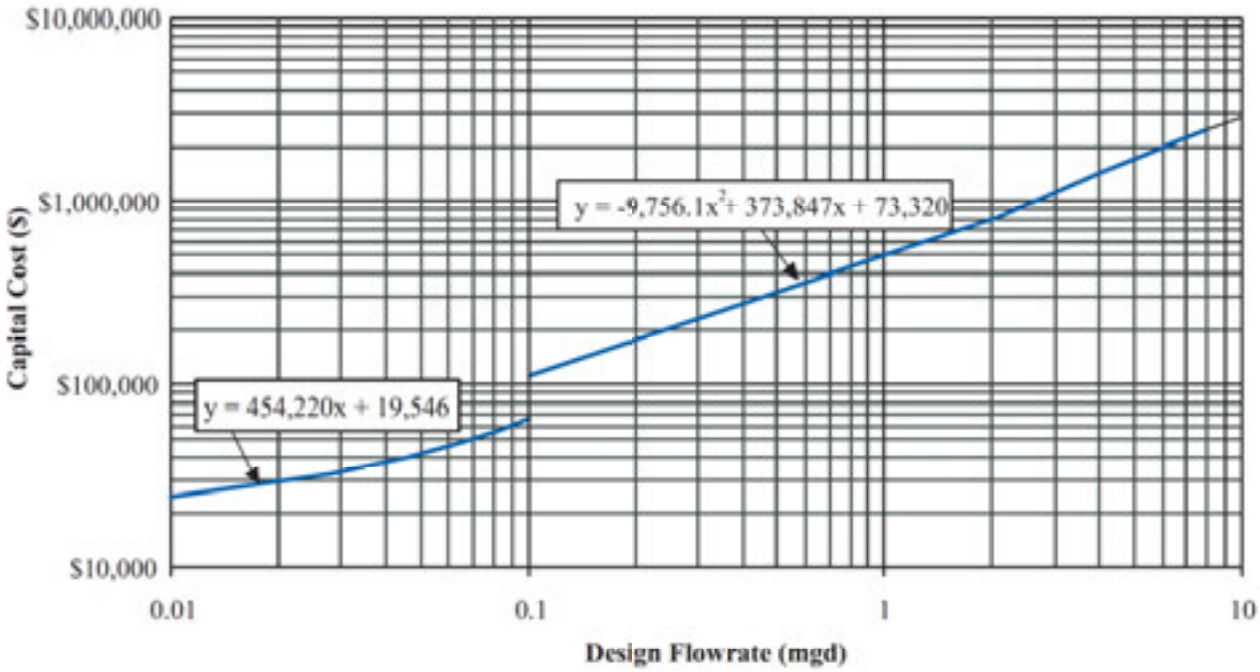


Figure 4-7. Ion Exchange (20-50 mg/L SO_4^{2-}) Capital Costs.

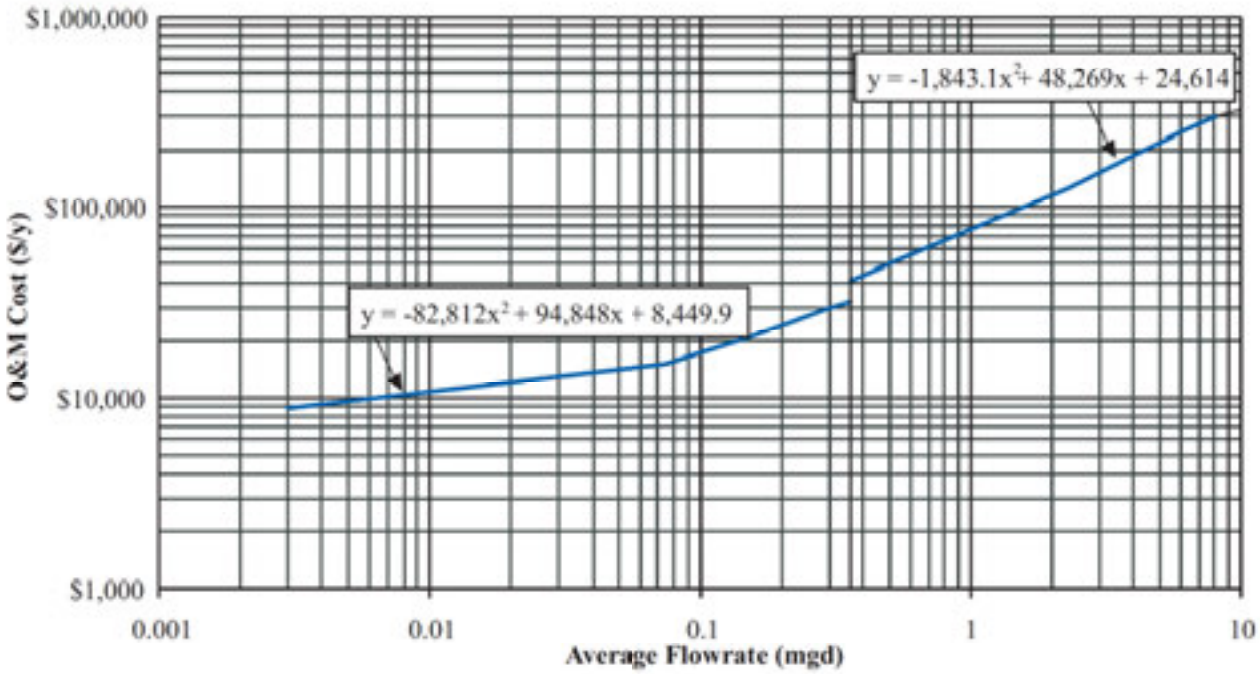


Figure 4-8. Ion Exchange (20-50 mg/L SO_4^{2-}) O&M Costs.

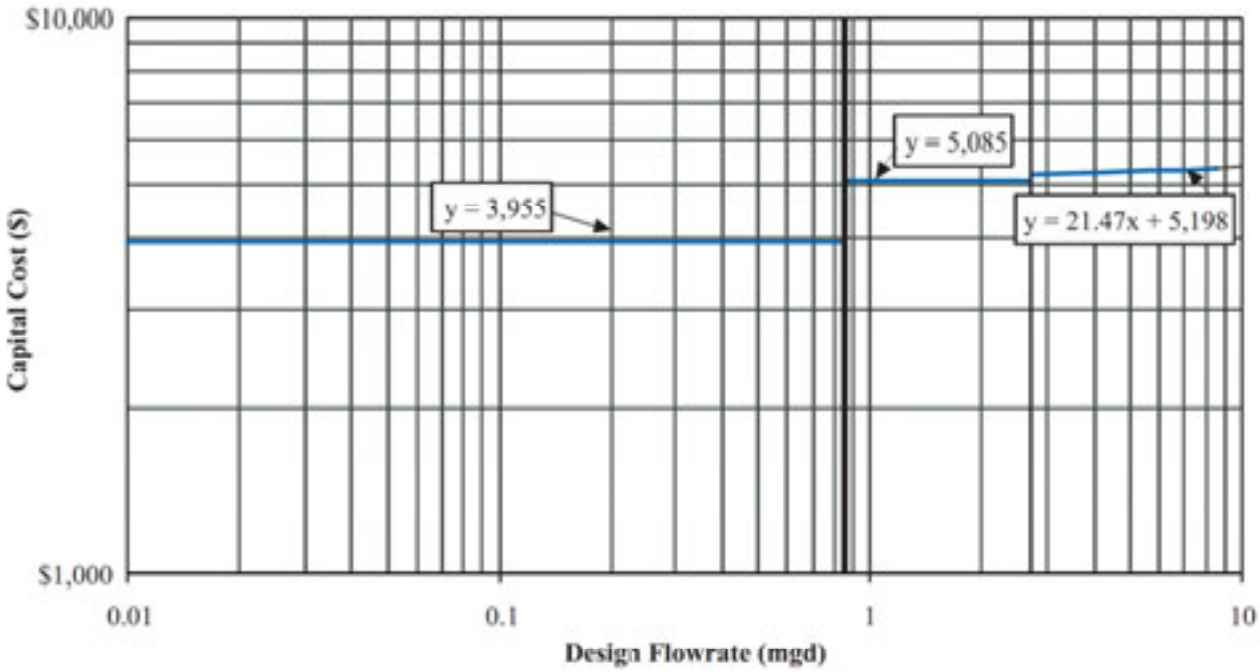


Figure 4-9. Ion Exchange (20-50 mg/L SO_4^{2-}) Waste Disposal Capital Costs.

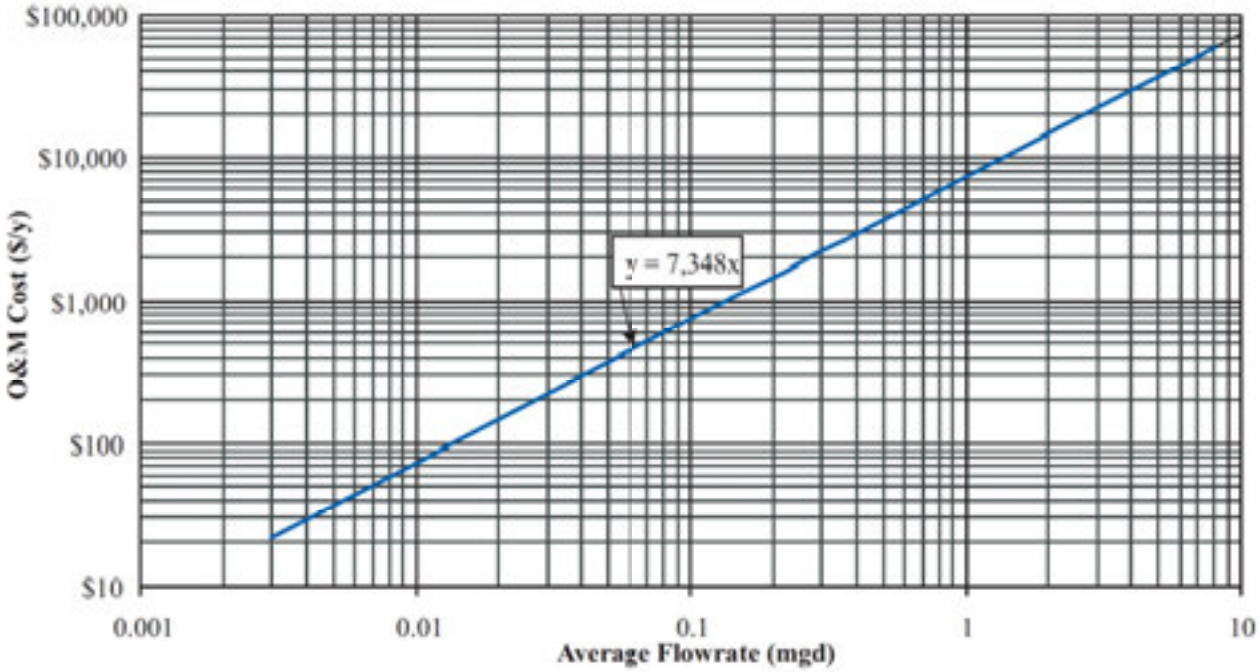


Figure 4-10. Ion Exchange (20-50 mg/L SO_4^{2-}) Waste Disposal O&M Costs.

4.3 Activated Alumina System Costs

Costs presented in the following charts make the following assumptions:

- A new AA system is installed.
- AA media is disposed of in a non-hazardous landfill rather than regenerated.
- Four treatment modes are assumed:
  - No pH adjustment, Natural pH of 7-8, run length is 10,000 BV.
  - No pH adjustment, Natural pH of 8-8.3, run length is 5,200 BV.
  - pH adjusted to 6.0 using hydrochloric acid, run length is 23,100 BV.
  - pH adjusted to 6.0 using sulfuric acid, columns are good for 15,400 BV.
- Capital Cost Design Assumptions:
  - Redundant column included for operation during media replacement.
  - Costs for constructing housing for the equipment are included.
  - Capital costs include both pre- and post-treatment pH adjustment if pH adjustment is used.
- O&M Cost Design Assumptions:
  - Power costs are $0.08/kwh.
  - pH adjustment costs are included.
  - Labor rate for small systems is $28/hour. The loaded labor rate for large systems is $52/hour.

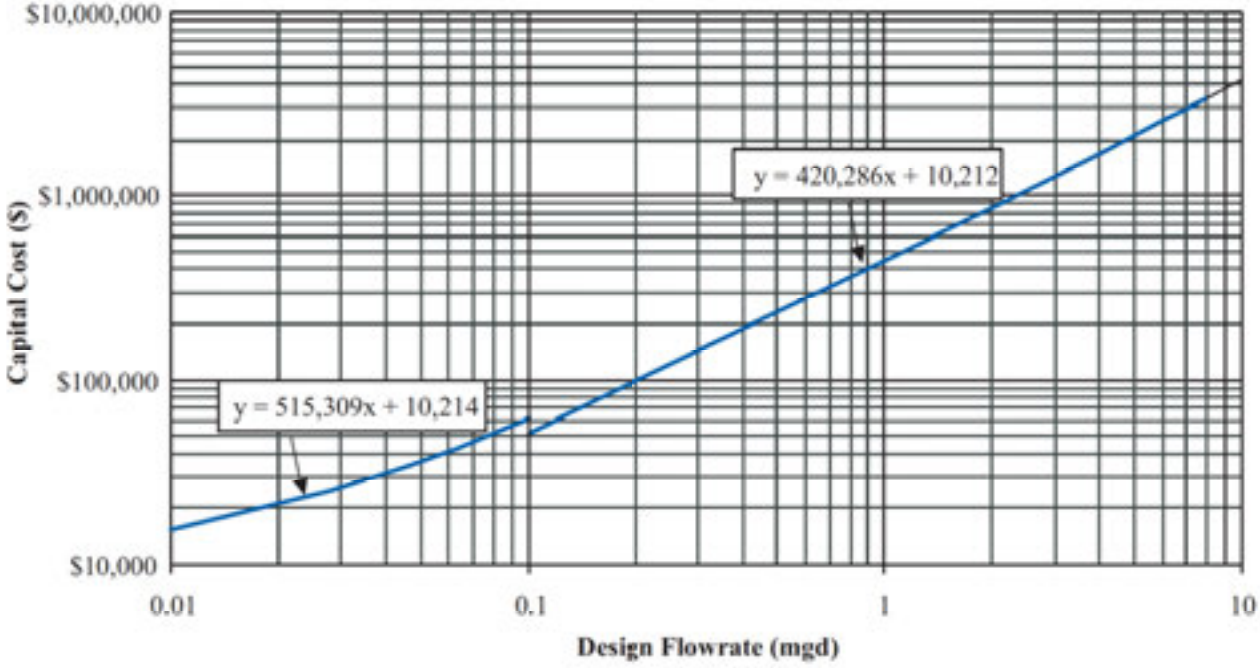


Figure 4-11. Activated Alumina (Natural pH) Capital Costs.

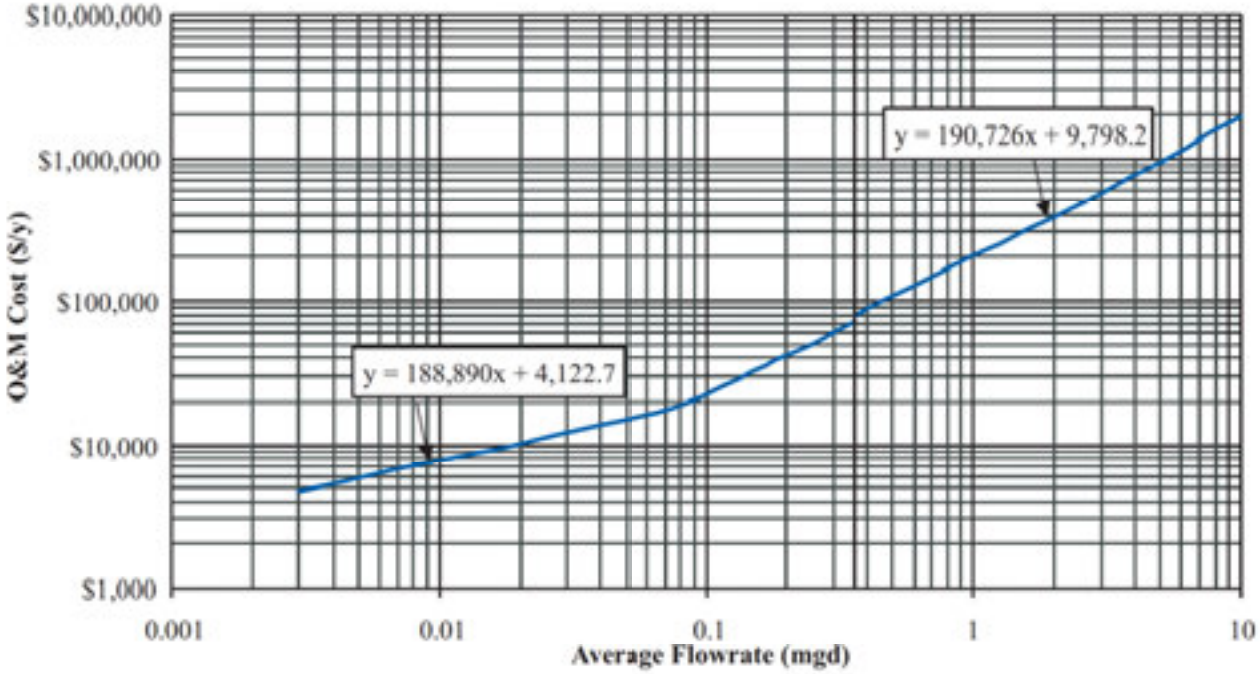


Figure 4-12. Activated Alumina (Natural pH of 7-8) O&M Costs.

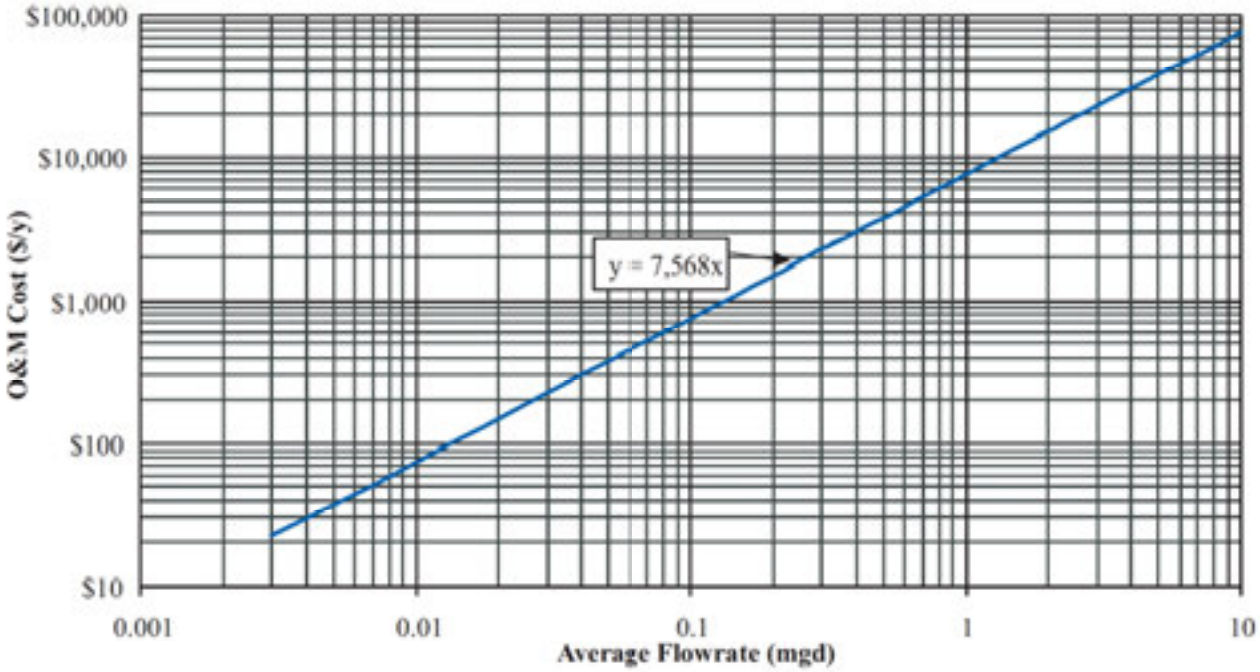


Figure 4-13. Activated Alumina (Natural pH of 7-8) Waste Disposal O&M Costs.

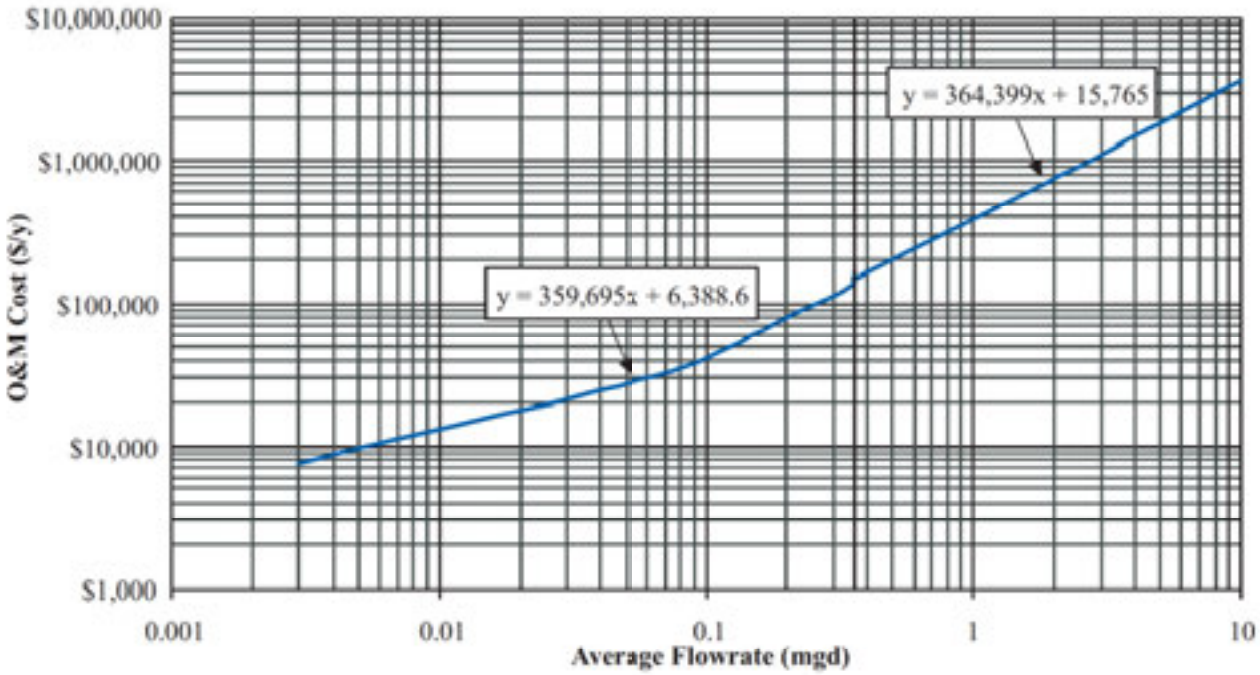


Figure 4-14. Activated Alumina (Natural pH of 8-8.3) O&M Costs.

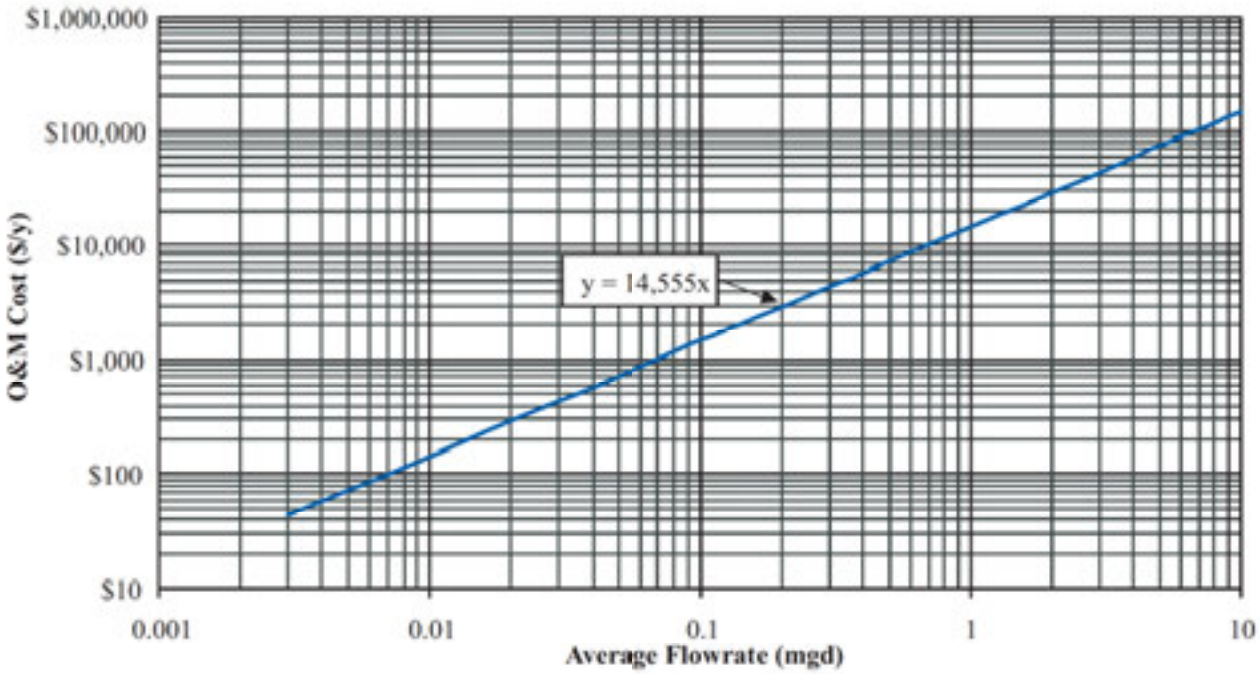


Figure 4-15. Activated Alumina (Natural pH of 8.0-8.3) Waste Disposal O&M Costs.

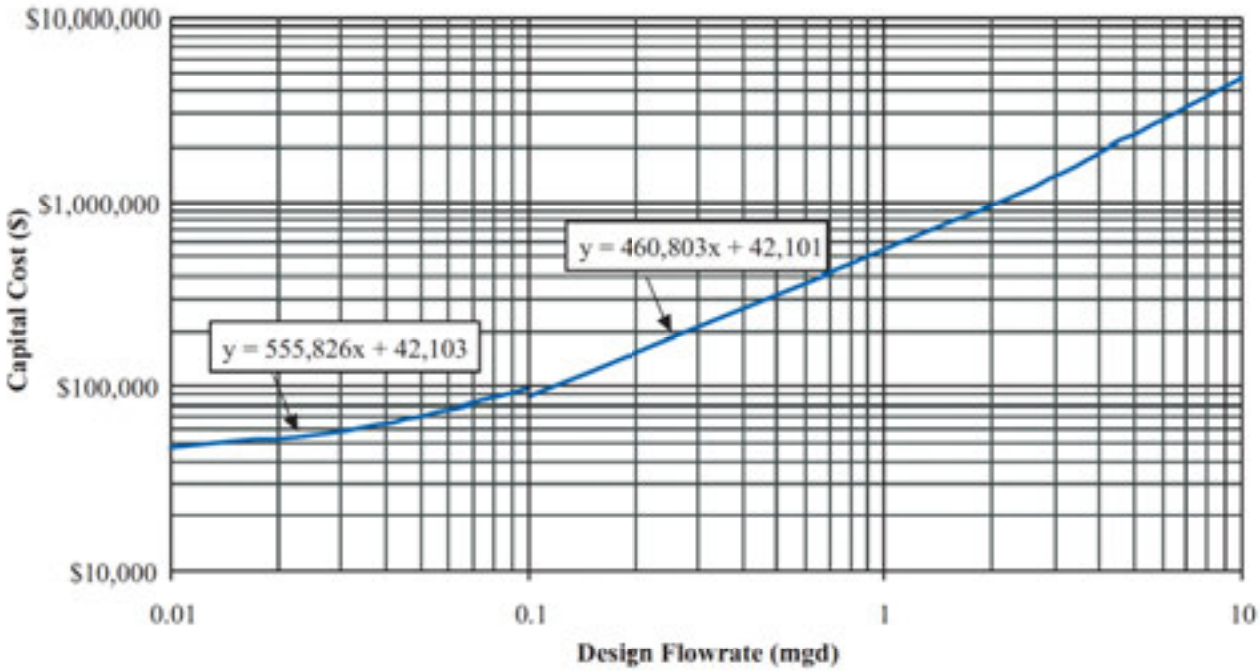


Figure 4-16. Activated Alumina (pH Adjusted to 6.0) Capital Costs.

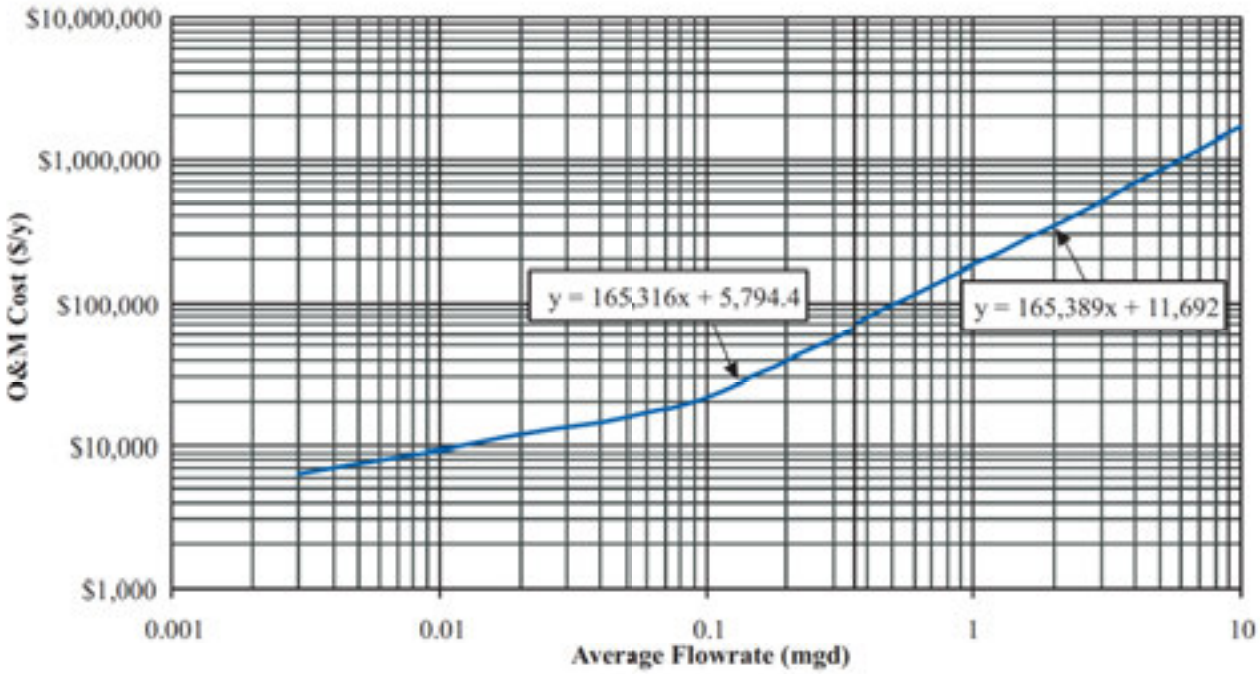


Figure 4-17. Activated Alumina (pH adjusted to 6.0 - 23,100 BV) O&M Costs.

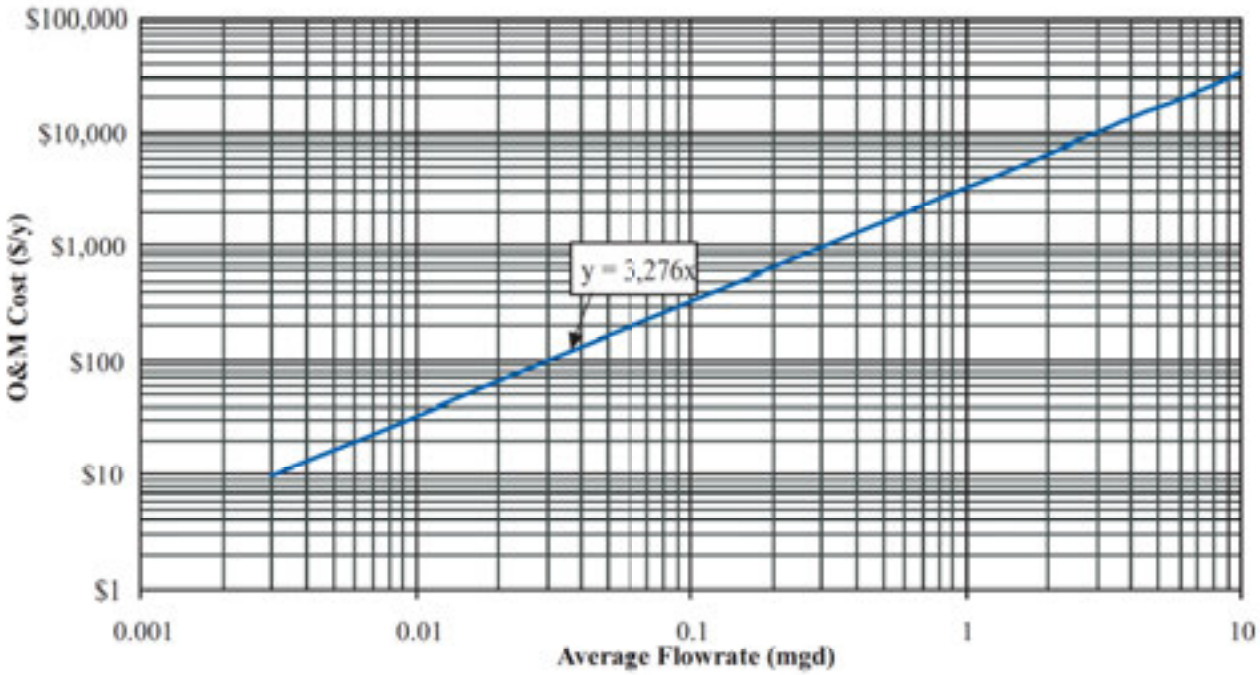


Figure 4-18. Activated Alumina (pH adjusted to 6.0 - 23,100 BV) Waste Disposal O&M Costs.

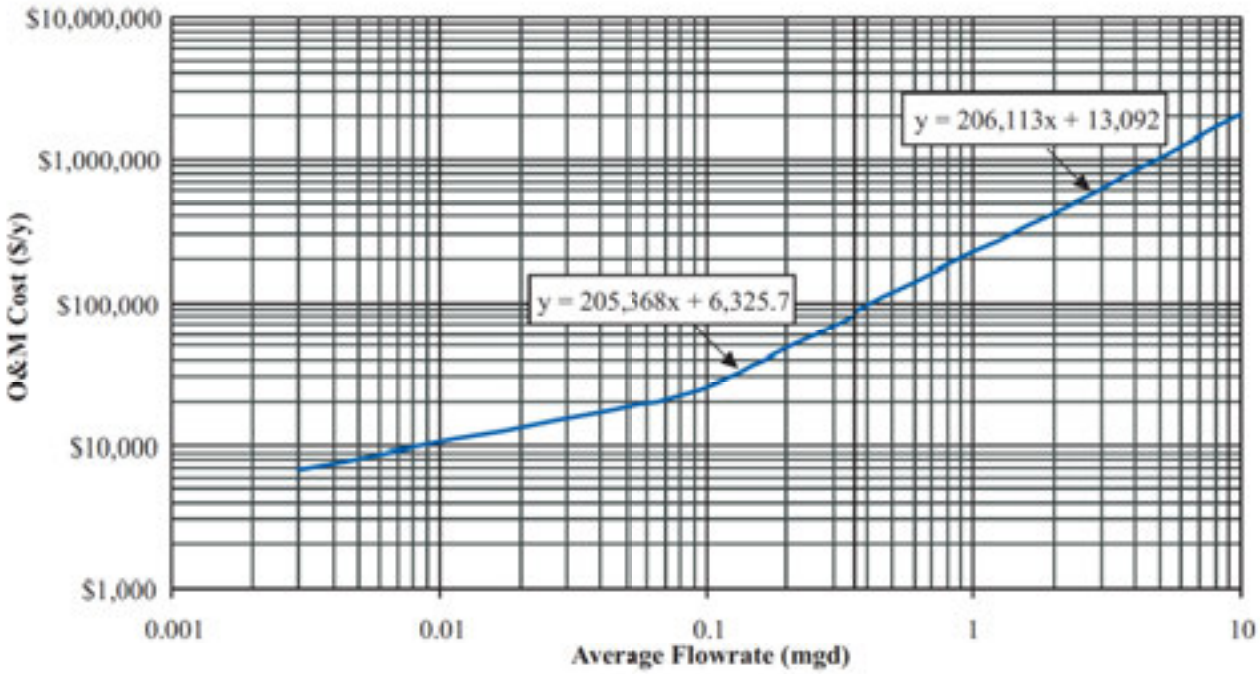


Figure 4-19. Activated Alumina (pH adjusted to 6.0 - 15,400 BV) O&M Costs.

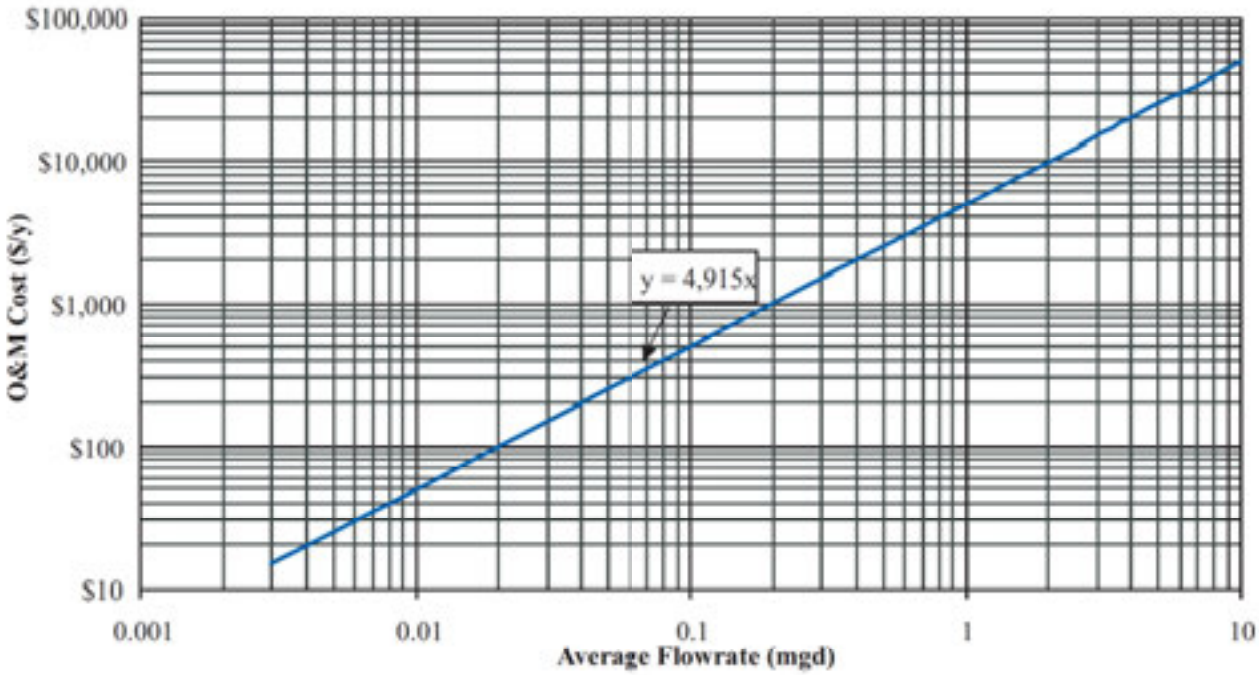


Figure 4-20. Activated Alumina (pH adjusted to 6.0 - 15,400 BV) Waste Disposal O&M Costs.

4.4 Iron Based Sorbent System Costs

IBS are relatively new technologies and, as such, costs for IBS treatment systems have not yet been developed.

4.5 Greensand System Costs

Costs presented in the following charts make the following assumptions:

- A new greensand filtration system is installed.
- Potassium permanganate feed rate of 10 mg/L (however, chlorination will work also).
- Hydraulic loading rate of 4 gpm/sft.
- Backwash flowrate of 10-12 gpm/sft.
- Backwash waste is discharged to a POTW (i.e., indirect discharge).

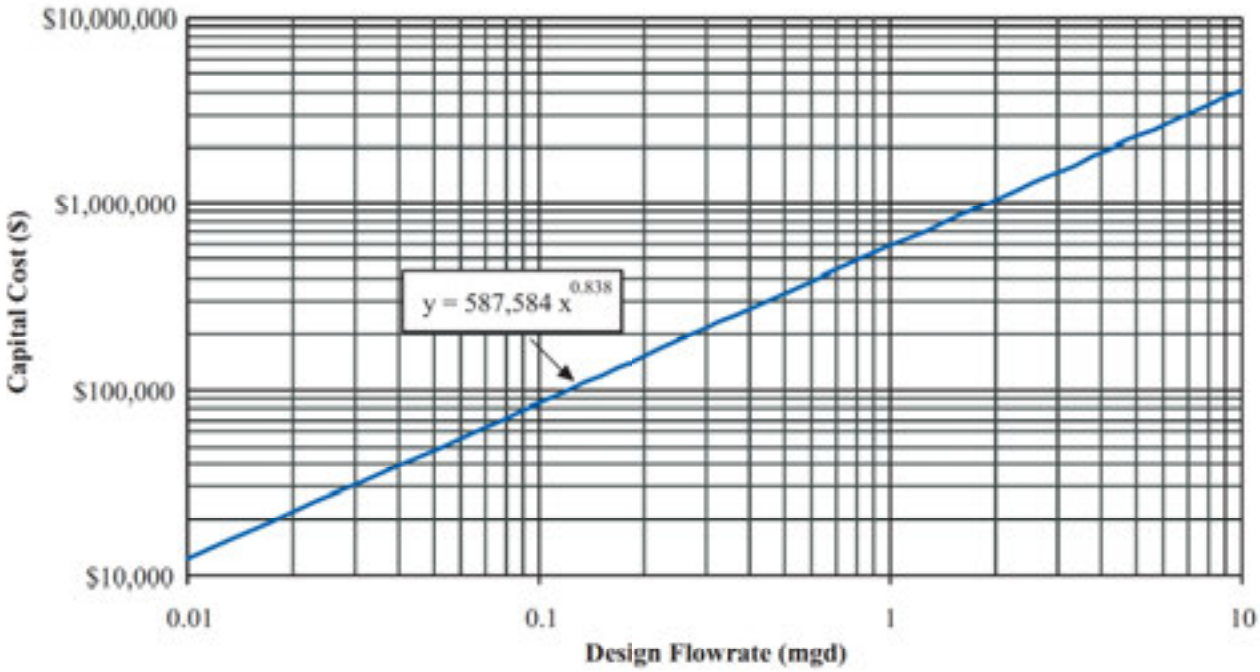


Figure 4-21. Greensand Capital Costs.

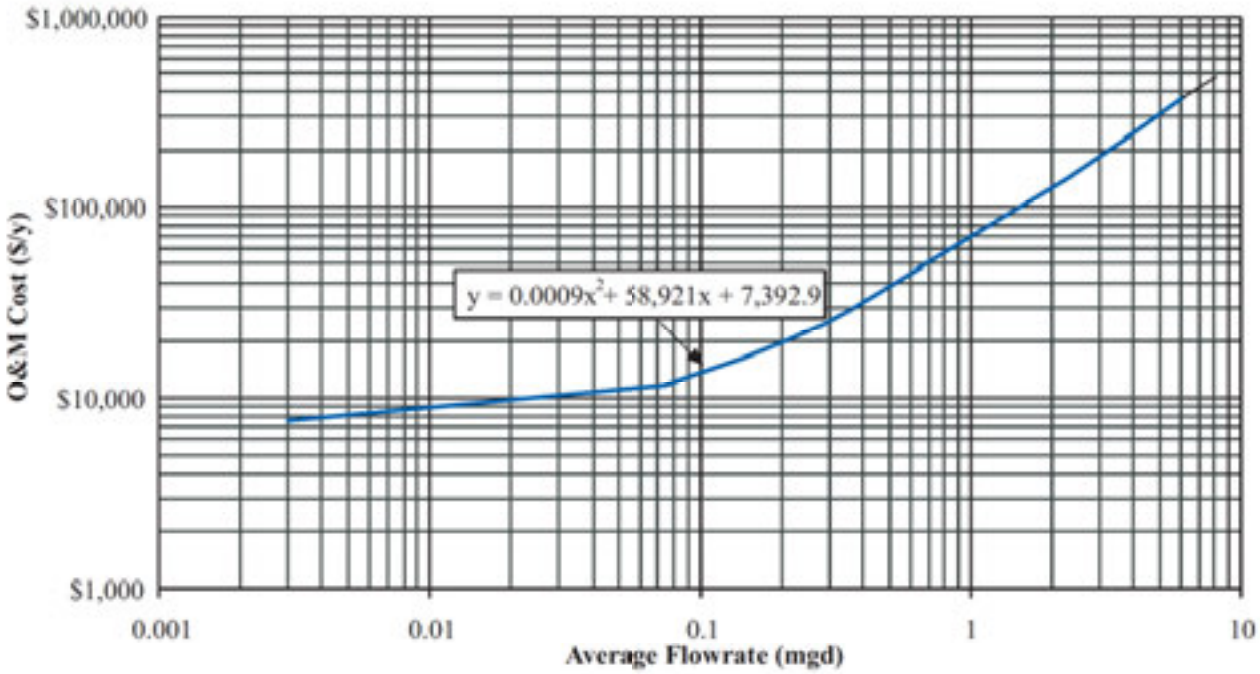


Figure 4-22. Greensand O&M Costs.

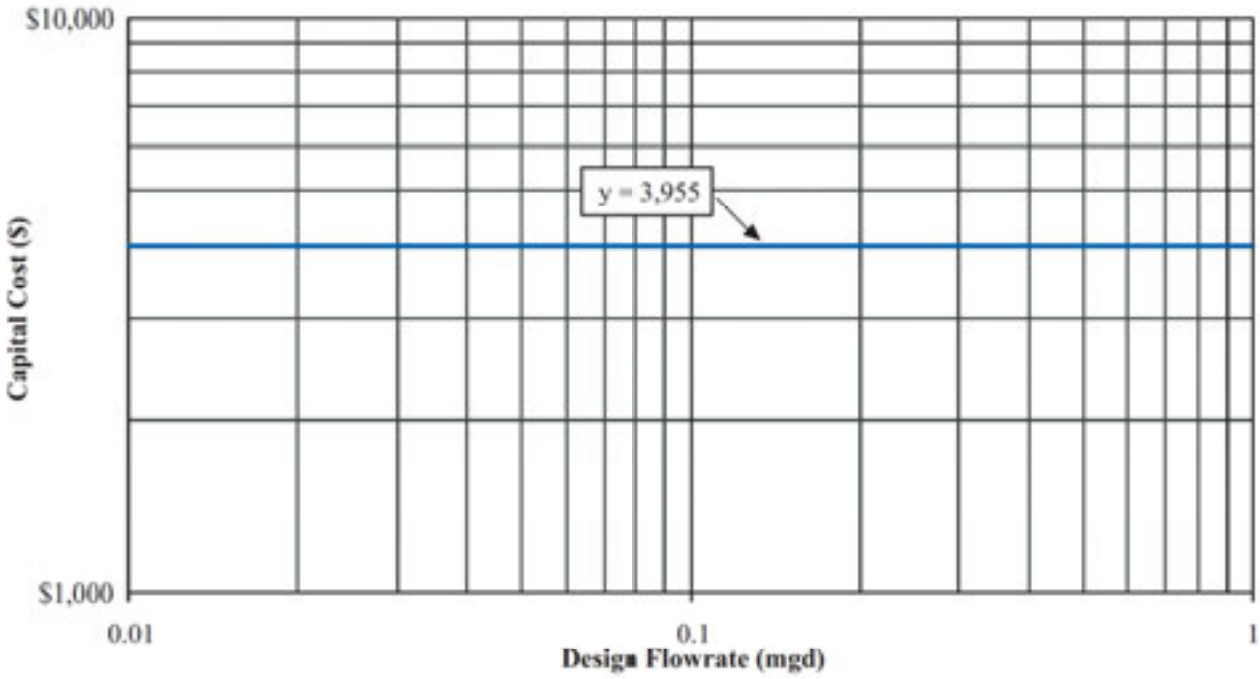


Figure 4-23. Greensand Waste Disposal Capital Costs.

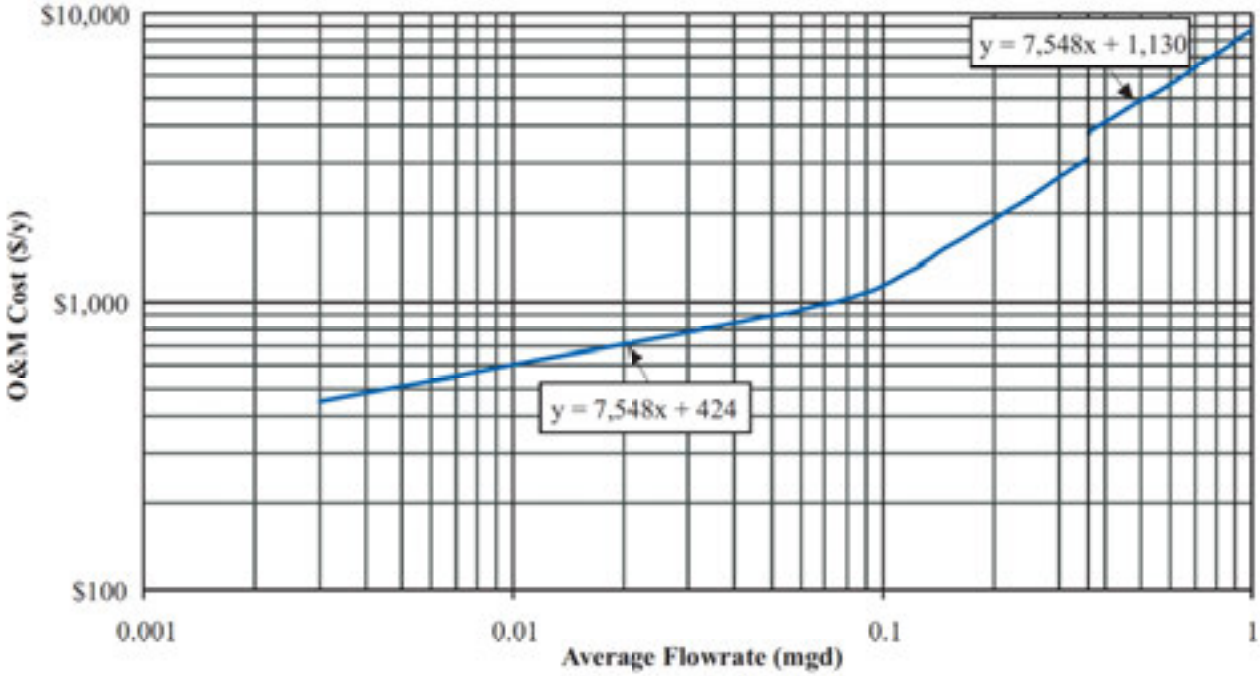


Figure 4-24. Greensand Waste Disposal O&M Costs.

4.6 Coagulation Assisted Microfiltration System Costs

Costs presented in the following charts make the following assumptions:

- Ferric chloride dose of 25 mg/L.
- For Systems Less Than 1 MGD:
  - Package plants with a hydraulic loading rate of 5 gpm/sft.
  - Sodium hydroxide dose of 20 mg/L for pH control.
  - Standard MF.
- For Systems Larger Than 1 MGD:
  - Rapid mix for 1 minute.
  - Flocculation for 20 minutes.
  - Sedimentation at 1000 gpd/sft using rectangular tanks.
  - Standard MF.
- Waste is dewatered before being disposed of in a non-hazardous landfill. Costs are given for dewatering performed either mechanically or non-mechanically. Land costs are not included in the waste disposal costs.

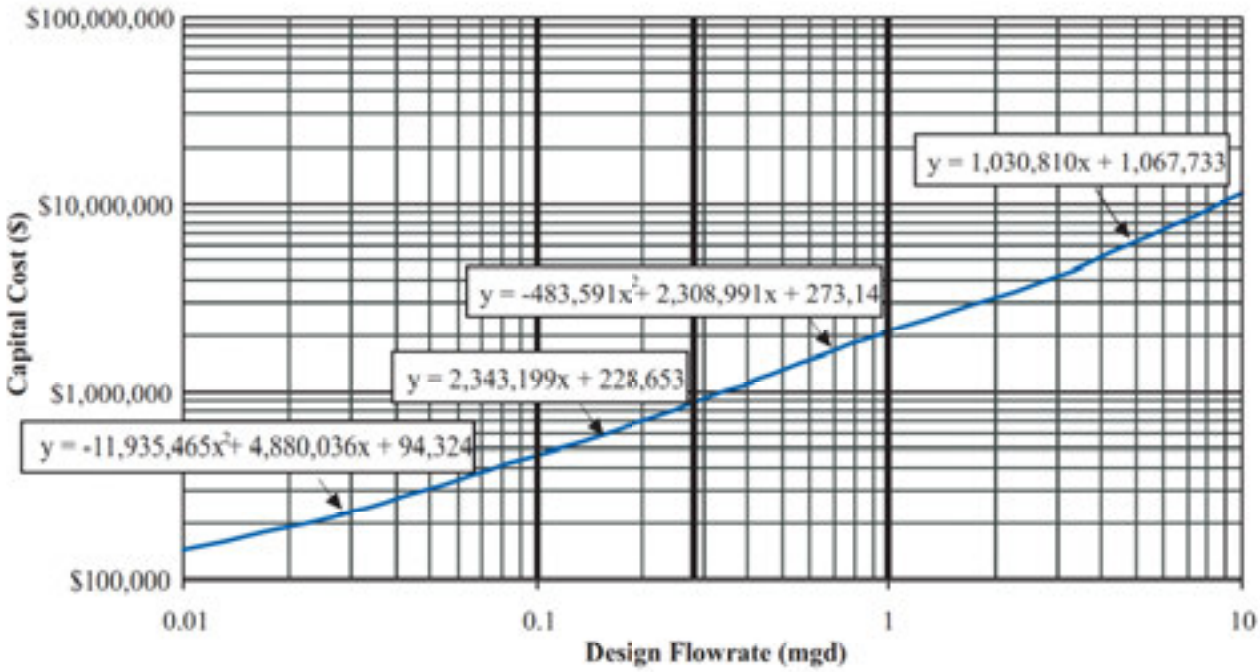


Figure 4-25. Coagulation Assisted Microfiltration Capital Costs.

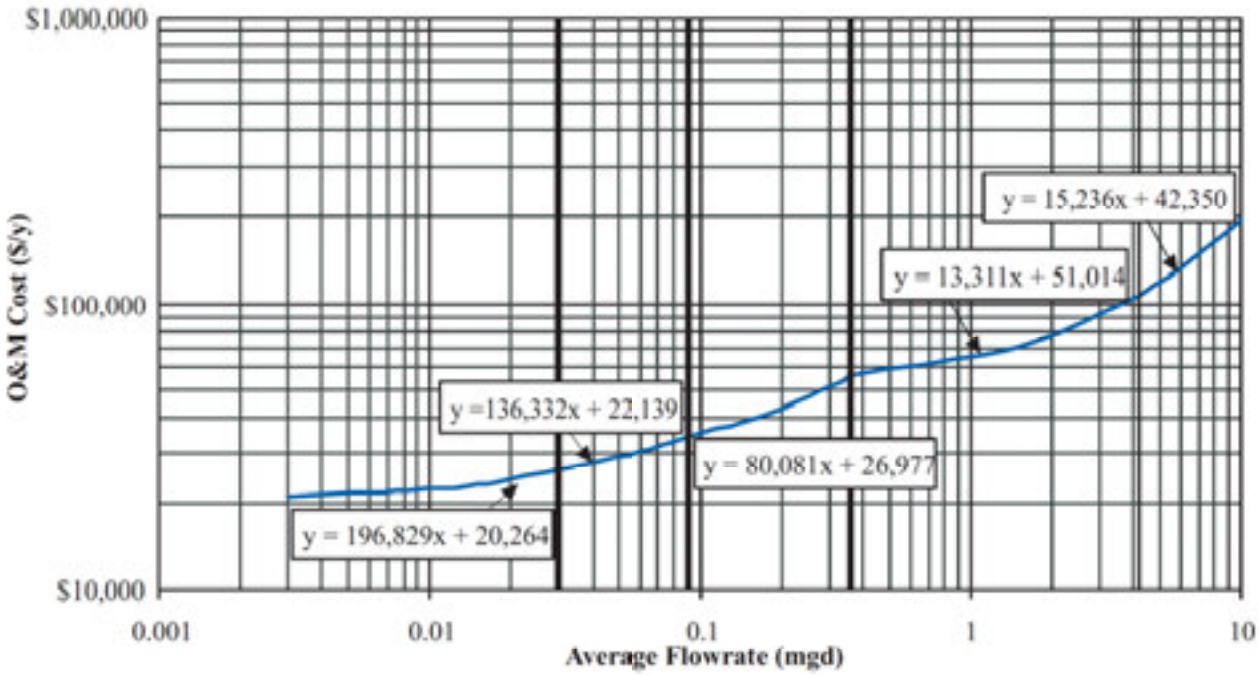


Figure 4-26. Coagulation Assisted Microfiltration O&M Costs.

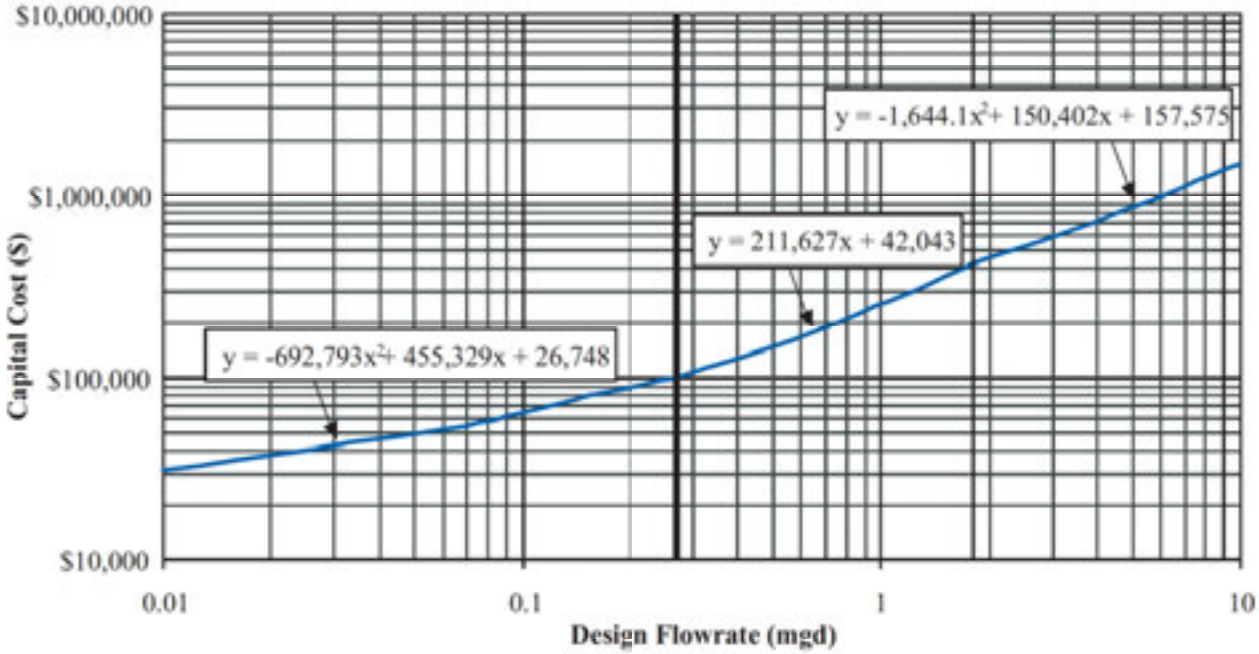


Figure 4-27. Coagulation Assisted Microfiltration (w/ Mechanical Dewatering) Waste Disposal Capital Costs.

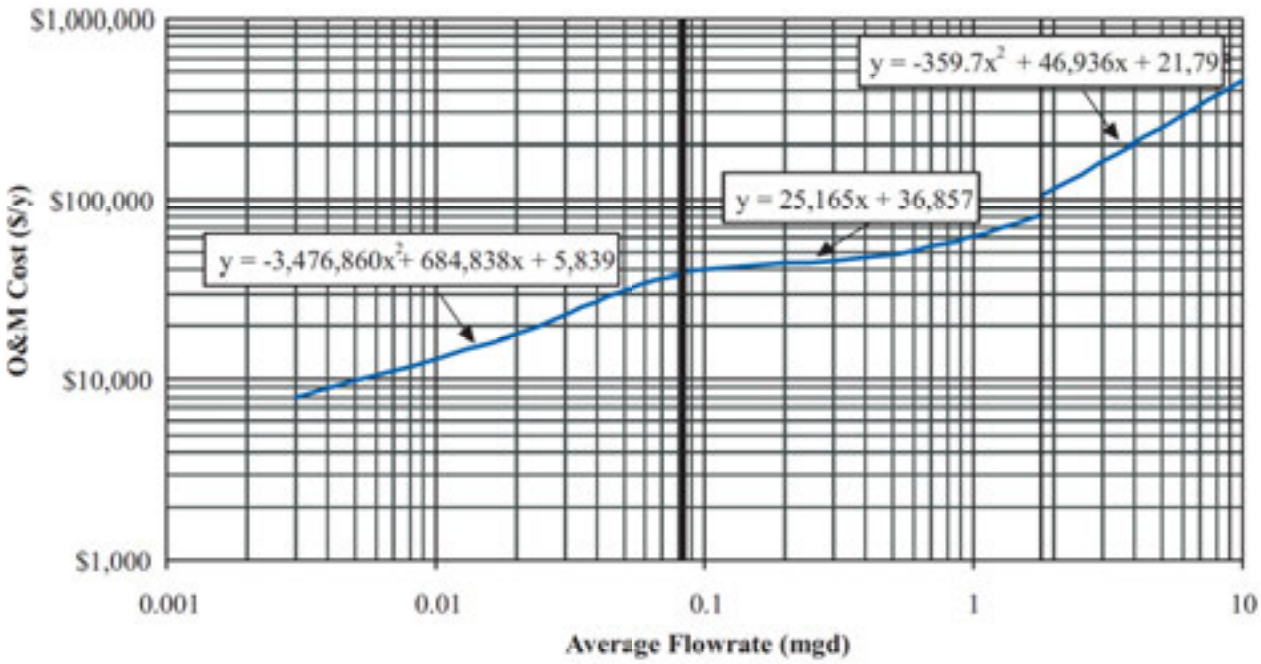


Figure 4-28. Coagulation Assisted Microfiltration (w/ Mechanical Dewatering) Waste Disposal O&M Costs.

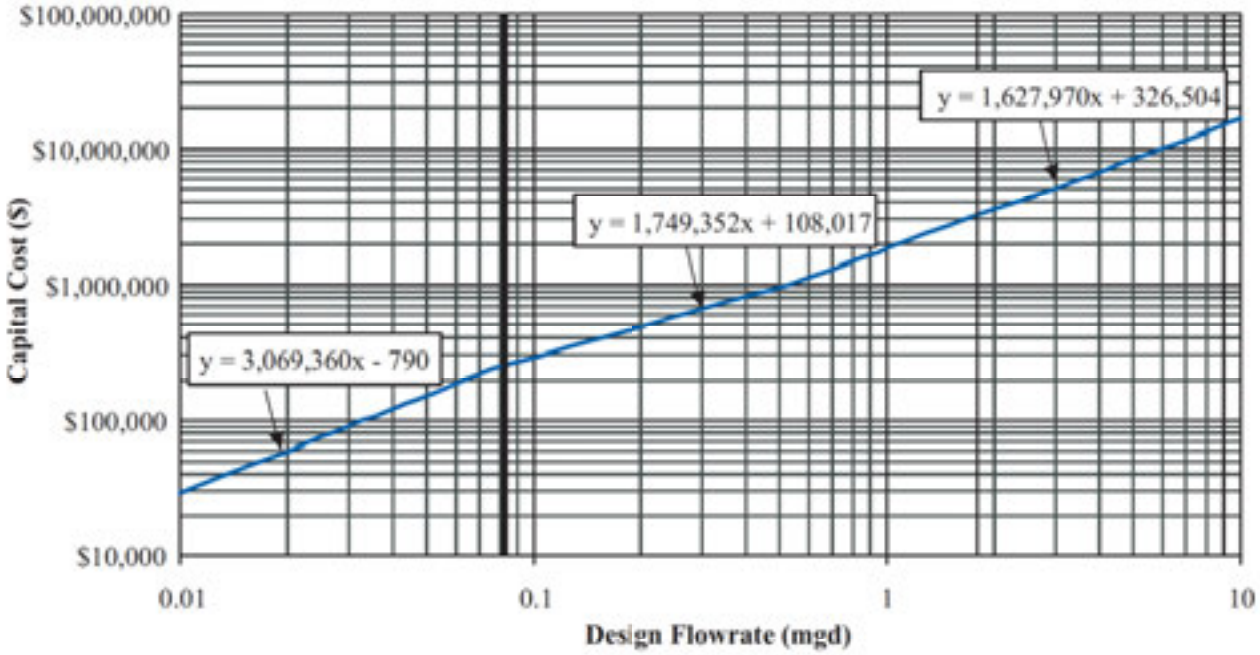


Figure 4-29. Coagulation Assisted Microfiltration (w/ NonMechanical Dewatering) Waste Disposal Capital Costs.

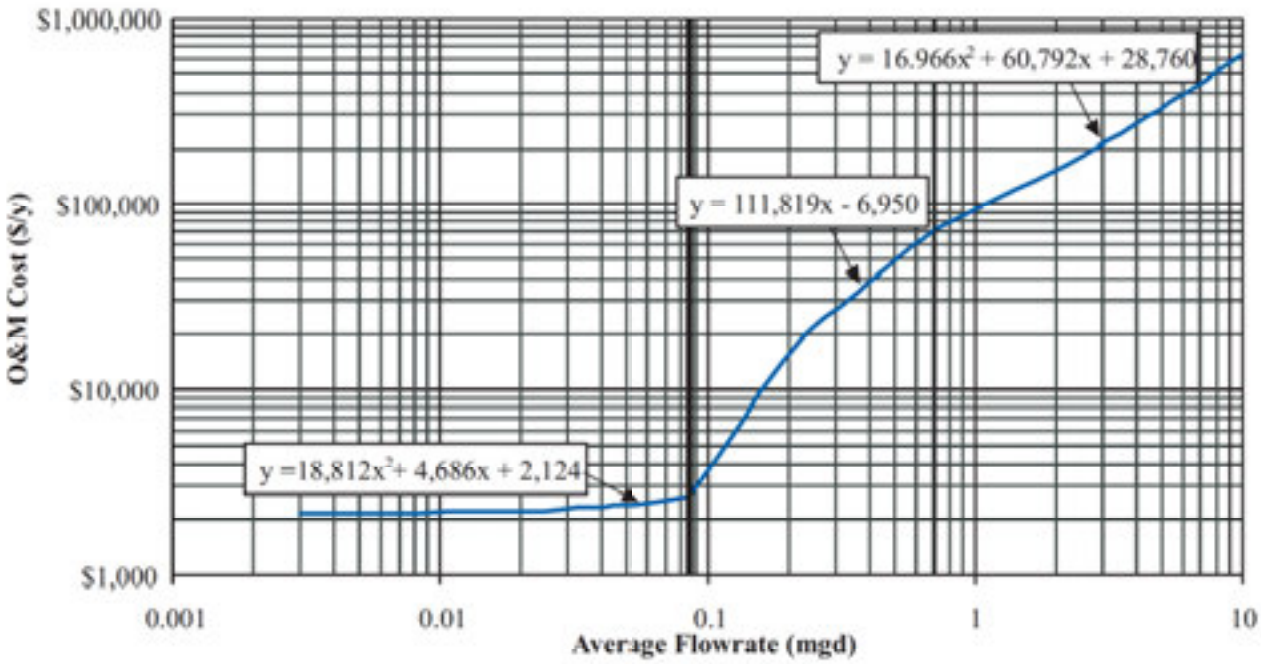


Figure 4-30. Coagulation Assisted Microfiltration (w/ NonMechanical Dewatering) Waste Disposal O&M Costs.

4.7 Coagulation/Filtration System Enhancement Costs

Costs presented in the following charts make the following assumptions:

- A coagulation/filtration system is already installed. Costs are only for system enhancement for arsenic removal.
- Assumptions about the Existing Coagulation/Filtration System:
  - Existing coagulation/filtration system removes 50% of the arsenic without enhancement.
  - Ferric chloride dose of 25 mg/L.
  - Polymer dose of 2 mg/L.
  - Lime dose of 25 mg/L for pH control.
  - Systems less than 1 MGD are package plants with a hydraulic loading rate of 5 gpm/sft.
  - Systems Larger Than 1 MGD:
    - Rapid mix for 1 minute.
    - Flocculation for 20 minutes.
    - Sedimentation at 1000 gpd/sft using rectangular tanks.
    - Dual media gravity filters running at a hydraulic loading rate of 5 gpm/sft.
- Assumptions for the Enhancement of the Coagulation/Filtration System:
  - Additional ferric chloride dose of 10 mg/L.
  - Additional feed system for increased ferric chloride dose.
  - Additional lime dose of 10 mg/L for pH adjustment.
  - Additional feed system for increased lime dose.

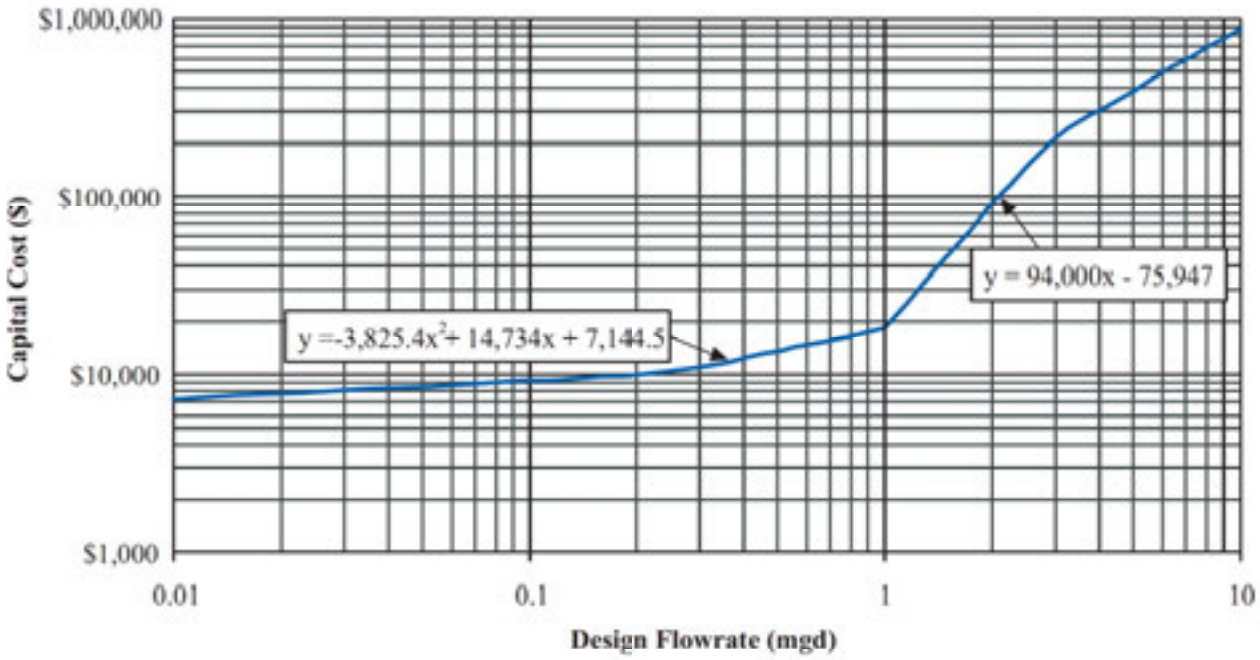


Figure 4-31. Coagulation/Filtration System Enhancement Capital Costs.

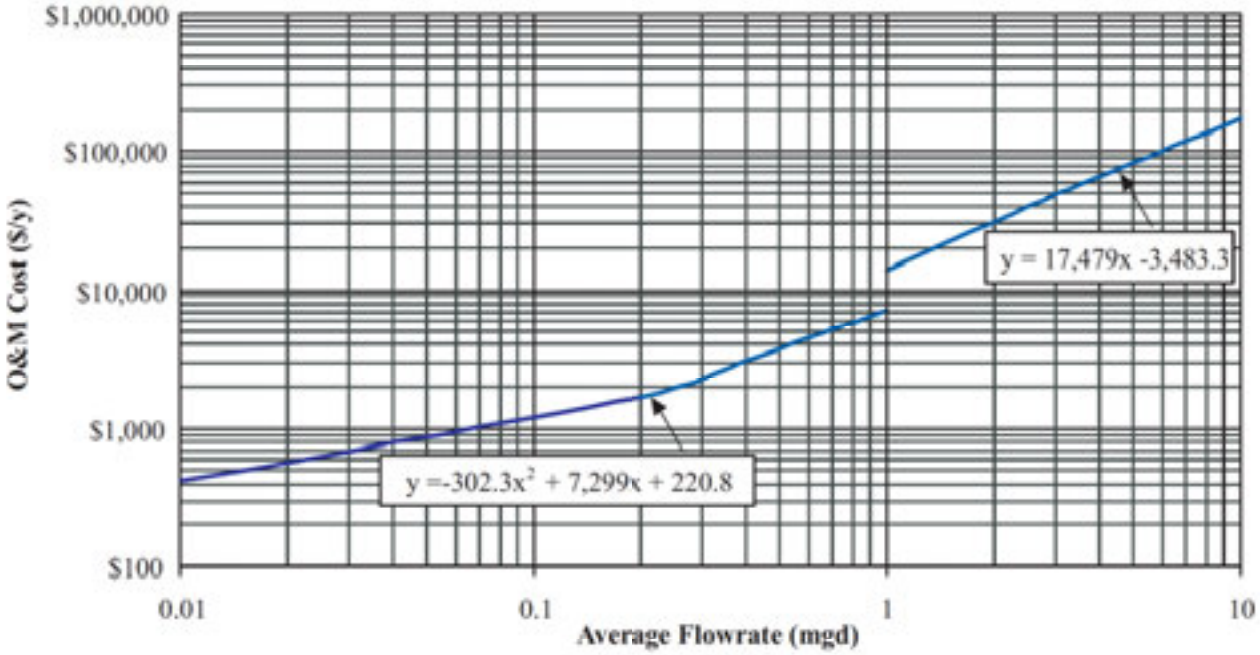


Figure 4-32. Coagulation/Filtration System Enhancement O&M Costs.Lime Softening System Enhancement Costs

4.8 Lime Softening System Enhancement Costs

Costs presented in the following charts make the following assumptions:

- An LS system is already installed. Costs are only for system enhancement for arsenic removal.
- Lime dosage of 250 mg/L.
- Carbon dioxide dosage of 35 mg/L for recarbonation.
- Assumptions about the Existing LS System:
  - Systems less than 1 MGD are package plants.
  - Systems Larger Than 1 MGD:
    - Rapid mix for 1 minute.
    - Flocculation for 20 minutes.
    - Sedimentation at 1500 gpd/sft using circular tanks.
    - Dual media gravity filters running at a hydraulic loading rate of 5 gpm/sft.
- Assumptions for the Enhancement of Existing LS System:
  - Additional lime dose of 50 mg/L.
  - Additional feed system for increased LS dose.
  - Additional carbon dioxide dose of 35 mg/L for recarbonation.
  - Additional feed system for increased carbon dioxide dose.

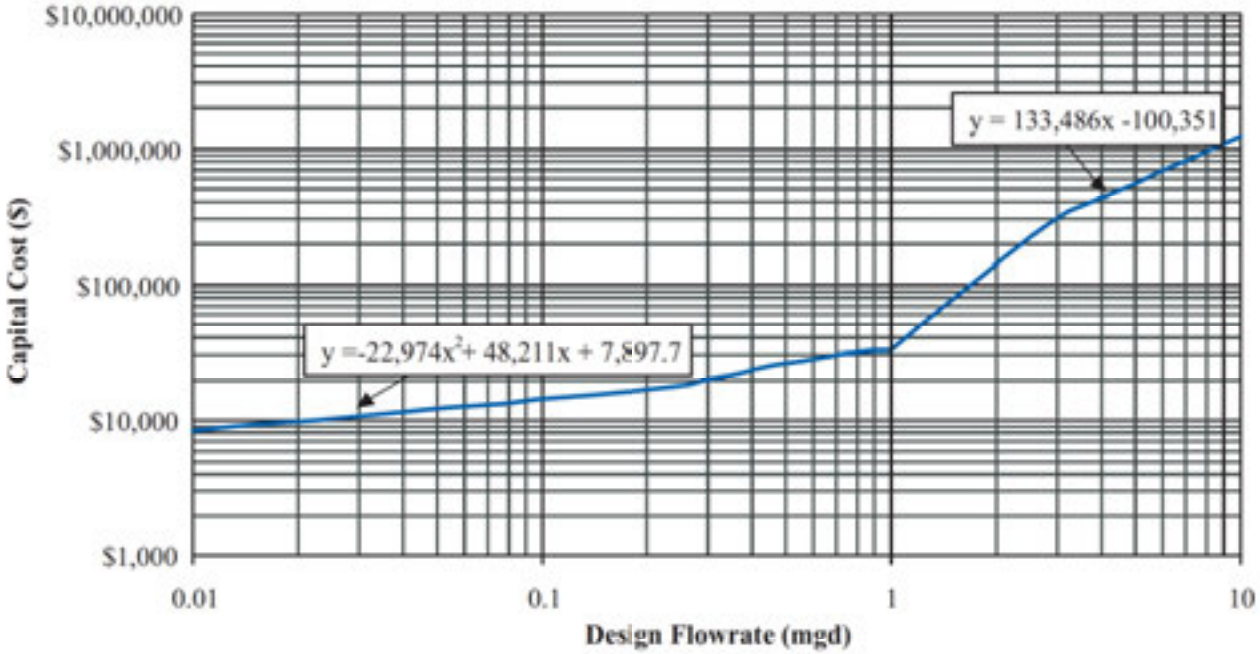


Figure 4-33. Lime Softening Enhancement Capital Costs.

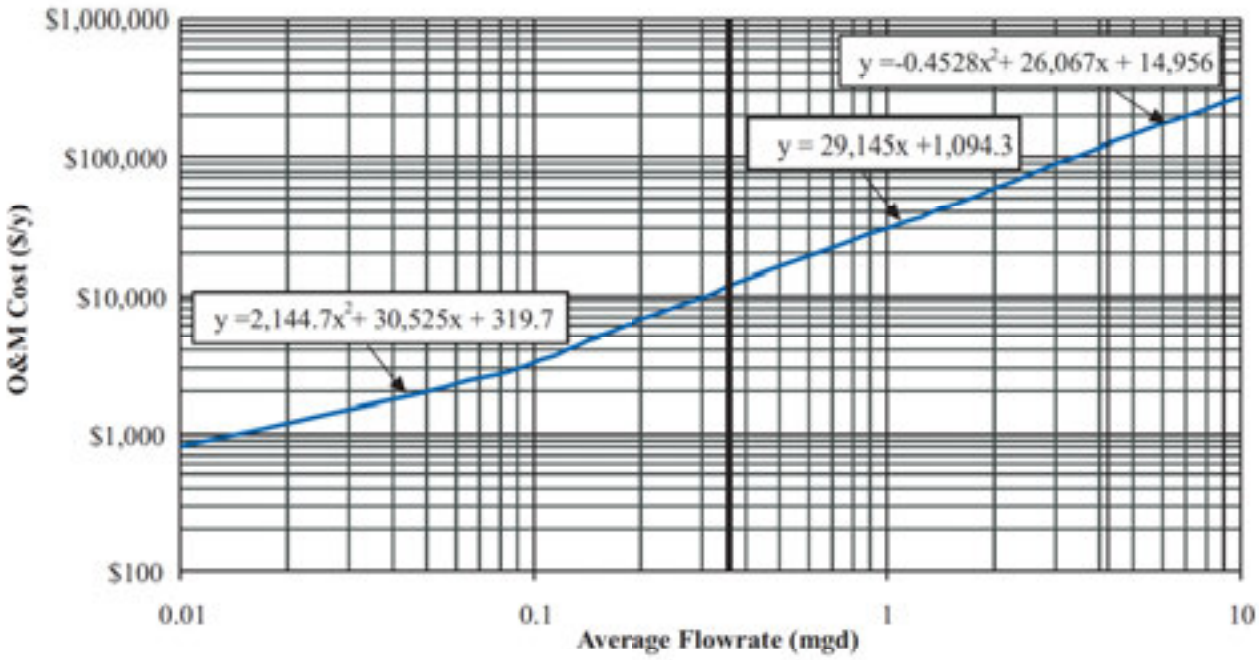


Figure 4-34. Lime Softening Enhancement O&M Costs.

4.9 Point-of-Use Reverse Osmosis System Costs

Costs presented in the following charts make the following assumptions:

- In an average household, there are 3 individuals using 0.53 gallon each per day for a total of 579 gallons per year.[10]
- Life of POU unit is 5 years.
- Duration of cost study is 10 years.
- Cost of water meter and automatic shut-off valve included.
- No shipping and handling included.
- If the water is chlorinated, dechlorination may be required. Costs for dechlorination are not included.
- Volume discount schedule—retail for a single unit, 10 percent discount for 10 or more units, 15 percent discount on more than 100 units.
- Installation time—1 hour unskilled labor (POU)
- Minimally skilled labor—$14.50 per hour (population less than 3,300 individuals).
- Skilled labor—$28 per hour (population greater than 3,300 individuals).
- O&M costs include maintenance, replacement of pre-filters and membrane cartridges, laboratory sampling and analysis, and administrative costs.

[10] USEPA, 1998.

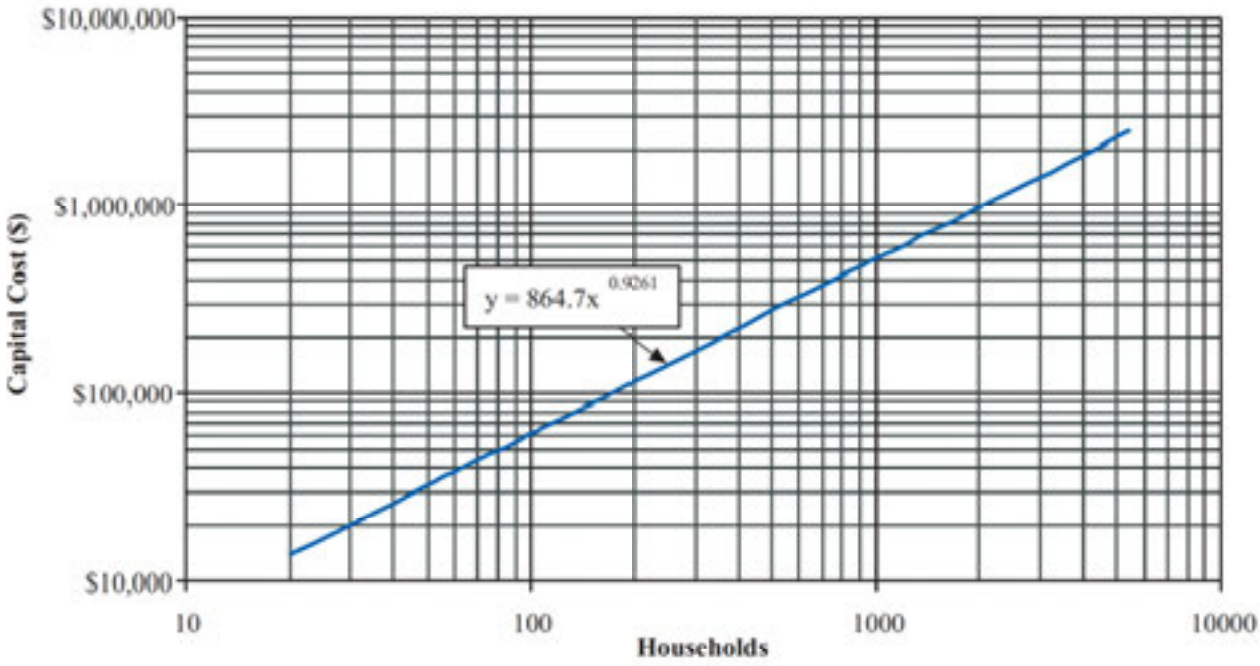


Figure 4-35. POU Reverse Osmosis Capital Costs.

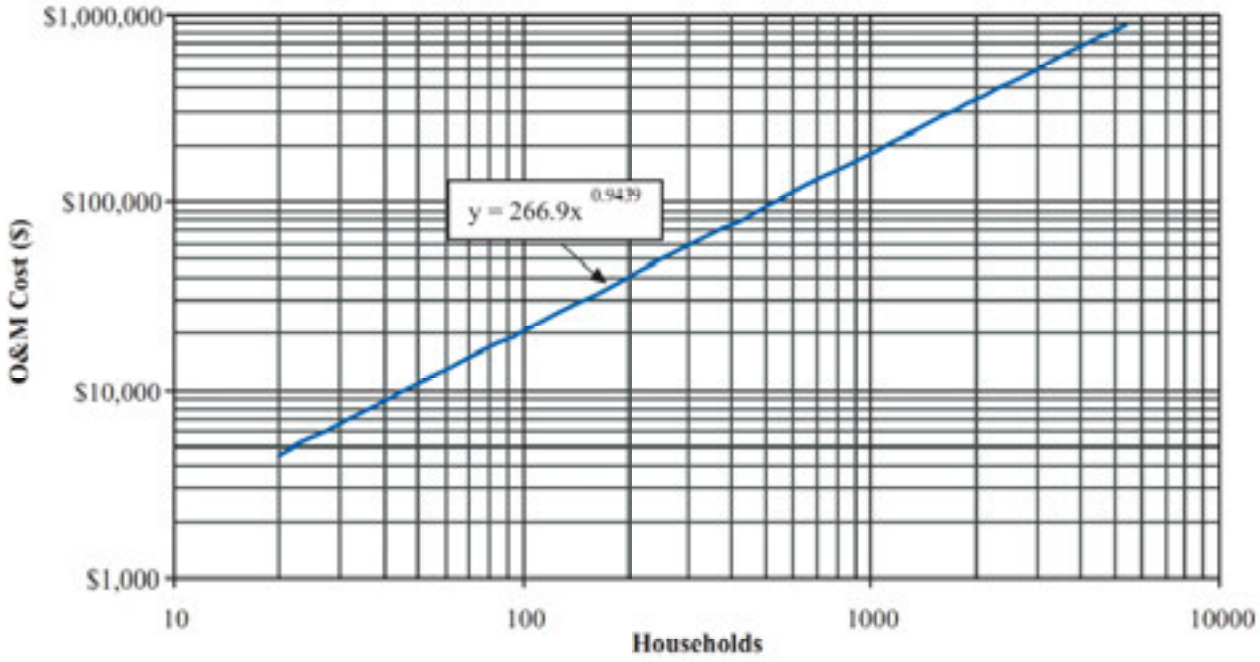


Figure 4-36. POU Reverse Osmosis O&M Costs.

4.10 Point-of-Use Activated Alumina System Costs

Costs presented in the following charts make the following assumptions:

- In an average household, there are 3 individuals using 0.53 gallon each per day for a total of 579 gallons per year.[11]
- Life of POU unit is 5 years.
- Duration of cost study is 10 years.
- Cost of water meter and automatic shut-off valve included.
- No shipping and handling included.
- Volume discount schedule—retail for a single unit, 10 percent discount for 10 or more units, 15 percent discount on more than 100 units.
- Installation time—1 hour unskilled labor (POU)
- Minimally skilled labor—$14.50 per hour (population less than 3,300 individuals).
- Skilled labor—$28 per hour (population greater than 3,300 individuals).
- O&M costs include maintenance, replacement of pre-filters and membrane cartridges, laboratory sampling and analysis, and administrative costs.

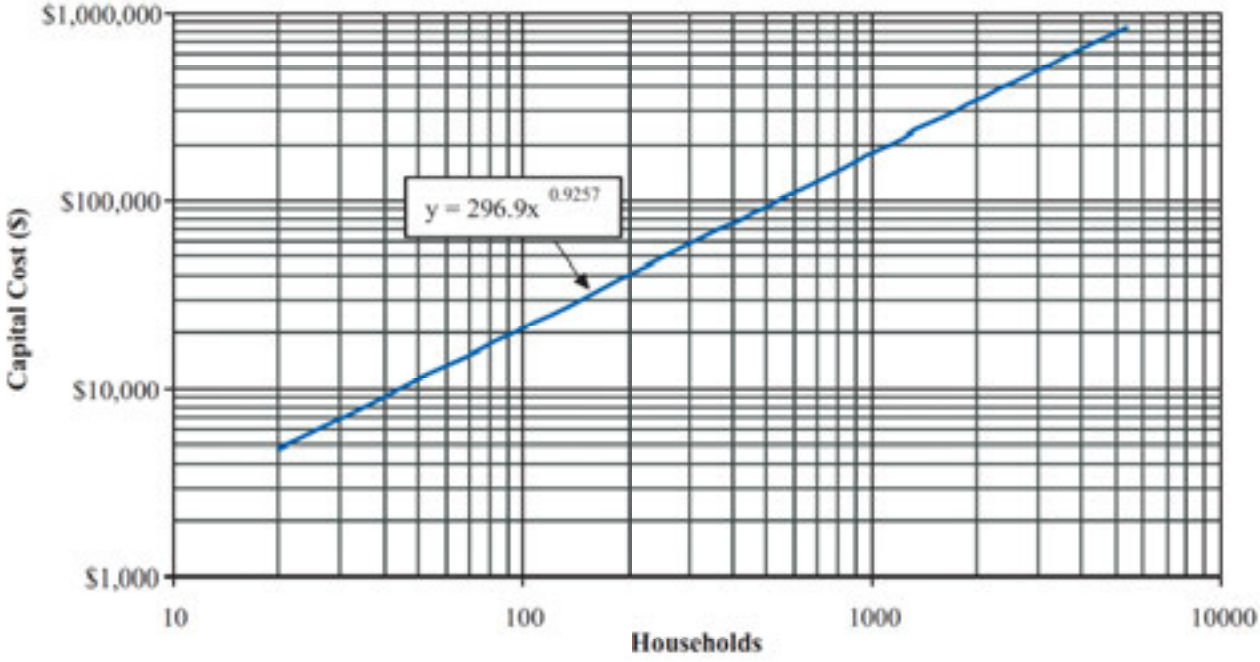


Figure 4-37. POU Activated Alumina Capital Costs.

[11] USEPA, 1998.

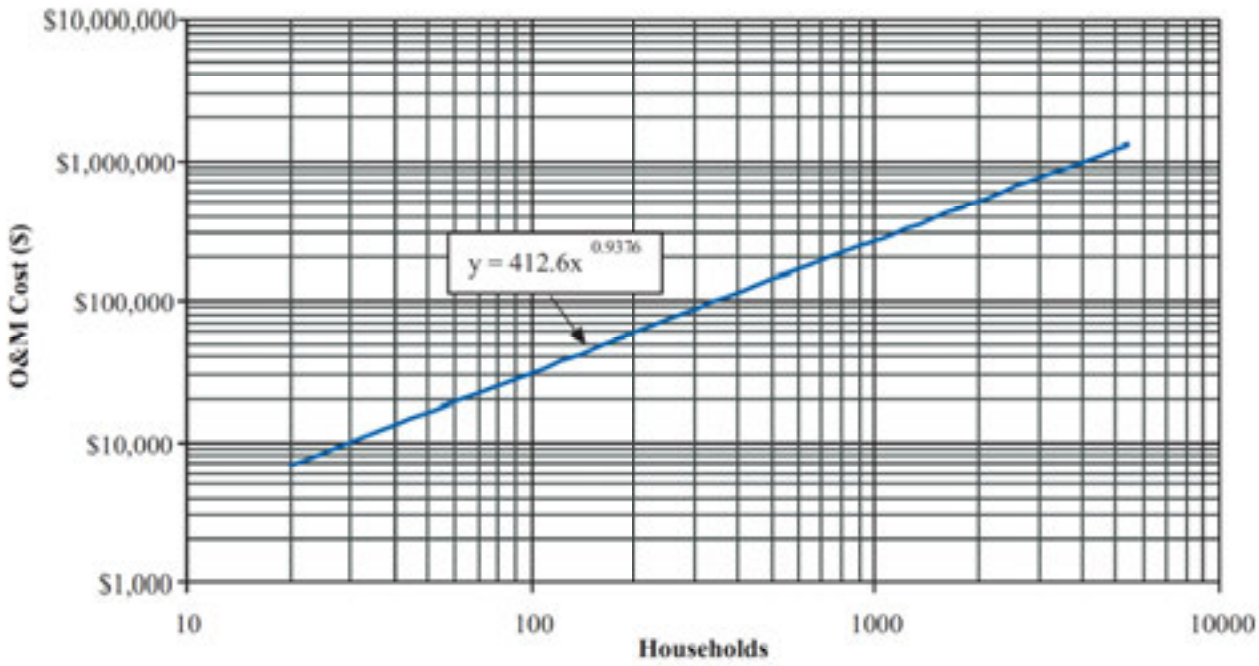


Figure 4-38. POU Activated Alumina O&M Costs.

4.11 Point-of-Use Iron Based Sorbent System Costs

Iron based sorbents (IBS) are relatively new technologies and, as such, the costs for using small IBS units in a POU scheme have not been well defined. Costs for an IBS POU system are anticipated to be similar to those of an AA POU system.

Section 5
Pre-Oxidation Design Considerations

The conversion of reduced inorganic As(III) to As(V) is critical for achieving optimal performance of *all* unit processes described in this Handbook. Conversion to As(V) can be accomplished by providing an oxidizing agent at the head of any proposed arsenic removal process. Chlorine and permanganate are highly effective for this purpose. They oxidize As(III) to As(V) within one minute in the pH range of 6.3 to 8.3. Ozone rapidly oxidizes As(III) but its effectiveness is significantly diminished by the presence of sulfides or TOC. Solid phase oxidants such as Filox-R™ have also been shown to oxidize As(III). Chlorine dioxide and monochloramine are ineffective in oxidizing As(III). UV light, by itself is also ineffective. However, if the water is spiked with sulfite, UV photo-oxidation shows promise. Because of these considerations, only chlorine, permanganate, ozone, and solid phase oxidants are discussed in this section.

5.1 Chlorine Pre-Oxidation Design Considerations

The primary applications of chlorine in water treatment include pre-oxidation, primary disinfection, and secondary disinfection. Several arsenic removal processes, particularly membranes, are chlorine sensitive and/or intolerant. In these instances, the utility should consider an alternate oxidation technology. If this is the case, but the system already has chlorination capabilities in place, the process of modifying the existing system to achieve As(III) oxidation is complicated. One alternative is the application of a pre-chlorination—dechlorination—arsenic removal—re-chlorination treatment setup. However, this alternative may be more costly than integrating a permanganate pre-oxidation system.

Chlorine can be added either as liquid sodium hypochlorite (Equation 5-1) or dissolved gas (Equation 5-2). In either case, biocidal hypochlorous acid is generated.

$$NaOCl + H_2O \rightarrow HOCl + NaOH \qquad \text{Eqn. 5-1}$$

$$Cl_2 + H_2O \rightarrow HOCl + HCl \qquad \text{Eqn. 5-2}$$

The first step in selecting the most appropriate method of chlorination is to determine the chlorine flow requirements for the particular application. Chlorine demand can be calculated with Equation 5-3.

$$M_{Cl_2} = Q \cdot \delta_{Cl_2} \cdot \left(0.012 \frac{\text{min}}{\text{d}} \cdot \frac{\text{L}}{\text{gal}} \cdot \frac{\text{lb}}{\text{mg}} \right) \qquad \text{Eqn. 5-3}$$

where:

M_{Cl_2} = Chlorine Mass Flow (lb/day of Cl_2),

Q = Design Flow Rate (gpm), and

δ_{Cl_2} = Chlorine Dose (mg/L as Cl_2).

Careful consideration should be given to the chlorine dose estimate. Most waters contain substances other than As(III) that exert chlorine demand. In many cases, these substances compete for chlorine more aggressively than As(III). Section 2.2.1 lists the chlorine demand for the stoichiometric conversion of As(III), Fe^{2+}, Mn^{2+}, and HS^-. Chlorine will also react with ammonia and TOC. Simple chlorine demand bench testing can be used to ascertain the instantaneous and ultimate chlorine demand of particular water. The applied chlorine dose should be three times the ultimate chlorine demand.

$$\delta_{Cl_2} = 3 \cdot D_{Cl_2} \qquad \text{Eqn. 5-4}$$

Where:

δ_{Cl_2} = Chlorine Dose (mg/L as Cl_2), and

D_{Cl_2} = Ultimate Chlorine Demand (mg/L as Cl_2).

Selection of the type of chlorination system should include consideration of capital and operating costs, O&M requirements, code restrictions, containment requirements, footprint, and safety concerns. This Handbook will address the following options, which are considered most viable for small water systems:

- Commercial liquid hypochlorite feed system
- On-site hypochlorite generation system

The application of chlorine gas for chlorination is not discussed as it is more hazardous, frequently more expensive, and frequently less applicable to small systems.

5.1.1 Commercial Liquid Hypochlorite

Liquid sodium hypochlorite can be purchased as a 5¼% or 12½% strength solution. The solution must be delivered to the facility by tanker trucks or in drums on a regular basis. The solution is stored on-site in a tank and metered into the system by a small pump. Figure 5-1 shows a flow diagram for a typical liquid hypochlorite process. Figure 5-2 is a typical flow schematic for a flooded suction hypochlorite metering system.

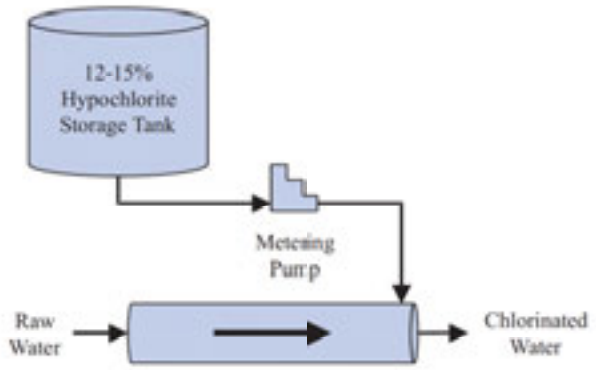


Figure 5-1. Typical Liquid Hypochlorite Process Flow Diagram.

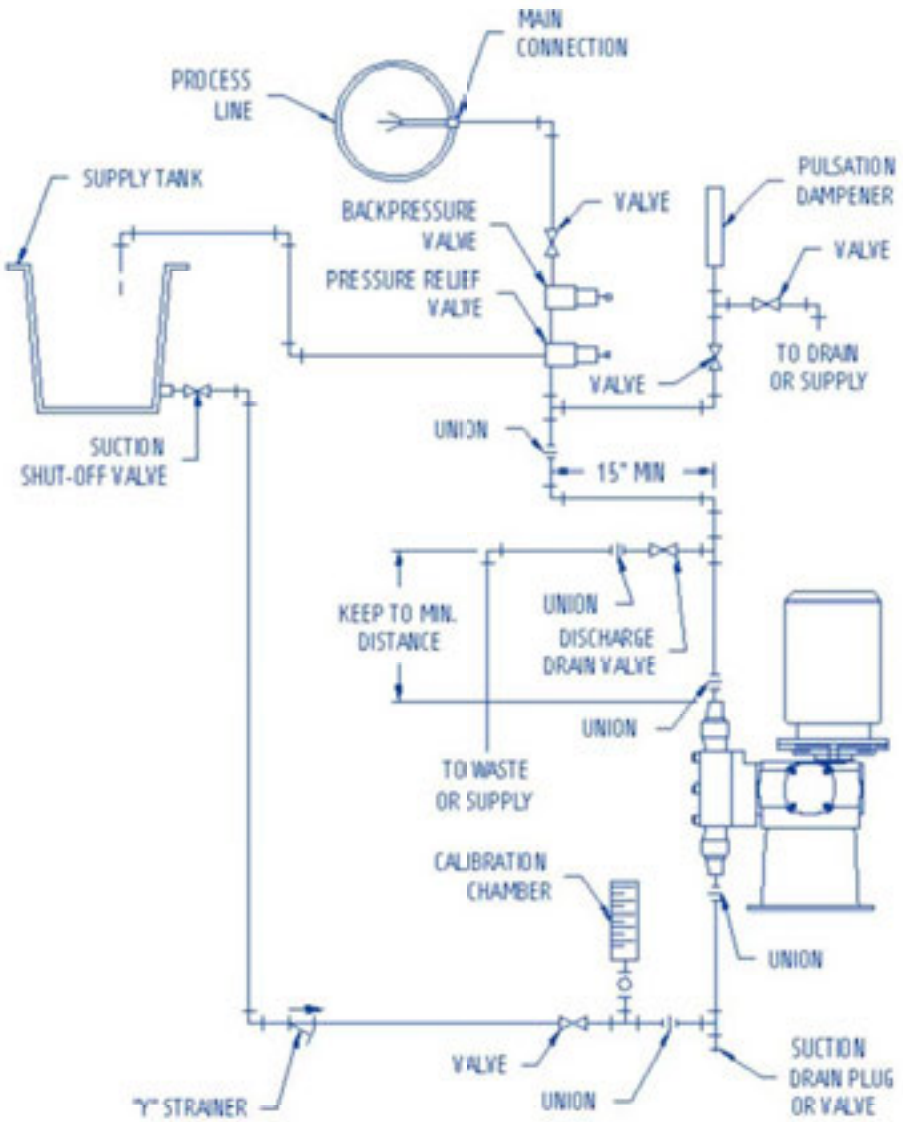


Figure 5-2. Liquid Hypochlorite System Schematic (USFilter, Wallace & Tiernan).

The flow rate of liquid hypochlorite required to meet chlorine mass flow requirements can be approximated by Equation 5-5. This flow rate should be used to size the metering pump, as well as provide an estimate of chemical operating costs.

$$Q_{Cl_2} = \frac{M_{Cl_2}}{C_{Cl_2}} \left(\frac{d}{24\,hr} \right) \qquad \text{Eqn. 5-5}$$

Where:

Q_{Cl_2} = Hypochlorite Metering Pump Rate (gph) and

M_{Cl_2} = Chlorine Mass Flow (lb/day of Cl_2).

C_{Cl_2} = Concentration of Chlorine Solution (lbs Cl_2/gal).

For 12.5 wt% Sodium Hypochlorite, the concentration is 1.26 lbs/gal.
For 5.25 wt% Sodium Hypochlorite, the concentration is 0.47 lbs/gal.
For 0.008 wt% Sodium Hypochlorite, the concentration is 0.068 lbs/gal.

The required capacity of the storage tank is contingent upon the desired frequency of tanker truck deliveries. Tanks are commonly sized to provide 7-21 days of storage. Because commercial strength liquid hypochlorite is a Class 1 Liquid Oxidizer, storage of more than 4,000 pounds represents a non-exempt quantity and requires special precautions. The storage volume required may be calculated as follows.

$$V = \left(Q_{Cl_2} \cdot t\right) \cdot \left(24 \frac{hr}{day} \right) \qquad \text{Eqn. 5-6}$$

Where:

V = Storage Volume (gal),

Q_{Cl_2} = Hypochlorite Metering Pump Rate (gph), and

t = Storage Time (days).

5.1.2 On-Site Hypochlorite Generation

On-site generation of sodium hypochlorite is accomplished by adding electricity to a saturated (32%) brine solution. The strength of hypochlorite produced is 0.8%, which is below the hazardous material threshold of 1%. These systems can be constructed piecewise or purchased as pre-engineered units.

Figure 5-3 shows a typical flow diagram for an on-site hypochlorite generation system. The equipment requirements of an on-site generation system, which can be seen in Figure 5-4, include a salt saturator, hypochlorite storage tanks, electrolyzers, rectifiers, controls, and hypochlorite metering pumps. The following material inputs are required per pound of chlorine generated: 3.5 lbs NaCl salt, 15 gallons of water, and 2.5 kWh of electrical energy.

Figure 5-5 shows an on-site hypochlorite generator that will produce up to 36 lbs of chlorine per day.

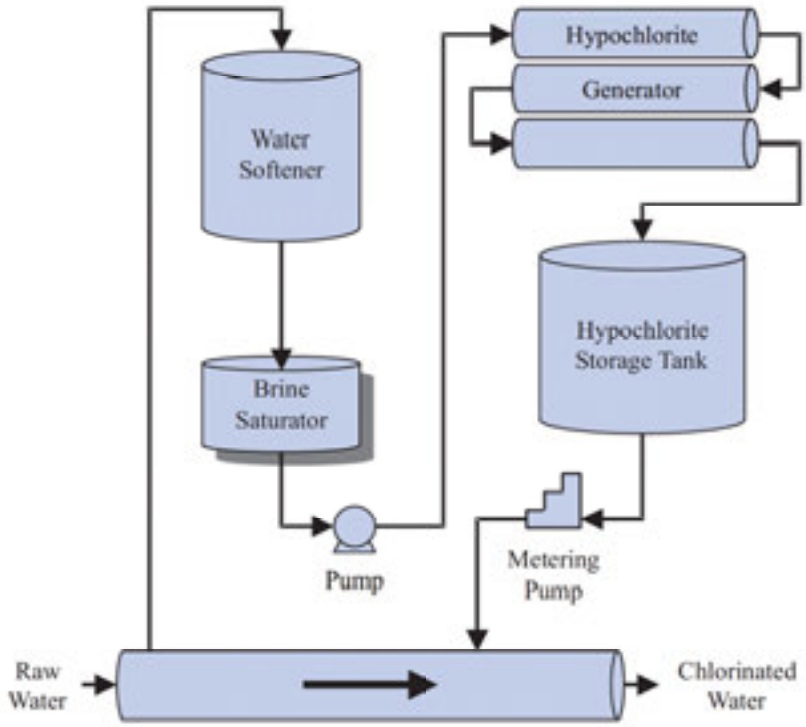


Figure 5-3. Typical On-Site Hypochlorite Generation Process Flow Diagram.

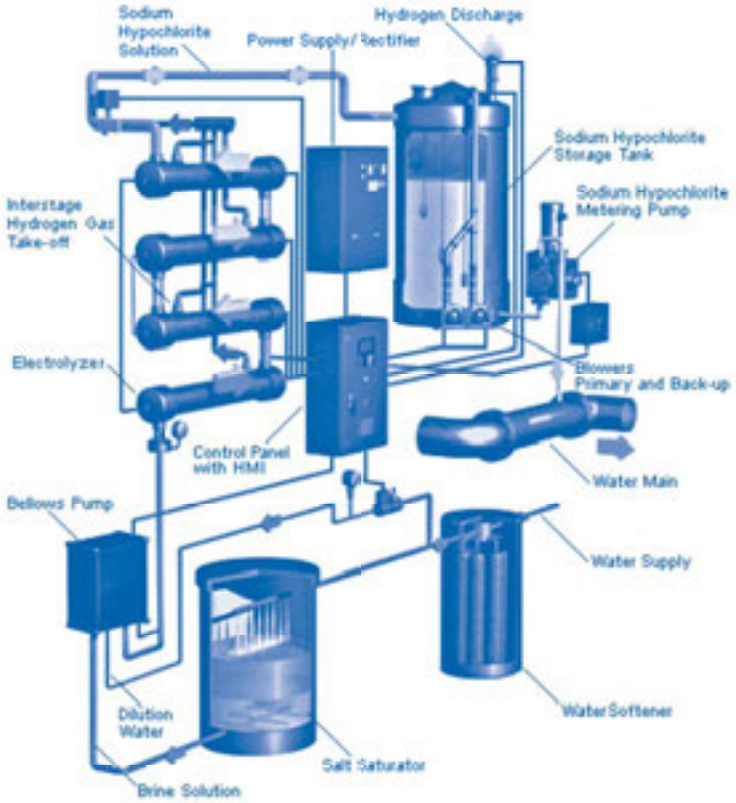


Figure 5-4. On-Site Hypochlorite Generation System Schematic (USFilter, Wallace & Tiernan).

Figure 5-5. On-Site Hypochlorite Generation System (Severn Trent Services).

5.2 Permanganate Pre-Oxidation Design Considerations

The primary applications of permanganate (MnO_4^-) in water treatment include preoxidation (particularly for iron and manganese) and taste and odor control. Potassium permanganate exists in solid, granular form, but is typically applied as a saturated liquid (60 g/L at room temperature).

Permanganate is not biocidal against drinking water pathogens, so there should be negligible residual leaving the treatment works. Manganese particulates (MnO_2) are produced as a result of permanganate oxidation reactions. To prevent the accumulation of these deposits in the distribution system, post-filtration treatment must be applied.

Potassium permanganate is a Class 2 Solid Oxidizer. The storage of more than 250 lbs necessitates special hazardous waste precautions. Potassium permanganate can be purchased in a variety of quantities, including 55-lb (25-kg) pails, 110-lb (50-kg) kegs, and 330-lb (150-kg) drums. The solids can be stored indefinitely if kept in a covered container and maintained in a cool, dry environment. Special handling and safety requirements should be employed when working with solid potassium permanganate, including the use of goggles, rubber gloves, and an approved NIOSH-MSHA dust and mist respirator.

Careful consideration should be given to the permanganate dose estimate. Most waters contain substances other than As(III) that exert oxidant demand. Section 2.2.2 lists the permanganate demand for the stoichiometric conversion of As(III), Fe^{2+}, Mn^{2+}, and HS^-. Permanganate reacts aggressively with organic materials. Permanganate may also be consumed during the regeneration of MnO_2 media. The ultimate permanganate demand is the sum of all these factors. The applied dose should be three times larger than the ultimate permanganate demand.

$$\delta_{MnO_4} = 3 \cdot D_{MnO_4} \qquad \text{Eqn. 5-7}$$

Where:

δ_{MnO_4} = Permanganate Dose (mg/L as Mn) and

D_{MnO_4} = Ultimate Permanganate Demand (mg/L as Mn).

The application of potassium permanganate is straightforward. Permanganate solution is prepared by loading solid potassium permanganate into a storage silo. A feeder meters the permanganate into a dry hopper, which allows the solids to be pulled into a water stream where it dissolves. The permanganate solution is then stored in a solution tank until it is metered into the water to be treated. This process is shown in the flow diagram in Figure 5-6. For small systems looking to maintain simplicity, manually loading solids into a solution tank filled with water to create batch quantities of permanganate solution is recommended.

Pre-engineered drum inverters (Figure 5-7) and dry feeders (Figure 5-8) are available in several different styles, including gravimetric weigh-belt and volumetric (hopper) type.

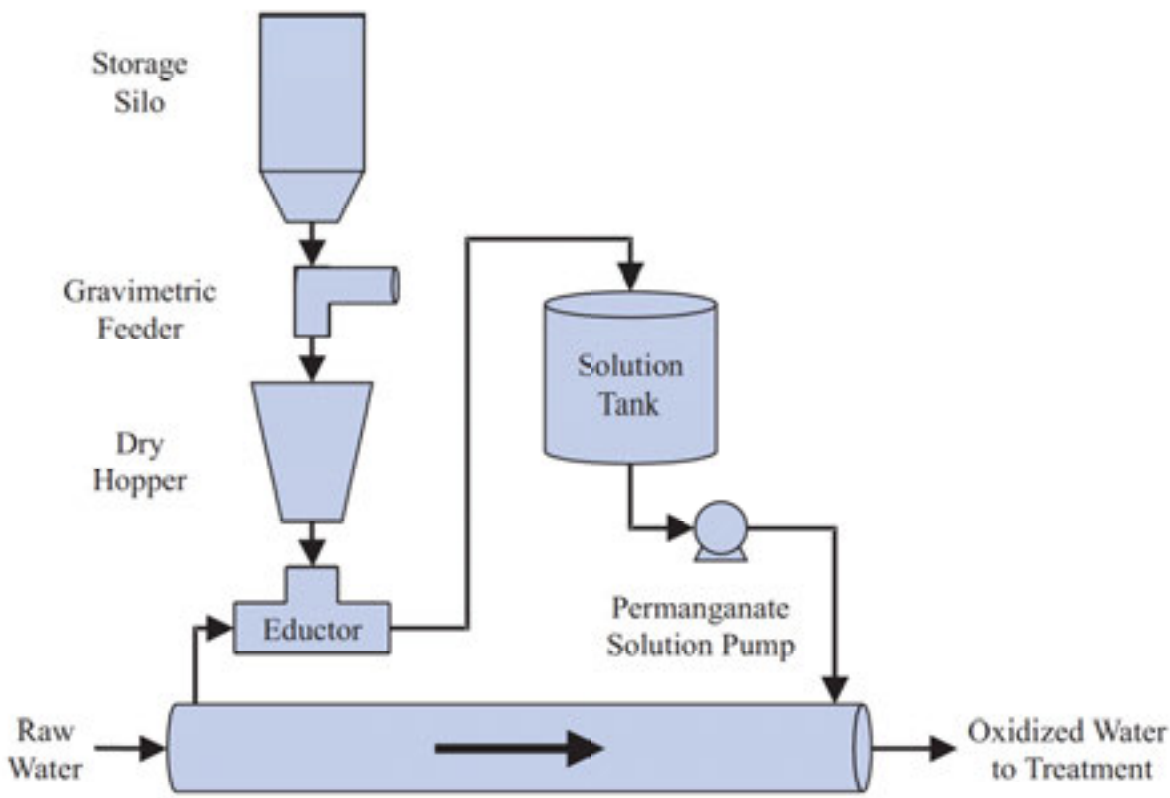


Figure 5-6. Typical Permanganate Process Flow Diagram.

Figure 5-7. Permanganate Dry Feed System (Merrick Industries, Inc.).

Figure 5-8. Permanganate Dry Feed System (Acrison, Inc.).

The stock solution is then metered into the water system with the use of a small pump. The flow rate of solution required to meet the dose requirements are contingent upon the strength of the stock solution, according to Equation 5-8.

$$Q_{MnO_4} = \frac{Q \cdot \delta_{MnO_4}}{C_{MnO_4} - \delta_{MnO_4}} \cdot \left(60 \frac{\text{min}}{\text{hr}}\right) \qquad \text{Eqn. 5-8}$$

Where:

Q_{MnO_4} = Permanganate Metering Pump Rate (gph),

Q = Design Flowrate (gpm),

δ_{MnO_4} = Permanganate Dose (mg/L), and

C_{MnO_4} = Permanganate Stock Solution Concentration (mg/L).

5.3 Ozone Pre-Oxidation Design Considerations

Ozone can be used in water treatment for disinfection, oxidation, and taste and odor control. Ozone is a gas and is created either by passing air through an electrical discharge or by irradiating air with UV light. The UV method is much less expensive, quite reliable, and can produce ozone in a 0.1% concentration.

Careful consideration should be given to the ozone dose estimate. Most waters contain substances other than As(III) that exert oxidant demand. Section 2.2.3 lists the ozone demand for the stoichiometric conversion of As(III), Fe^{2+}, Mn^{2+}, and HS^-. Ozone will also react with TOC. The ultimate ozone demand is the sum of all these factors. The applied dose should be three times larger than the ultimate ozone demand.

$$\delta_{O_3} = 3 \cdot D_{O_3} \qquad \text{Eqn. 5-9}$$

Where:

δ_{O_3} = Ozone Dose (mg/L) and

D_{O_3} = Ultimate Ozone Demand (mg/L).

To create ozone, an air stream is passed through a tube irradiated with UV light. This excites the oxygen (O_2) molecules and causes some of them to form ozone (O_3). The air stream containing ozone is injected and mixed into the raw water, which then passes into a contactor, which provides time for the ozone to dissolve into the water. The mixture then flows into a de-gas separator that allows the un-dissolved gasses to separate to the top where they leave the separator, pass through a residual ozone gas destructor, and are off-gassed. The contactor and de-gas separator also provide time for ozone to oxidize the As(III) into As(V), which, depending on interfering reductants that may be present, could be as long as 2.2 minutes. Figure 59 below shows a process flow diagram for a typical ozonation process.

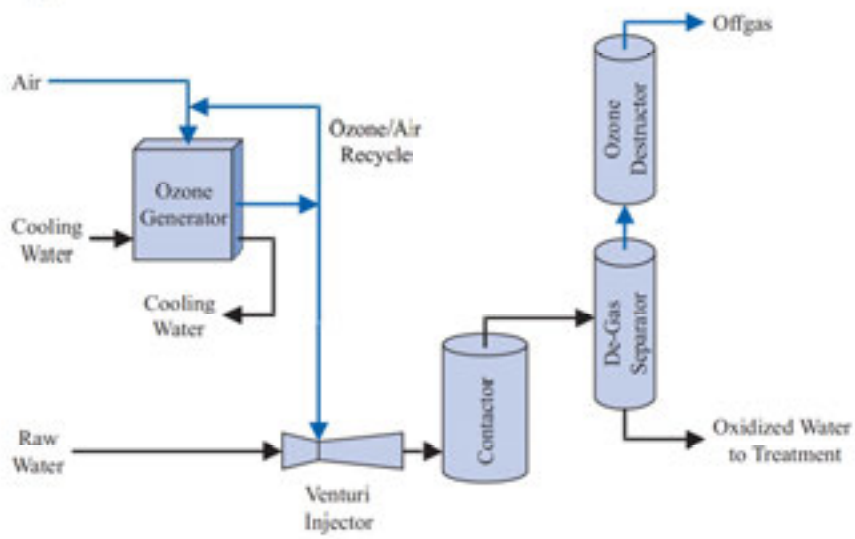


Figure 5-9. Typical Ozonation Process Flow Diagram.

The ozone generator can be sized by taking the flowrate times the ozone dose as shown in the equation:

$$M_{O_3} = \delta_{O_3} \cdot Q \cdot \left(0.2271 \frac{L}{gal} \cdot \frac{g}{mg} \cdot \frac{min}{hr} \right) \qquad \text{Eqn. 5-10}$$

Where:

M_{O_3} = Ozone Mass Flow (g/h O_3)

δ_{O_3} = Ozone Dose (mg/L) and

Q = Design Flowrate (gpm).

Figure 5-10 shows an ozone generator that will produce up to 35 g/h (583 mg/min) of ozone.

Figure 5-10. Ozone Generator and Contactor (ProMinent).

5.4 Solid Phase Oxidant Pre-Oxidation Design Considerations

Filox-R™ is a solid, granular manganese dioxide media typically used to remove iron and manganese from drinking water. FiloxR™ media has also been shown to effectively catalyze the oxidation of As(III) to As(V) using dissolved oxygen.

For most ground water sources, the dissolved oxygen content will be very low. Oxygen may need to be added depending upon the concentrations of interfering reductants. An alternative to adding oxygen is to increase the empty-bed contact time (EBCT) to overcome the interfering reductants. If oxygen addition is selected, it can be done by injecting air into the water stream using a venturi air injector as shown below in process flow diagram Figure 5-11. Figure 5-12 shows the schematic of an air injection assembly. The water and air are allowed to mix for a short period of time and then the undissolved gasses are removed from the water by a degassing unit. The oxygenated water then flows downward through a column of FiloxR™ media.

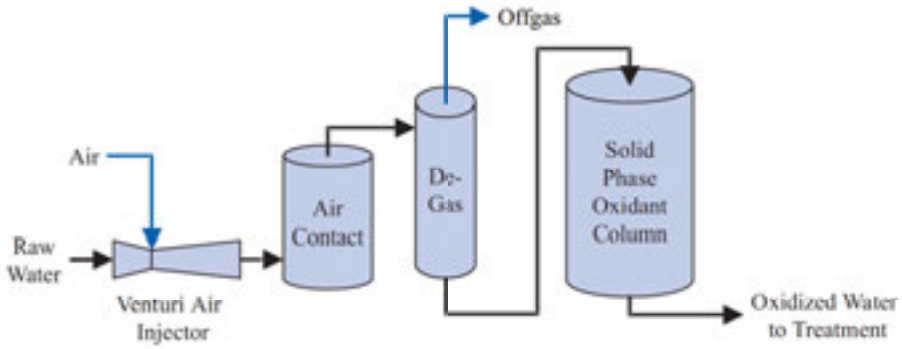


Figure 5-11. Typical Solid Phase Oxidant Arsenic Oxidation Process Flow Diagram.

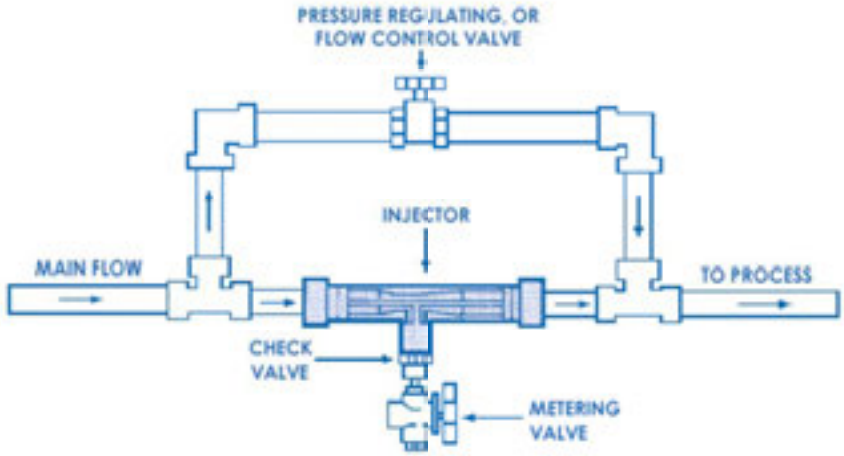


Figure 5-12. Venturi Air Injector Assembly Schematic (Mazzei).

Careful consideration should be given to the dissolved oxygen dose estimate. Most waters contain substances other than As(III) that exert oxidant demand. Section 2.2.4 lists the oxygen demand for the stoichiometric conversion of As(III), Fe^{2+}, Mn^{2+}, and HS^-. FiloxR™ may also catalyze oxidation with TOC. The ultimate ozone demand is the sum of all these factors. The applied dose should be at least ten times larger than the ultimate oxygen demand as seen in the equation below. Some test runs by Ghurye and Clifford with interfering reductants used as much as 65 times the stoichiometric oxygen demand (Ghurye and Clifford, 2001).

$$\delta_{O_2} = 10 \cdot D_{O_2} \qquad \text{Eqn. 5-11}$$

Where:

δ_{O_2} = Oxygen Dose (mg/L) and
D_{O_2} = Ultimate Oxygen Demand (mg/L).

The EBCT is the other important design criteria for a solid-phase oxidant system. Tests using FiloxR™ were successful with EBCTs of 1.5 minutes. If oxygen was not present in 10 to 65 times the stoichiometric demand, EBCTs of 6 minutes were required. (Ghurye and Clifford, 2001).

Typical hydraulic loading rates for Filox-R™ systems are 10 to 20 gpm/sft. Given this and the EBCT, the height of the Filox-R™ bed can be determined using the equation:

$$Z \geq HLR \cdot EBCT \cdot \left(\frac{cft}{7.48\ gal}\right) \qquad \text{Eqn. 5-12}$$

Where:

Z = Depth of Media (ft),
HLR = Hydraulic loading rate (gpm/sft), and
EBCT = (Minimum) Empty Bed Contact Time (min).

Additional typical design and operating parameters for a Filox-R™ system are given in Table 5-1.

Table 5-1. Typical Filox-R™ Design and Operating Parameters.

Parameter	Value	Units
Bulk Density Filox-R™ [1]	114	lbs/cft
Freeboard [1]	30-50%	
Filox-R™ Media [1]	≥ 20	in.
Hydraulic loading rate [2]	10-20	gpm/sft
Empty Bed Contact Time [3]	1.5-6.0	min.
Minimum Backwash Flowrate [1]	12-15	gpm/sft

[1] Recommendation by Matt-Son, Inc., *Filox-R™ Media,* Form No. FXR-01.
[2] Recommendation by Matt-Son, Inc., *Filox-R™ Media,* Form No. FXR-06.
[3] Ghurye and Clifford, 2001.

5.5 Comparison of Pre-Oxidation Alternatives

Table 5-2 provides a review of issues pertinent to the five pre-oxidation methods previously discussed.

Table 5-2. Comparison of Pre-Oxidation Alternatives.

Criteria	Liquid Sodium Hypochlorite System	On-Site Hypochlorite Generation System	Permanganate Solution Feed System	Ozone Generation	Solid Oxidant System
Safety and Regulatory Issues	• HazMat regulations for safety and handling apply. • Potential for corrosive vapors in the presence of moisture. • Emergency response plan required with local fire department. • Secondary containment required.	• Below 1% threshold for hazardous classification. • Exempt from HazMat regulations. • No secondary containment requirements.	• Solid permanganate poses dust and inhalation hazard.	• Poisonous and reactive gas.	• None.
Space Requirements	• Space requirements are small, assuming the Uniform Fire Code (UFC) exempt criteria are met.	• Space requirements are large. There must be room for salt storage, brine tanks, hypochlorite holding tanks, electrolytic equipment, as well as instrumentation & control and power.	• Space requirements are small. Additional space may be required for storage of solid permanganate.	• Space requirements are small.	• Space requirements are small.
Chemical Characteristics	• 5¼ or 12½% sodium hypochlorite solution. Degrades over time. • Decay of solution creates chlorate byproduct. • Increases pH of water slightly.	• Stable sodium hypochlorite solution (0.8%). • Constant application concentration. • Chlorate formation low to none. • Increases pH of water slightly.	• Stable permanganate solution, generally 3-4%. • Reacts rapidly with dissolved organics.	• Gas. • Very strong oxidizer.	• Solid. • Requires dissolved oxygen in the water.
Chemical Delivery	• Liquid hypochlorite delivered by tanker truck, 55-gal drum, or 5-gal pail.	• Salt delivered in 50-lb bags or 2000-lb totes.	• Solid permanganate available in 25-kg pails, 50-kg kegs, and 150-kg drums.	• N/A	• N/A
Labor	• Periodic delivery. • Dilution procedures.	• Salt delivery. • Weekly loading of salt into brine tank.	• Load dry feeder. • Dilution procedures.	• N/A	• N/A
Operation and Maintenance	• Low day-to-day O&M. Long-term material maintenance could be a problem because of corrosive effects of liquid hypochlorite.	• Moderate O&M, mainly associated with salt handling. Change electrode cells every five years.	• Low day-to-day O&M for automated systems. • Stains everything purple.	• Low day-to-day O&M.	• Low day-to-day O&M.
Off-Normal Operation	• A temporary bleach solution can be mixed in the storage tank.	• A temporary bleach solution can be mixed in the day tank.	• N/A	• N/A	• N/A
Community Relations	• HazMat signage required.	• No HazMat regulations. Hydrogen byproduct vented to atmosphere.	• N/A	• N/A	• N/A

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Section 6
Sorption Process Design Considerations

This section describes the design of sorptive processes, including AA, modified AA, IBS, and IX. For reasons previously cited, the discussion about AA, modified-AA, and IBS are restricted to non-regenerable applications. Conversely IX is most economically feasible when used in a regenerable process.

6.1 Process Flow

Despite the availability of several different types of sorptive treatment processes, the overall treatment approach for each is similar. Pre-treatment can consist of oxidation, to convert As(III) to As(V), and pre-filtration stages when turbidity is high, as well as optional pH adjustment and pre-filtration backwash. Next, the water is fed through a column packed with sorptive media. Post-treatment consists of an optional pH re-adjustment stage and some media have an option for regenerating the media. Typically, the entire process is carried out under pressure. Figure 6-1 shows a typical sorption treatment process while Figure 6-2 shows the same flow diagram with the optional media regeneration and pH adjustment and re-adjustment. Dashed lines and boxes indicate optional streams and processes.

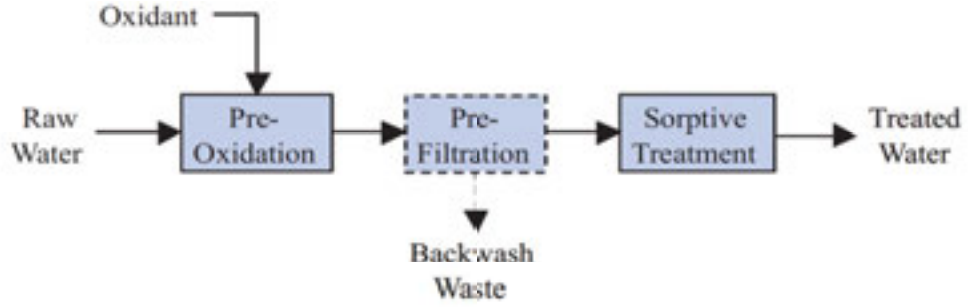

Figure 6-1. Sorption Treatment Process Flow Diagram w/o pH Adjustment and Regeneration.

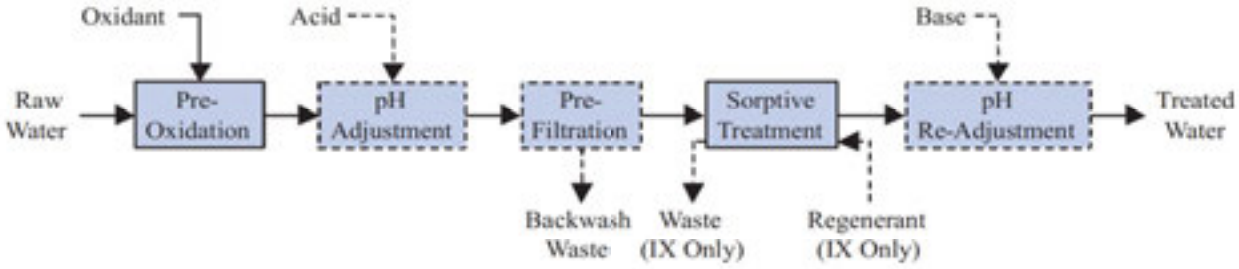

Figure 6-2. Sorption Treatment Process Flow Diagram w/ pH Adjustment and Regeneration.

Pre-filtration is strongly recommended when the source water turbidity is above 0.3 NTU. Suspended solids in the feed water can clog sorption sites and impair process hydraulics. One prefiltration option for smaller systems is backwashable cartridge filters.

The performance of AA treatment is highly pH-sensitive. Treatment conducted under acidic conditions (pH 5.5-6.0) can be expected to produce run lengths 5 to 20 times longer than treatment conducted under natural pH conditions. As a result, in the decisions trees in Section 3, conventional AA is only recommended over IBS when the pH is naturally low or the system is willing to adjust the pH below 6.0. In most cases, pH adjustment will require chemical addition of a strong acid, such as sulfuric (H_2SO_4) or hydrochloric (HCl) acid. Dose requirements depend on the background pH and buffering capacity of the water.

6.2 Column Rotation

Sorption processes are conducted using two or more columns in series. The first column in the treatment process is referred to as the roughing column, and the last sorption column is referred to as the guard column. Frequently, there is an additional column on standby. The roughing column serves as the primary arsenic removal column. The guard column is intended to capture arsenic breakthrough as soon as it occurs from the roughing column.

The columns are operated in this manner until arsenic breakthrough of the roughing column occurs, which is detected by periodic grab samples. Breakthrough is generally defined as the time when the effluent arsenic concentration is equal to 50% of the feed water arsenic level. However, this number can be adjusted after piloting or operation to optimize the economics of the process. At this point, adsorptive sites on the roughing column have become saturated and the column should be taken off-line for media replacement or regeneration, after which it is placed in standby mode to wait for the next column rotation. The guard column is then promoted to the roughing column position and the standby column becomes the guard column in the series. Figure 6-3 illustrates how the columns' positions are rotated between roughing, guard, and standby operation modes.

The number of columns to be placed in series depends on the estimated lifetime of each column and the desired monitoring and media change-out or regeneration frequency. IX processes operating with sulfate in the feed may have a sulfate roughing column at the head of the operation to remove sulfate before arsenic is removed by the arsenic roughing column.

Typically two parallel process trains are used. This provides operational redundancy and, by staggering their operation, chromatographic peaking may be reduced.

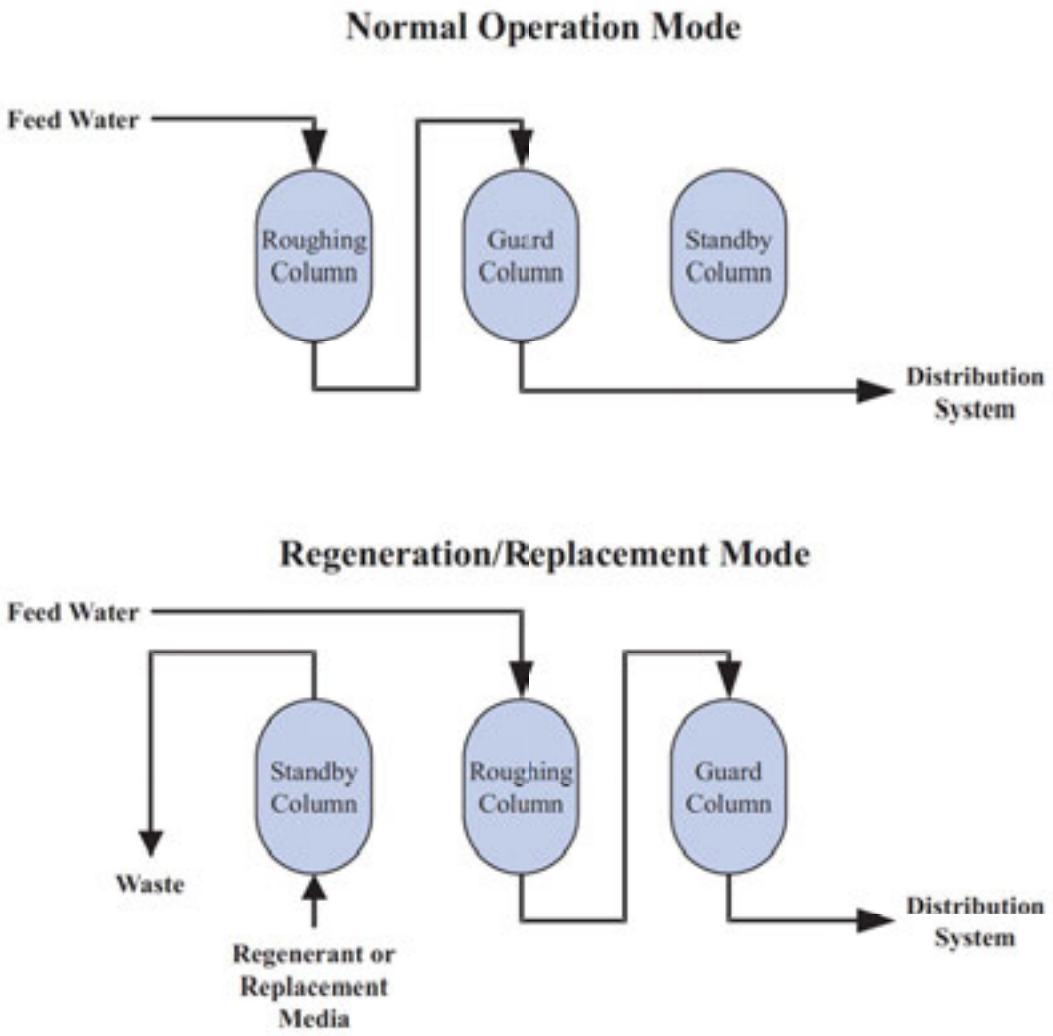

Figure 6-3. Sorption Column Operation Modes.

6.3 Sorption Theory

To understand operation of sorption processes, it is important to understand fundamental ion exchange theory. An important consideration in sorption processes is the mass transfer zone (MTZ), which can be viewed as a wave or a zone of activity (i.e., non-equilibrium between liquid and media phases) for a particular contaminant. As depicted in Figure 6-4, the MTZ also represents the front of the exhaustion zone for a particular contaminant. Exhaustion zones and MTZ waves are typically considered for the target contaminant (i.e., arsenic) and any species that have a higher exchange affinity for the media. Arsenic must compete with other anions for exchange sites according to the selectivity sequence for the particular media (see Section 2). Previously sorbed arsenic can be displaced by anions of higher selectivity. Exhaustion and MTZs order themselves according to the selectivity sequence, as illustrated in Figure 6-4. Other sorbed contaminants, such as carbonate (CO_3^{2-}) and nitrate (NO_3^-), would be present further down from the As(V) MTZ.

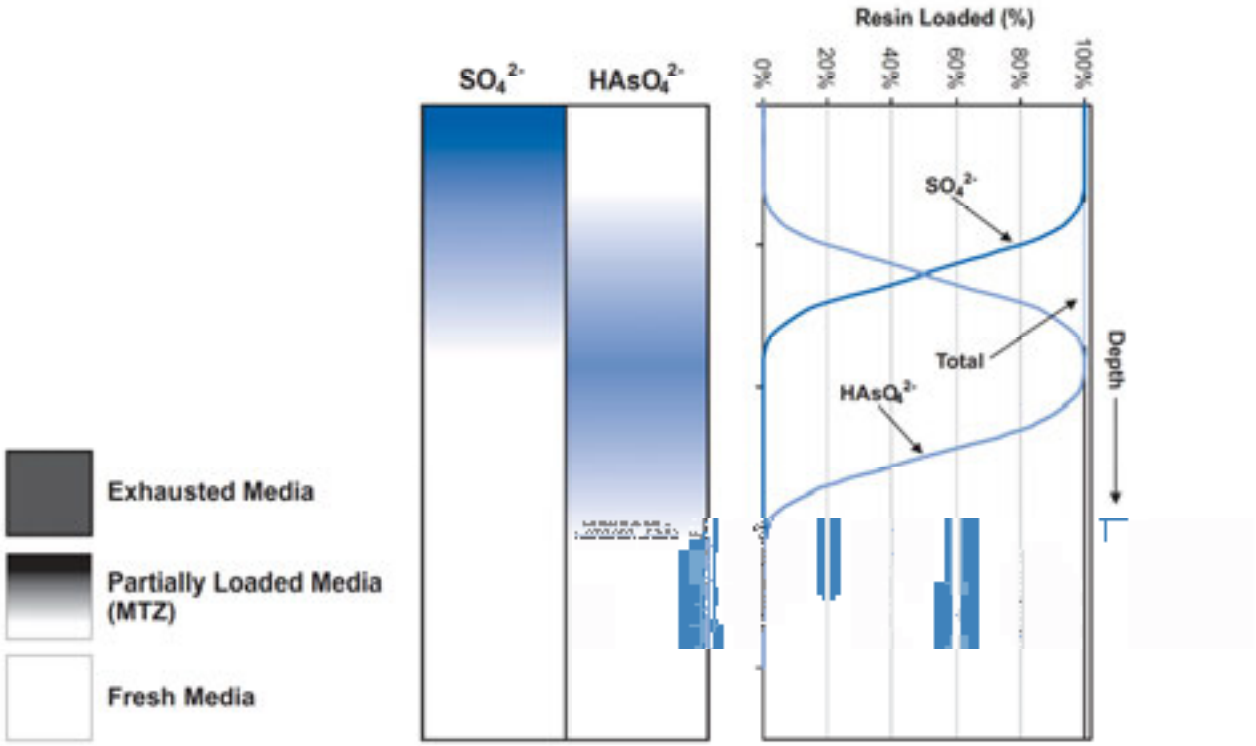

Figure 6-4. Multi-Component Ion Exchange.

6.3.1 Non-Regenerated Sorption Processes

For the purpose of this Handbook, processes utilizing AA, modified-AA, or IBS media are referred to as non-regenerated sorption treatment. These technologies are most applicable to small utilities when used as a one-time application with subsequent media disposal and replacement.

Processes utilizing conventional AA function best when the solution pH is less than 6.0. At this pH, the hydroxide (OH^-) concentration is less than 0.2 mg/L. Since this is at least an order-of-magnitude less than the arsenic concentration, hydroxide provides little competition against arsenic for exchange sites. There are several types of modified-AA that have demonstrated enhanced arsenic removal performance under natural pH conditions (6.0-9.0) but these were not designated as BATs by the USEPA when the rule was promulgated.

IBS treatment has been described as chemisorption (Selvin et al., 2000), which is typically considered to be irreversible. Therefore, although phosphate and arsenic compete for sorption sites, neither has the ability to displace the other. In this instance, there is a single exhaustion zone and MTZ comprised of both As(V) and phosphate contaminants.

6.3.2 Ion Exchange Processes

As(V) can be removed through the use of SBA in either chloride or hydroxide form, although the former is more commonly used for drinking water applications. The expense

and low capacity of IX resin generally renders it uneconomical for one-time application and disposal. Instead, periodic regeneration should be applied to restore the exchange capacity of the resin.

Figure 6-4 illustrates a resin-phase loading profile down an IX column for treatment of hypothetical natural water containing arsenic and sulfate. As arsenic is exchanged with anions on the SBA, the arsenic band develops and its MTZ moves downward. The same phenomenon is true for sulfate ions. However, because of its higher exchange affinity, sulfate anions displace the arsenic, thereby forcing the arsenic-exhausted region and the arsenic MTZ downward further.

An important consideration in the application of IX treatment is the potential for chromatographic peaking of nitrate (NO_3^-) and nitrite (NO_2^-). These contaminants pose an acute health risk, and as such are regulated under the SDWA with primary MCLs of 10 mg/L (as N) and 1 mg/L (as N), respectively. According to the selectivity sequence provided in Section 2.3.1, nitrate and nitrite will also replace chloride on exchange sites, although with less preference than As(V) or sulfate. As a result, the region of nitrate and nitrite activity will reside further down the column (relative to the activity of sulfate and As(V)), as illustrated in Figure 6-5. These species will chromatographically peak before As(V), and this peaking could produce water that does not meet the aforementioned MCLs. Utilities with source water with measurable quantities of nitrite or nitrate should be aware of this phenomenon and plan column operation to avoid this occurrence.

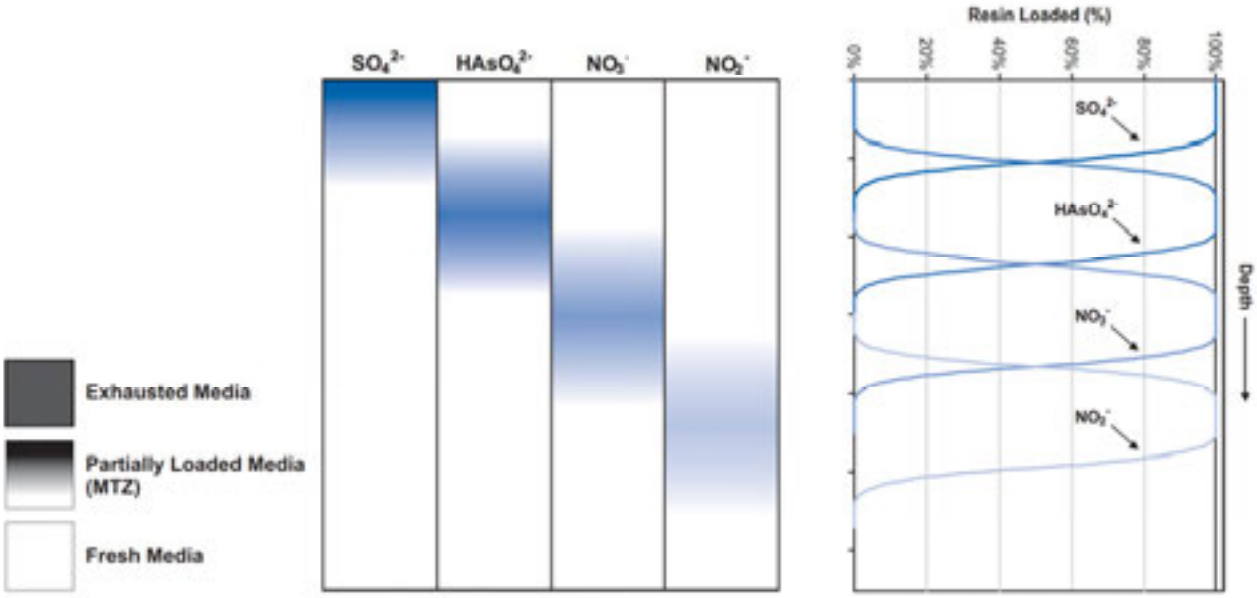

Figure 6-5. Activity of Nitrate and Nitrite During Ion Exchange.

The removal of carbonate (CO_3^{2-}) by IX resin can also lead to a pH drop of 0.5 to 1.0 units, particularly at the beginning of a run. This impact can be minimized by post-treatment addition of soda ash or caustic soda or by sequencing the regenerative cycles of parallel process trains. Pilot testing is recommended to evaluate the impact on pH for the specific water in question.

6.4 Process Design & Operational Parameters

Design and operational parameters for sorption treatment processes vary significantly depending on the specific technology chosen, and to a lesser degree on the media type. The most appropriate way to identify the optimal engineering parameters for a particular treatment application is to conduct on-site pilot column studies with the media of interest.

Regenerable IX processes involve three operating modes: (1) Loading; (2) Regeneration; and (3) Rinsing. Loading can be conducted with flow in either the downward or upward direction, although the former is more common in water treatment applications. Once the column is fully loaded it should be taken off-line. The next step is regeneration with concentrated brine for chloride-based SBA, which can be conducted in either the downward or upward direction. The latter case is generally more effective, although care must be taken to prevent fluidization of the media. Prior to returning the column to service, water rinsing should be conducted to displace regenerant solution from the column. Slow rate and fast rate rinsing should be conducted in sequence, with each displacing about 2-3 bed volumes of solution per column.

Table 6-1 details key design and operational parameters for AA, IBS, and IX processes. As described in Section 2, non-regenerable AA and IBS process are recommended for small utilities. Therefore, rinsing and regeneration data is only provided for ion exchange processes.

Table 6-1. Typical Sorption Treatment Design and Operating Parameters.				
Parameter	**IX**	**AA**	**IBS**	**Units**
Media Bulk Density	40-44	40-47	72-75	lbs/cft
Minimum Column Layers				
Freeboard	90% [1,2]	50% [3]	50%	-
Media	36-60 [2]	36-60 [3]	32-40	in.
Operating Conditions				
Hydraulic Loading Rate	8-12 [2]	4-9 [3]	5-8	gpm/sft
Empty Bed Contact Time	1.5-5	5 [3]	5-10	min.
Downflow Pressure Drop [4]	0.7-1.3 [2]	0.1 [6]	N/A	psi/ft
Maximum Pressure Differential	14	5	3.5	psi
Backwash Conditions				
Backwashing Flow Rate	3-4 [2]	7 [3]	-	gpm/sft
Backwashing Duration	5-20 [2]	10 [3]	-	min
Regeneration Conditions [1]				
Brine Strength	6-10 [2]	-	-	wt%
Downflow Rate	2-6	-	-	gpm/sft
Regenerant Volume	20 [2]	-	-	gal/cft resin
Rinsing Conditions				
Slow Rinse Rate	0.4-4	-	-	gpm/sft
Fast Rinse Rate	2-20	-	-	gpm/sft
Displacement Requirements	4-6	-	-	bed volumes

[1] This will be very resin specific. Check with the resin manufacturer before design.
[2] Rubel, 2001a Draft.
[3] Rubel, 2001b Draft.
[4] This depends on temperature, type of media, and hydraulic loading rate.
[5] For strong base anion exchange resin at 70°F and 10 gpm/sft.
[6] For AA at 2 gpm/sft.
N/A - Not Available.

6.5 Column Design

The vessels should be made from typical, well-known materials of construction such as carbon steel or fiberglass and must be NSF approved. The vessels should have distribution and collector systems that provide a uniform distribution of fluids during all phases of the operation. More detail on these accessories is provided in Section 7. Also, it is advisable to install sight-glasses in order to check resin levels.

Columns placed in series are referred to as a treatment train. The utility should evaluate the number of parallel treatment trains based on the desired redundancy and state design standards. Figure 6-6 shows a commercially available multiple-column IX treatment train.

Figure 6-6. Ion Exchange System (Tonka Equipment Company).

6.5.1 Column Diameter

Once the number of parallel treatment trains has been established, column diameter can be calculated based on the recommended hydraulic loading rate of the particular media and the design flowrate. Hydraulic loading rate is the flowrate per unit of cross-sectional area and is proportional to the linear velocity of the fluid through the bed. Recommended maximum hydraulic loading rates are provided in Table 6-1. Column diameter (D) can be calculated using the equation:

$$D = \left(\frac{4 \cdot Q}{\pi \cdot n_P \cdot HLR} \right)^{0.5} \qquad \text{Eqn. 6-1}$$

Where:

- D = Column Diameter (ft),
- Q = Design Flowrate (gpm),
- n_p = Number of Parallel Treatment Trains, and
- HLR = Hydraulic loading rate (gpm/sft).

The benefits of lower hydraulic loading rates include a sharper MTZ and potentially better media utilization. However, a lower hydraulic loading rate also translates into a larger column footprint.

Consider an example where IX will be used to treat a design flowrate of 70 gpm. The utility has decided to provide no parallel treatment trains. Based on a recommended maximum hydraulic loading rate of 10 gpm/sft, the column diameter should be 3 feet.

$$D = \left(\frac{4 \cdot 70\,\text{gpm}}{\pi \cdot 1 \cdot 10\,\text{gpm/sft}} \right)^{0.5} = 3\,\text{ft}$$

6.5.2 Column Height

The depth of sorptive media required can be calculated based on the selected hydraulic loading rate and consideration of the minimum empty bed contact time. Values of EBCT are provided in Table 6-1.

$$Z \geq HLR \cdot EBCT \cdot \left(\frac{\text{cft}}{7.48\,\text{gal}} \right) \qquad \text{Eqn. 6-2}$$

Where:

Z = Depth of Sorptive Media (ft),
HLR = Hydraulic loading rate (gpm/sft), and
EBCT = (Minimum) Empty Bed Contact Time (min).

Returning to the previous example, suppose the specific resin selected had a minimum EBCT of 3 minutes. The total depth of sorptive media required for the primary treatment columns would be 4 feet.

$$Z = \left(10\,\frac{\text{gpm}}{\text{sft}} \right) \cdot (3\,\text{min}) \cdot \left(\frac{\text{cft}}{7.48\,\text{gal}} \right) = 4\,\text{ft}$$

The depth of sorptive media (Z) should then be used in conjunction with the column freeboard to determine column height. For ease of change-out, all columns should be sized similarly.

$$H = Z \cdot (1 + F) \qquad \text{Eqn. 6-3}$$

Where:

H = Column Height (ft),
Z = Depth of Sorptive Media (ft), and
F = Freeboard Allowance (% expressed as a decimal).

For the previous example, if the freeboard requirement was 50% of media depth, the column height should be 6 feet.

$$H = (4\,\text{ft}) \cdot (1 + 0.5) = 6\,\text{ft}$$

Therefore, for this particular example, the design should include a single treatment train consisting of three columns (i.e., roughing, guard, and standby). All columns should be 3 feet in diameter by 6 feet tall and contain 4 feet of media. The process flow diagram for this example is provided as Figure 6-7.

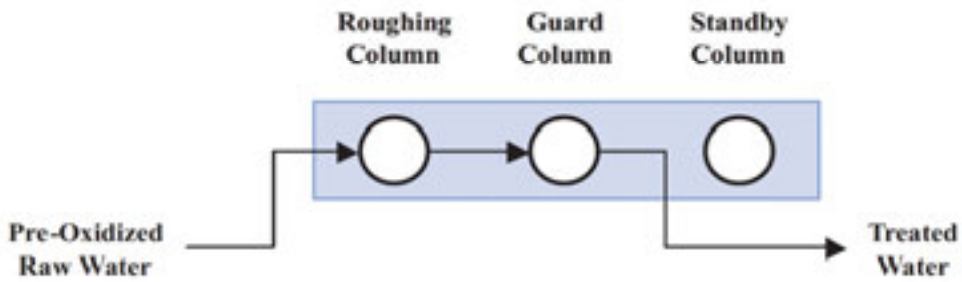

Figure 6-7. Process Flow Diagram for Example Problem.

The following constraints should also be considered:

- Small column aspect ratios (i.e., H:D <1) can lead to flow maldistribution.
- Large column heights can lead to excessive pressure drop.
- The available building footprint.
- The available building height.

6.6 Media Replacement Frequency

It is advantageous for a utility to obtain a rough estimate of the optimal operating time until media exhaustion occurs. This is important for establishing an appropriate O&M and monitoring schedule. The optimal filter run time until media exhaustion can be calculated as:

$$\tau = BV_e \cdot EBCT \cdot \left(\frac{hr}{60\ min}\right) \qquad \text{Eqn. 6-4}$$

Where:

τ = Optimal Filter Run Time (hr),
BV_e = Number of Bed Volumes to Exhaustion, and
EBCT = Empty Bed Contact Time (min).

The roughing column should be operated until 50% arsenic breakthrough occurs. Therefore, the actual filter run time will be less than the calculated optimal filter run time (t). The deviation will depend on the efficiency of the sorption/exchange process and the width of the MTZ.

Consider an example where the estimated lifetime of a particular combination of media and raw water was 1,357 BV. If the columns are sized to provide an EBCT of 3 minutes, the optimal run time until media exhaustion is 68 hours.

$$\tau = (1{,}357\ \text{Bed Volumes}) \cdot (3\ min) \cdot \left(\frac{hr}{60\ min}\right) = 68\ hr$$

6.7 Regeneration of Ion Exchange Resin

IX resins are essentially unusable for arsenic removal unless they can be efficiently regenerated. Because of the high selectivity of SBA for sulfate (SO_4^{2-}), the exchange capacity would be exhausted within a few days for many natural waters. The cost of the virgin resin is far too great to dispose of it at that time.

Chloride-based SBA can be regenerated with concentrated brine (1-5 mole/L) in either the upflow or downflow mode. The more concentrated the regenerant solution, the greater the fraction of the bed that is regenerated. It should be noted, however, that regeneration efficiencies are generally less than 100%. Therefore, successive runs can be expected to be slightly shorter in duration.

Utilities should consider the size of the brine holding tank, as they are typically much larger than the IX columns themselves. Based on previous studies (AwwaRF, 2000), roughly 4 BVs of spent brine are produced per regeneration. The regeneration duration can be calculated as:

$$t_R = \frac{Z}{G_R} \cdot \left(7.48 \frac{\text{gal}}{\text{cft}}\right) \cdot (4\ \text{BV}) \qquad \text{Eqn. 6-5}$$

Where:
t_R = Regeneration Duration (min),
Z = Depth of Sorptive Media (ft/BV), and
G_R = Regeneration Flux (gpm/sft).

Following regeneration, this brine can either be disposed of via indirect discharge (assuming local TBLLs are met) or stored for recycle. In the case of recycle, it may be necessary to add salt to bring the strength of the brine back to the range 15 mole/L.

For a conventional IX process, spent regenerant will contain arsenic and sulfate in a ratio approximately corresponding to their relative concentration in the raw water. If the water contains a moderate amount of competing ions, it is possible that the brine waste will contain less than 5.0 mg/L of arsenic, and thus will not exceed the TC values. However, in most instances, the liquid waste stream will contain more than 5.0 mg/L of arsenic. This will force utilities to consider disposal and waste treatment options. If indirect discharge to a local POTW is the waste disposal method chosen, a spent brine holding tank may be required in order to slowly release the spent brine to the POTW.

Rinsing with water is typically conducted after regeneration to flush out residual brine and prepare the column for normal operation. Generally 4 to 6 BV of rinse water are used per regeneration. This waste may be added with the brine waste being sent to the POTW.

IX resin typically lasts 4-8 years before chemical and mechanical degradation necessitates media replacement.

6.8 Waste Handling Systems

This section addresses three types of waste: backwash water from pre-filters, spent regenerant, and spent media.

The two most probable methods for disposal of backwash water from pre-filters are indirect disposal through a POTW or by settling the solids, recycling supernatant, and sending the solid sludge to a landfill.

Regarding brine used in IX regeneration, there are two waste disposal options. Spent brine that contains less than 5.0 mg/L of arsenic can either be disposed of via indirect discharge or treated on-site. The feasibility of indirect discharge of regenerant waste will be dictated by local TBLLs for TDS. The concentration of TDS in the spent regenerant can be approximated as:

$$C_{TDS} = \left(58.4 \frac{\text{g NaCl}}{\text{mole}}\right) \cdot \overline{M}_{Brine} \qquad \text{Eqn. 6-6}$$

Where:

C_{TDS} = Concentration of Total Dissolved Solids (g/L) and

$\overline{M}_{Brine}$ = Brine Molarity (mole/L).

When indirect discharge is not an option, the system must deal with the waste on-site. The most common approach for treating brine waste (containing less than 5.0 mg/L of arsenic) is chemical precipitation with iron-based salts and subsequent solids thickening. Thickening can be conducted using a settling basin, or for more rapid results, mechanical dewatering equipment. The brine decant can then be sent to an evaporation pond.

Spent brine used in the regeneration of arsenic-laden resin may be classified as hazardous. Therefore, manipulating the chemical form of the waste on-site constitutes treatment of a hazardous waste, which has extensive permit and cost implications. As a result, when the brine waste stream contains over 5.0 mg/L of arsenic, indirect discharge to a POTW is considered the only viable option for small utilities. When this option is unavailable, on-site regeneration of arsenic-laden resin should not be performed. Rather, the resin should be disposed of at a municipal solid waste landfill and replaced with fresh resin.

The appropriate disposal method for spent resin is dependant on the results of the TCLP, as described in Section 1.

Section 7
Pressurized Media Filtration Process Design Considerations

This section describes the design of a typical pressurized granular-media filtration system including sand filtration and iron and manganese oxidation/filtration systems. Although the following information specifically describes a pressurized greensand filter, it can be applied to any pressurized granular media filtration system.

7.1 Process Flow

In a typical media filtration process, seen in Figure 7-1, the raw water is first put through a pre-oxidation step. Dashed lines and boxes indicate optional streams and processes. If the preoxidant is chlorine, potassium permanganate, or ozone, the As(III) and any natural iron will be oxidized to As(V) and Fe III respectively. If, however, aeration (aeration tower) is used for iron oxidation, the air oxidation process will not oxidize As(III) to As(V) and the addition of a chemical preoxidant would be required. If greensand is being used as the filter media, potassium permanganate and chlorine also provides the oxidant for the continuous regeneration of the greensand media.

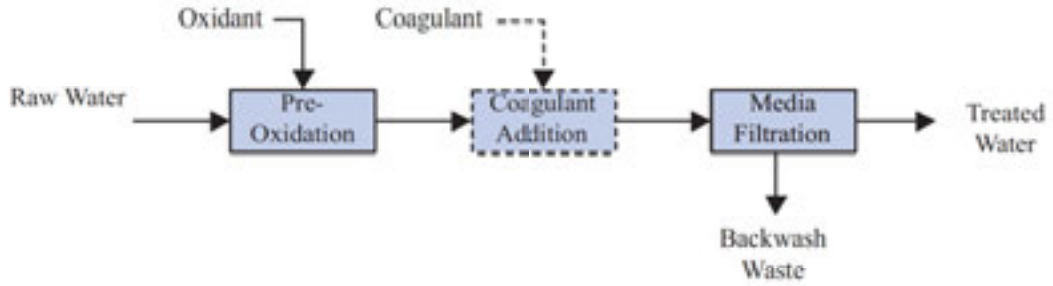

Figure 7-1. Typical Media Filtration Process Flow Diagram.

It should be noted that, although greensand can be regenerated in either batch or continuous methods, only the continuous regeneration method has been shown to also oxidize the As(III) to As(V) so that arsenic can be removed. Therefore, under most circumstances, only the continuous regeneration method is recommended for arsenic removal.

After pre-oxidation, a coagulant addition step may be necessary if the iron concentration or the Fe:As ratio is low. Next, the water is passed through filters containing granular media before being sent to the distribution system. Typically, three or more filters are provided in parallel.

Media filters are operated in three different modes: (1) Filtration; (2) Backwash; and (3) Filter-To-Waste (FTW). In the operating mode, all filters are fed in parallel with flow in the downward direction. The effluent is sent to the distribution system as shown in Figure 7-2.

After some time of operation, solids captured by the filtration media will impede the flow and increase the differential pressure across the filter. To restore hydraulic capacity, the filter will have to be backwashed. The backwash flow is in the upward direction, which fluidizes the granular media and washes the accumulated solids out of the filter. In some instances, air scouring is conducted prior to fluid backwashing. Air scouring bubbles large volumes of air upward through the filter. This assists in breaking apart conglomerates of filtered material, allowing the subsequent fluid backwash to more easily remove the captured solids. An air scour also reduces the volume of backwash waste that is generated.

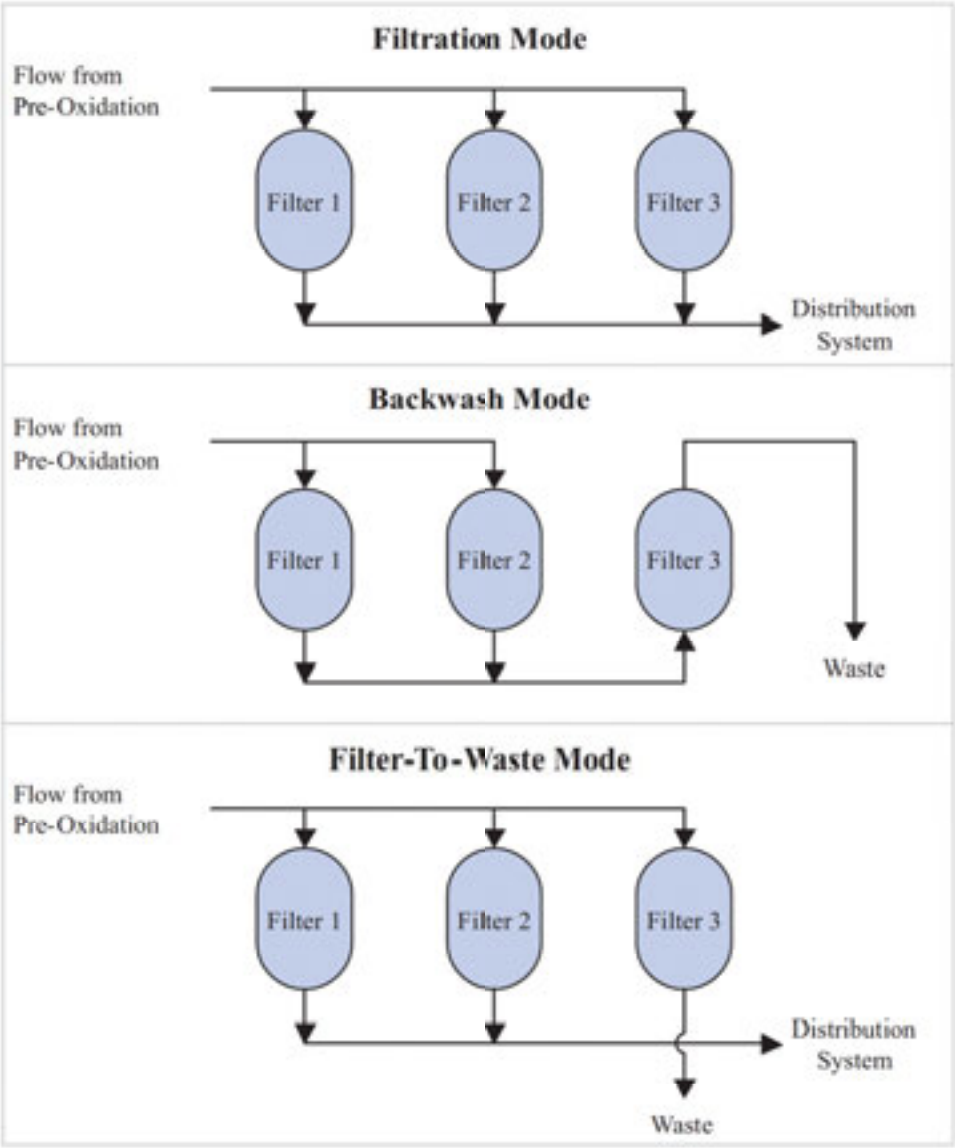

Figure 7-2. Media Filtration Process Flow Modes.

After backwashing, the media is allowed to settle and downward flow is reinstated with the filter effluent going to waste. This re-stratifies the column, setting it up for operation. It also reduces the amount of particulate matter that gets into the distribution system. After the FTW mode, the filter is returned to standard operation.

7.2 Process Design & Operational Parameters

Table 7-1 lists design and operational parameters typical of media filtration systems.

Table 7-1. Typical Greensand Column Design and Operating Parameters.

Parameter	Value	Units
Media Bulk Density		
Anthracite Media [1]	50	lbs/cft
Greensand Media [2]	85	lbs/cft
Garnet Media [3]	140	lbs/cft
Support Gravel [4]	100	lbs/cft
Column Layers		
Freeboard [1,2]	50%	of Anthracite and Greensand
Anthracite Media [5]	12-24	in.
Greensand Media [6]	15-24	in.
Garnet Media [3]	4	in.
Support Gravel [4]	18-30	in.
Operational Parameters		
Hydraulic loading rate [7,8]	3-5	gpm/sft
Max Pressure Differential	8-10	psi
Backwash Parameters		
Minimum Backwash Flowrate [2]	12	gpm/sft
Backwash Duration	15	min.
Backwash Frequency	1-7	days
Bed Expansion [2]	40%	minimum
Air Scouring Rate	0.8-2.0	scfm/sft
Filter-to-Waste Parameters		
FTW Hydraulic loading rate	3-5	gpm/sft
FTW Duration	5	min.

[1] Recommendation by Clack Corporation, Anthracite, Form No. 2354.
[2] Recommendation by Clack Corporation, Manganese Greensand, Form No. 2349.
[3] Recommendation by Clack Corporation, Garnet, Form No. 2355.
[4] Recommendation by Clack Corporation, Filter Sand and Gravel, Form No. 2352.
[5] Clack Corporation, Anthracite, Form No. 2354 recommends 10-18 for multimedia filters but may need to be higher depending on iron concentrations.
[6] Clack Corporation, Manganese Greensand, Form No. 2349 recommends 30" but can be lower if used with continuous regeneration.
[7] Clack Corporation, Manganese Greensand, Form No. 2349 recommends 3-5 gpm/sft with 8-10 gpm/sft intermittent flow possible.
[8] Under some circumstances, continuous flowrates of 10 gpm/sft are possible.

7.3 Filter Design

Typically, granular-media pressure filters have multiple layers of media selected to maintain a coarse-to-fine grading from the top to bottom of the filter. The coarse, upper layer provides rough filtration and the bulk of the particulate retention while the fine, lower layer provides superior filtration. This scheme allows for longer runs times while maintaining filtration quality. A typical oxidation/filtration filter is shown in cross-section in Figure 7-3.

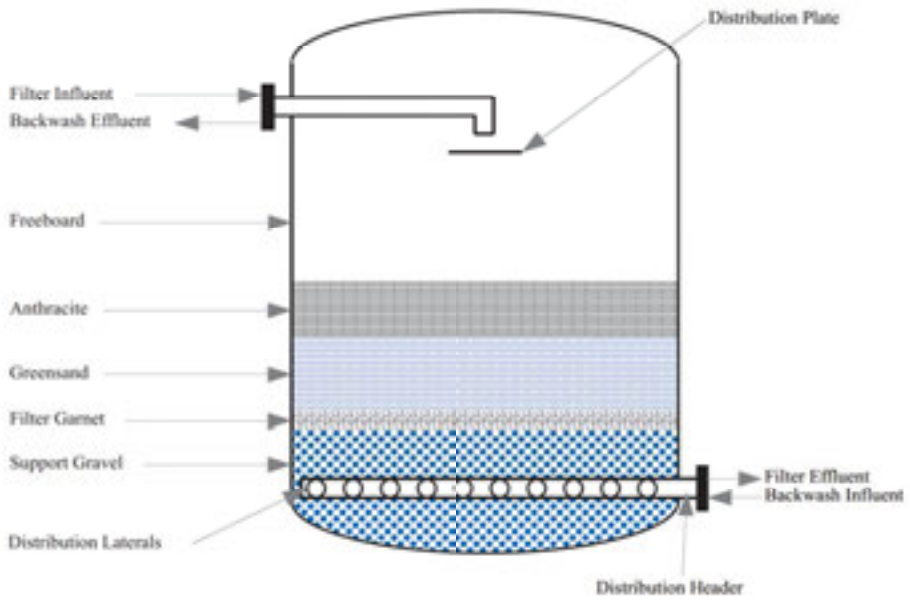

Figure 7-3. Schematic of a Vertical Greensand Pressure Filter.

In the manganese greensand oxidation/filtration process, the primary layer in the filter is made of a media that catalyzes iron and manganese oxidation, promotes its precipitation, and filters out the precipitate. For optimum arsenic removal, continuous chemical preoxidation with either potassium permanganate or chlorine is recommended. Arsenic is removed by the co-precipitation with the iron and, to a lesser degree, the manganese. Greensand, glauconite sand coated with a thin layer of MnO_2, is the most common of these types of materials.

Because greensand is very fine (16-60 mesh) it is susceptible to being overloaded with solids. To reduce the solids loading on the greensand a layer of filter coal such as anthracite is put on top. This layer also provides an area for the iron floc to coagulate. Because of anthracite's low density, the filter coal will naturally stratify as the top layer after backwash.

In order to keep the greensand from being slurried out the under-drain, a layer of filter garnet is placed below it. This filter garnet has a particle size of 8-12 mesh and a density almost 50% greater than the greensand. This puts the filter garnet below the greensand after stratification.

The bottom layer is support granite, which allows the water to flow easily into the lower distribution system and exit the filter. Because of its larger size, the support granite is not fluidized during backwash. Instead, it assists in distributing the backwash flow evenly throughout the filter.

When the media is backwashed, it will expand 30% to 50%. To accommodate this, the filter is designed with freeboard. Freeboard is the amount of space in the filter between the upper layer of media and the upper distribution manifold. The height of this freeboard is dependent on the height of media but is generally 40-50% of the settled height of the media that undergoes fluidization (i.e., anthracite and greensand in the case of a greensand filter).

Every filter will have an upper and lower distribution manifold. The upper manifold distributes the influent and collects the backwash water. The lower manifold collects filtered water and distributes backwash water. There are numerous designs for these distribution manifolds. Smaller diameter filters may have a distribution plate or a hub-lateral design shown in Figure 7-4. Larger diameter columns may have a header-lateral design, shown in Figure 7-5. The header-lateral design gives a more even distribution of the flow, which is much more important for the lower manifold, as flow distribution directly affects the effectiveness of the backwash.

Figure 7-4. Hub-Lateral Distribution System (Johnson Screens).

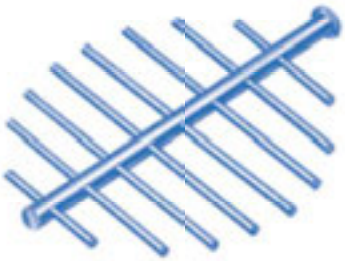

Figure 7-5. Header-Lateral Distribution System (Johnson Screens).

Typical media filtration installations include several filters in parallel. This allows one to be taken offline while the others continue to work. It also allows the other filters to provide the backwash water necessary to backwash a single filter. Figure 7-6 shows one potential valving arrangement that allows the use of multiple filters. Figure 7-7 and Figure 7-8 show pictures of commercially available pressurized media filters.

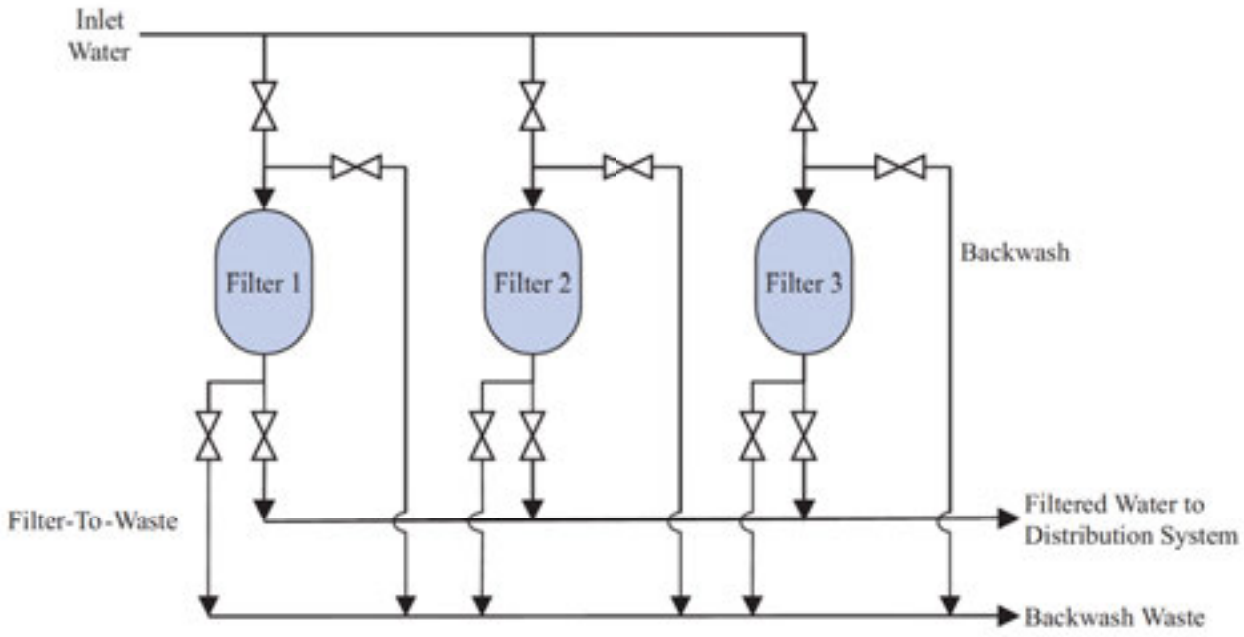

Figure 7-6. Multiple Media Filter Setup.

Figure 7-7. Pressurized Media Filter (USFilter).

Figure 7-8. Pre-Engineered Arsenic Filtration System (Kinetico).

7.3.1 Filter Diameter

The primary design variable for the granular media filters is the hydraulic loading rate. This is the flowrate the filters handle per horizontal cross-sectional area of media. Typical hydraulic loading rates for greensand filters range between 3 and 5 gpm/sft, although, under some circumstances, greensand filters can be successfully operated at hydraulic loading rates as high as 10 gpm/sft. Using this information, the number of filters, and the maximum flowrate for which the filters are designed (i.e., design flowrate), the filter diameter can be calculated using Equation 7-1.

$$D = \left(\frac{4 \cdot Q}{\pi \cdot n_P \cdot HLR} \right)^{0.5} \qquad \text{Eqn. 7-1}$$

Where:

- D = Column Diameter (ft),
- Q = Design Flowrate (gpm),
- n_P = Number of Parallel Treatment Trains, and
- HLR = Hydraulic loading rate (gpm/sft).

For the example of 3 parallel filters designed to treat a maximum of 300 gpm of water at a filter hydraulic loading rate of 5 gpm/sft, the filter diameter should be 5 feet.

$$D = \left(\frac{4 \cdot 300\,\text{gpm}}{\pi \cdot 3 \cdot 5\,\text{gpm/sft}} \right)^{0.5} = 5\text{ft}$$

7.3.2 Media Weight

The weight of each media layer can be calculated using the following equation:

$$W_j = \frac{\pi \cdot D^2 \cdot h_j \cdot \rho_j}{4} \qquad \text{Eqn. 7-2}$$

Where:

W_j = Weight of Media Layer *j* (lbs),
D = Column Diameter (ft),
h_j = Height of Media Layer *j* (ft), and
ρ_j = Bulk Density of Media *j* (lbs/cft).

For the previously calculated 5ft filters, using 1 ft of anthracite, 2.5 ft of greensand, 0.25 ft of filter garnet, and 2 ft of support granite, the media weights per filter are 982 lbs of anthracite, 4,172 lbs of greensand, 687 lbs of filter garnet, and 3,927 lbs of support granite, respectively. Typical densities for each of the media can be found in Table 7-1.

$$W_{Greensand} = \frac{\pi \cdot (5\text{ ft})^2 \cdot (2.5\text{ ft}) \cdot (85\text{ lbs/cft})}{4} = 4{,}172 \text{ lbs of greensand (per filter)}$$

7.4 Waste Handling System Design

Both the backwash water and the FTW water from granular media filtration processes pose disposal issues. The backwash flowrate can be calculated using the equation:

$$Q_{BW} = \frac{\pi}{4} \cdot D^2 \cdot G_{BW} \qquad \text{Eqn. 7-3}$$

Where:

Q_{BW} = Backwash flowrate (gpm),
G_{BW} = Backwash flux (gpm/sft), and
D = Column Diameter (ft).

The FTW flowrate is typically the same as the flowrate used in the filtration mode. Therefore, the volume of wastewater produced by the backwash and FTW modes can be calculated using the equation:

$$V_{WW} = Q_{BW} \cdot t_{BW} + \frac{Q}{n_P} \cdot t_{FTW} \qquad \text{Eqn. 7-4}$$

Where:

V_{WW} = Volume of Wastewater (gal),
Q_{BW} = Backwash Flowrate (gpm),
t_{BW} = Backwash Duration (min),
Q = Design flowrate (gpm),
n_P = Number of Parallel Treatment Trains, and
t_{FTW} = Filter-To-Waste Duration (min).

For example, assume the same 3-filter system as before (5-foot diameter, 300 gpm design flowrate, and 5 gpm/sft hydraulic loading rate) has a backwash flux of 12 gpm/sft, a backwash time of 15 minutes, and a FTW time of 5 minutes. The required backwash flowrate is then 236 gpm/filter and the wastewater volume created is 4,040 gallons per backwash per filter.

$$Q_{BW} = \frac{\pi}{4} \cdot (5\text{ ft})^2 \cdot \left(12 \frac{\text{gpm}}{\text{sft}}\right) = 236\text{ gpm (per filter)}$$

$$V_{WW} = \left(236 \frac{\text{gpm}}{\text{Filter}}\right) \cdot \left(15 \frac{\text{min}}{\text{Backwash}}\right) + \left(\frac{300\text{ gpm}}{3\text{ Filters}}\right)\left(5 \frac{\text{min}}{\text{Backwash}}\right) = 4{,}040 \frac{\text{gallons}}{\text{Filter} \cdot \text{Backwash}}$$

The wastewater can be disposed of in several different ways. The two most probable methods are indirect disposal through a POTW or by settling the solids and recycling the supernatant and sending the solids to a landfill.

In the indirect discharge through a POTW, a holding tank may be desired to eliminate the surging to the POTW system. In the liquid recycle/solids disposal method, a settling tank or basin is required. The holding basin or tank should be sized to hold at least two backwash/FTW cycles. In the above example, this leads to an 8,100 gallon tank.

7.5 Coagulant Addition System Design

The efficiency of arsenic co-precipitation to iron floc may vary depending on the concentration of iron and the iron:arsenic ratio. Optimal performance is obtained with an iron:arsenic mass ratio of at least 20:1. If the raw water does not meet these two parameters, iron addition may be required to provide enhanced coagulation. Ferric chloride ($FeCl_3$) is commonly available for use in potable water systems and can be obtained as a 38wt% liquid. The volumetric flowrate of ferric chloride solution required to meet a predetermined dose rate can be calculated with Equation 7-5.

$$Q_{FeCl_3} = \frac{Q \cdot \delta_{FeCl_3}}{C_{FeCl_3} \cdot \rho_{FeCl_3}} \cdot \left(0.003785 \frac{\text{kg} \cdot \text{mL}}{\text{mg} \cdot \text{gal}}\right) \qquad \text{Eqn. 7-5}$$

Where:

Q_{FeCl_3} = Ferric Chloride Metering Pump Rate (mL/min),

Q = Design flowrate (gpm),

δ_{FeCl_3} = Ferric Chloride Dose (mg/L),

C_{FeCl_3} = Ferric Chloride Stock Solution Concentration (wt%), and

ρ_{FeCl_3} = Density of Ferric Chloride (kg/L).

For example, if the design flow rate of water to be treated was 300 gpm and the water needed an additional 1.0 mg/L of iron, a 38-wt% solution of ferric chloride with a density of 1.42 kg/L could be added to the water at a rate of 6.1 mL/min to provide the required iron.

$$Q_{FeCl_3} = \frac{(300\text{ gpm}) \cdot (1\text{ mg/L})}{(0.38) \cdot (1.42\text{ kg/L})} \cdot \left(0.003785 \frac{\text{kg} \cdot \text{mL}}{\text{mg} \cdot \text{gal}}\right) = 2.1\text{ mL/min}$$

The required storage capacity for the ferric chloride solution can be calculated using Equation 7-6.

$$V = \frac{Q \cdot t \cdot \delta_{FeCl_3}}{C_{FeCl_3} \cdot \rho_{FeCl_3}} \cdot \left(0{,}00144 \frac{kg \cdot min}{mg \cdot d}\right) \qquad \text{Eqn. 7-6}$$

Where:

V = Storage Volume (gal),

Q = Design flowrate (gpm),

δ_{FeCl_3} = Dose Rate of Ferric Chloride (mg/L),

t = Storage Time (days),

C_{FeCl_3} = Ferric Chloride Stock Solution Concentration (wt%), and

ρ_{FeCl_3} = Density of Ferric Chloride (kg/L).

Using the same example and specifying 14 days of ferric chloride storage, the required storage volume would be 32.6 gallons.

$$V = \frac{(300\,gpm)\cdot(14\,days)\cdot(1\ mg/L)}{(0.38)\cdot(1.42\ kg/L)} \cdot \left(0.00144 \frac{kg \cdot min}{mg \cdot d}\right) = 11.2\ gal$$

A generalized flow diagram for a ferric chloride chemical addition system is shown in Figure 7-9. The ferric chloride should be stored in a tank made of either fiberglass-reinforced polyester or rubber-lined steel. A flow meter installed along the main water line is used to pace the addition of ferric chloride to the water flowrate. An isolation valve and check valve are used in the connection to the water line. After the ferric chloride addition, the water is mixed with an inline mixer and the dosed water is sent to the filters.

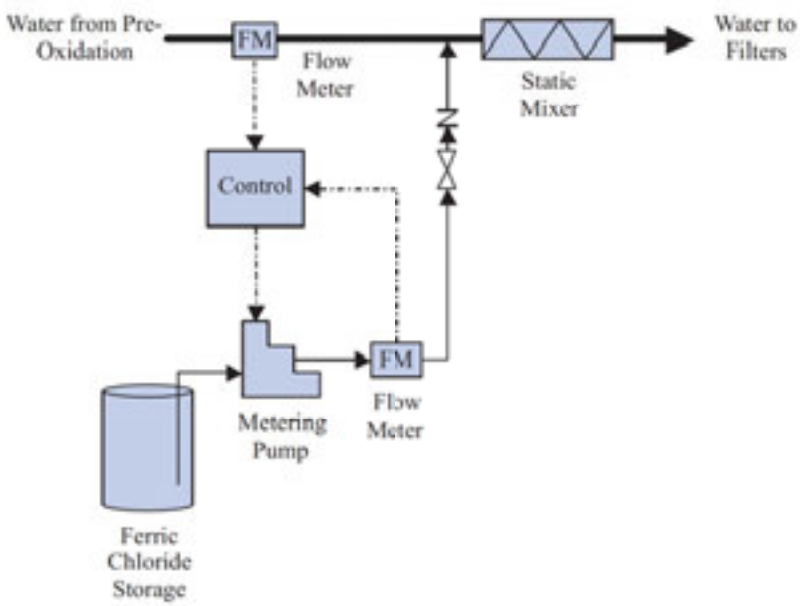

Figure 7-9. Ferric Chloride Addition Flow Diagram.

Section 8
Point-Of-Use Treatment

POU devices were approved as SSCTs for meeting the revised arsenic MCL. POU devices are attractive for removing contaminants that pose (solely) an ingestion risk, as is the case with arsenic. This is because a very small fraction of the total water supplied to a given household is ultimately consumed. In most cases, the POU unit is plumbed into the kitchen faucet. As such, the kitchen tap would be the only source from which water should be collected for consumption.

The primary advantage of employing POU treatment in a small system is reduced capital and treatment costs, relative to centralized treatment. On the downside, however, it is the utility's responsibility to maintain equipment. Therefore, these programs generally incur higher administrative and monitoring costs to make sure that all units are functioning properly. POU programs are an economically viable alternative to centralized treatment for systems serving up to 500 people.

Another downside is that the media or membranes used in POU treatment devices may be susceptible to microbial colonization. Higher levels of bacteria have been found in the finished water produced by some POU treatment devices, particularly those that incorporate an activated carbon element, than in the corresponding untreated water. Although no illnesses have been reported as a result of the use of these treatment devices, the health effects of these bacteria are still unknown. Therefore, additional monitoring and post-treatment disinfection may be required to ensure customer safety, increasing overall costs.

The primary criteria for selecting an appropriate POU treatment device are arsenic removal performance and cost. Additional considerations include third party certification to NSF/ANSI standards, appropriate mechanical warning devices, and ease of serviceability.

8.1 Treatment Alternatives

The technologies that are most amenable to POU treatment include column adsorption with AA, IBS, or RO with pre-filtration. The decision trees in Section 3 lead to the most appropriate POU technology among these choices.

8.1.1 Adsorption Point-of-Use Treatment

While finished water pH values will likely be much higher than the optimal pH for activated alumina (pH 6.0), it can be operated on a disposable basis at higher pH values. Modified AA and IBS provide improved treatment capacity across a broader pH range, and may be preferred depending upon the cartridge replacement frequency selected by the system. Column operation has the advantages of simple operation, low maintenance, low relative cost, small under-the-counter footprint, and high treatment capacity. Additionally, the break-

through kinetics of sorption technologies are slow and more readily detected by routine monitoring.

Figure 8-1 shows how POU adsorption equipment is typically connected to kitchen plumbing.

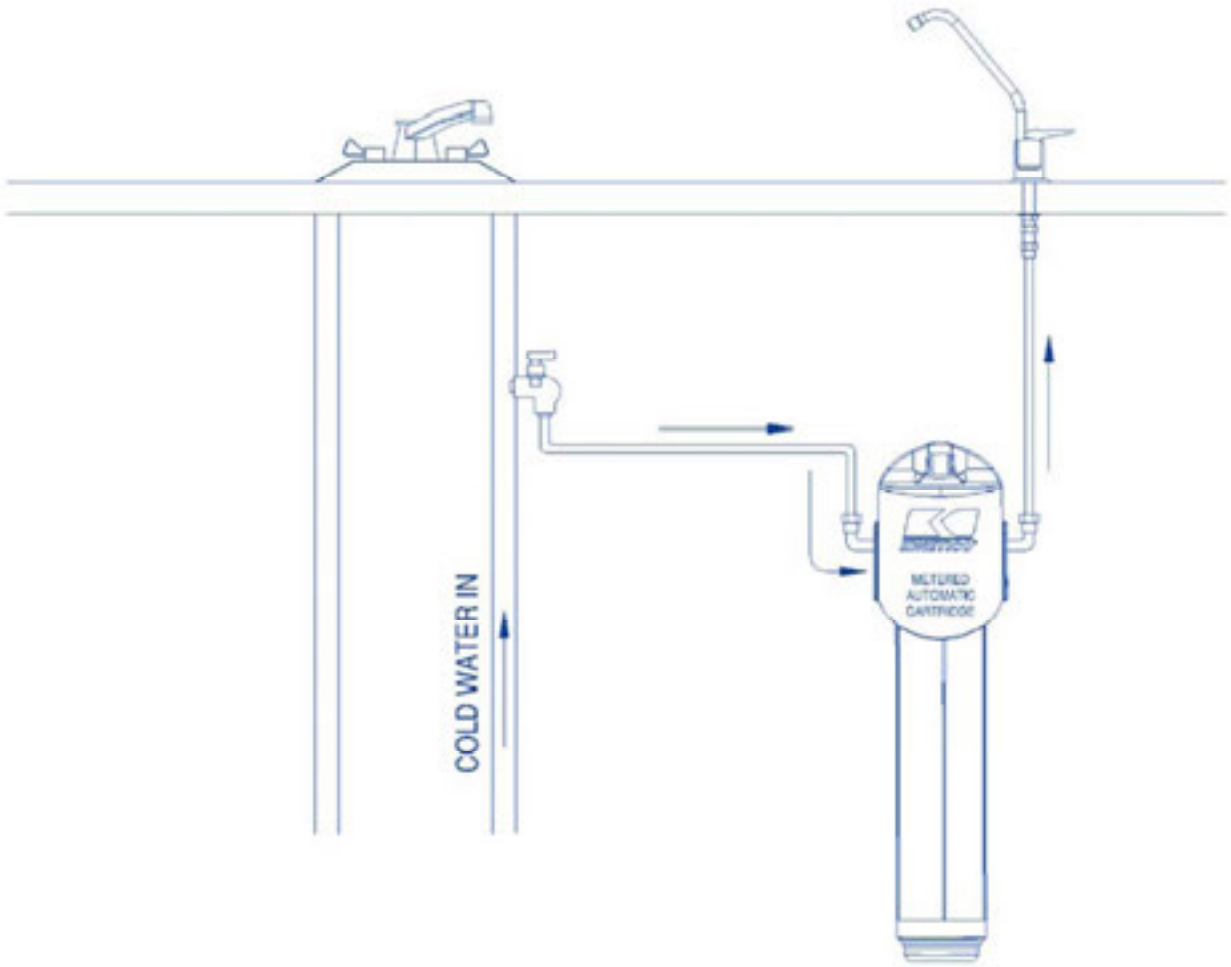

Figure 8-1. Point-Of-Use Adsorption Setup (Kinetico).

Adsorption columns are typically operated to a set volume to prevent arsenic leakage. This is accomplished through the use of a metered cartridge that provides flow totalization and will automatically shut-off water flow once the unit reaches the prescribed volume limit. Figure 8-2 shows a cross-section of one manufacturer's adsorption cartridge.

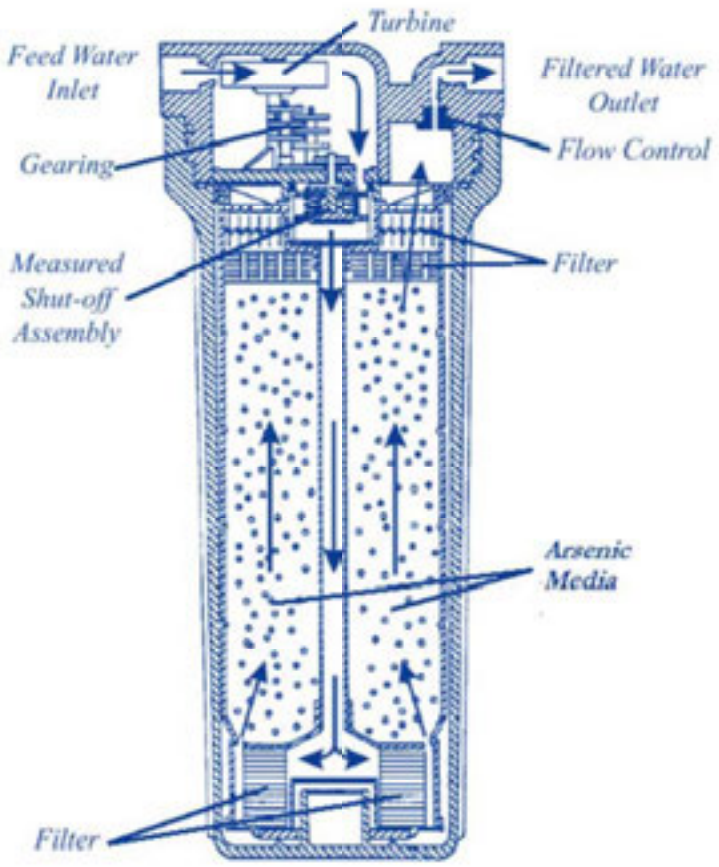

Figure 8-2. Metered Automatic Cartridge (Kinetico).

8.1.2 Reverse Osmosis Point-of-Use Treatment

RO POU devices are recommended for treating arsenic-rich water containing high levels of sulfates, phosphates, or total dissolved solids. When operating at typical tap pressures, RO devices commonly achieve greater than 95% As(V) rejection at a water recovery of 10-25%. Most units are designed with pre- and post-filters. Pre-filtration through granular media is applied to reduce solids loading and extend membrane life. For chlorine sensitive membranes, pre-filtration typically utilizes a dechlorinating media such as granular activated carbon. Post-filtration utilizes carbon or arsenic adsorbent media and serves as a final guard step.

Although the cost of RO POU devices is relatively high compared to other possible options, the immediate improvement of the overall water quality could make it very attractive to customers. The potential disadvantages associated with RO systems include poor water recovery, disposal of the reject stream, and high capital cost.

The most common types of membranes used for RO applications are cellulose acetate, thin-film polyamide composites, and sulfonated polysulfone. The membranes are manufactured in various forms, including tubes, sheets, and hollow fibers. The membrane is then constructed into a cartridge called an RO module, either spiral wound or hollow fiber.

Most RO POU devices operate at tap water pressure, and therefore have relatively poor water recoveries. Permeate is sent to a bladder tank large enough to meet on-demand requirements. Typical production rates range from 5-15 gpd.

Over time, the membrane surface will require cleaning in order to maintain performance. This capability is built in to most RO devices. Depending on the specific design, the water source for washing the membrane surface may either be feed water or permeate.

Figure 8-3 shows how RO POU equipment is typically connected to kitchen plumbing.

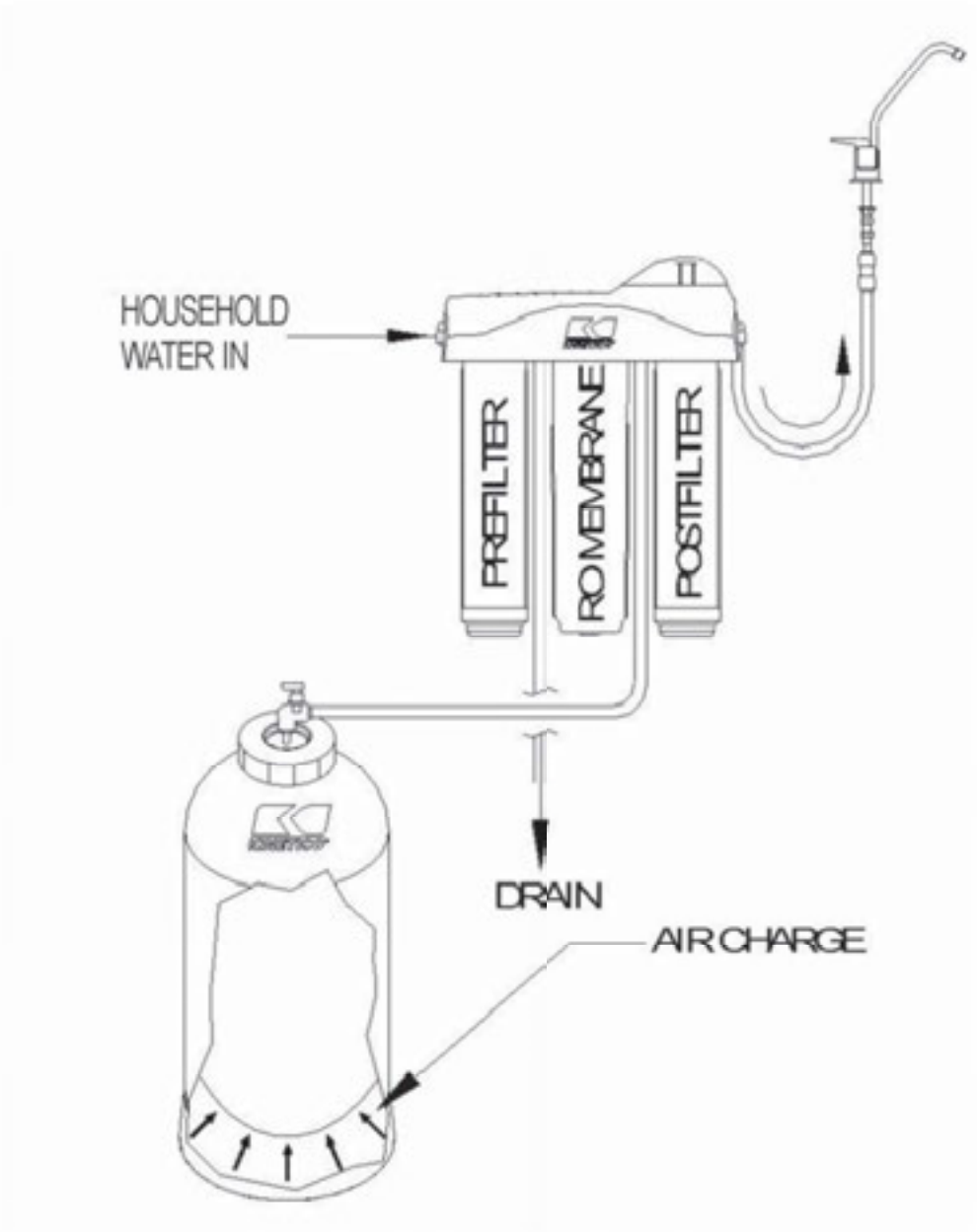

Figure 8-3. Point-Of-Use Reverse Osmosis Setup (Kinetico).

8.2 Implementation Considerations

Amendments to the SDWA in 1996 explicitly allow utilities to install POU treatment devices to achieve compliance with the NPDWRs. More information on the implementation of a POU program can be found in the USEPA's *Guidance for Implementing a Point-of-Use or Point-of-Entry Treatment Strategy for Compliance with the Safe Drinking Water Act* (USEPA, 2002b Draft).

The implementation of a centrally managed POU program is very different from application of centralized treatment. In many cases, the customer's acceptance of the treatment unit is affected by familiarity with the technology, the need for treatment, the appearance of the unit, and other subjective factors. Many homeowners currently employ some form of POU treatment such as carbon filtration or water softening. These products are generally used to enhance aesthetic properties of water, and are therefore used voluntarily. Under a centrally managed POU treatment program, all customers would be required to employ treatment devices in their home. As such, utility staff or contractors would need access inside individual homes to install treatment devices, make plumbing modifications, and make periodic O&M checks. The extent of customer acceptance and potential for resistance associated with this utility-customer interface are not well known.

8.2.1 Program Oversight

POU units must be owned, controlled, and maintained by the public water system or by a contractor hired by the public water system to ensure proper operation and maintenance of the device and compliance with MCLs. The utility must retain oversight of unit installation, maintenance, and sampling. While this provision does not require the utility to perform all maintenance or management functions – utilities are free to contract out these tasks – it does imply that *the utility retains final responsibility* of the quality and quantity of the water provided to the service community and must closely monitor all contractors. Further, the utility *may not* delegate its responsibility for the operation and maintenance of POU devices installed as part of a compliance strategy to homeowners.

The implications of this requirement to the utility are significant. The utility must decide whether it wants to implement the POU program in-house or contract out the necessary services. In one case, the utility would be the main contact with the customer, and utility staff would be responsible for installation, monitoring, record-keeping, and O&M activities. This raises several important issues. First, many small utilities often have difficulty finding the time and budget to hire, train, and retain operators. Second, utilities that elect to keep the work in-house must provide staff training on installation and O&M procedures. Third, the utility should consider the liability implications of entering individuals' homes to conduct work. If the utility decides to contract out the services, the vendor would be the main contact with the customer and the utility would need to monitor the contractor.

8.2.2 Cost

There are a number of cost elements involved in conducting a POU program. These include:

- Capital cost of POU devices. The typical cost ranges of RO devices and adsorption units are $300-$1,000 and $100-$300 each, respectively.
- Installation labor. Installation of each device is anticipated to take 30 to 60 minutes assuming no significant plumbing modifications are necessary.
- Installation parts
- Replacement parts. Carbon-based pre-filters typically cost between $15-50. New membranes typically cost about $150.
- Water quality analyses. Arsenic can be measured by a commercial laboratory for approximately $10-$20 per sample.
- O&M labor.

8.2.3 Compliance Monitoring

The current approach is that compliance monitoring would be conducted for each and every installed POU device, though only one-third within the same year. A representative monitoring approach that requires less frequency monitoring is under evaluation. States may have more stringent monitoring requirements. Samples can be taken by the utility or the contractor.

8.2.4 Mechanical Warnings

Each POU treatment device installed as part of a compliance strategy must be equipped with a warning device (e.g., alarm, light, etc.) that will alert users when their unit is no longer adequately treating their water. Alternatively, units may be equipped with an automatic shut-off mechanism to meet this requirement. Several communities have implemented POU treatment strategies using units equipped with water meters and automatic shut-off devices to disable the units after a specified amount of water has been treated to prevent contaminant breakthrough.

8.2.5 Operations and Maintenance

Periodic maintenance is necessary to ensure that the devices are functioning properly and producing tap water in compliance with the arsenic MCL. O&M activities consist of both regular scheduled tasks as well as emergency troubleshooting responses.

The sorbent media or RO membrane should be replaced periodically either on a set frequency or based on monitoring and tracking use. Both replacement schedules should be based on pilot testing results. The Arsenic Rule also stipulates that the POU device be equipped with mechanical warnings to ensure that customers are automatically notified of operational problems. Many devices include a programmable indicator that tracks cumulative water use, and serves as a convenient visual guide for the remaining life of the POU

device. However, it is not recommended that the utility depend solely on the customer for POU servicing. Rather, there should be an established schedule that is made public to the community and adhered to.

8.2.6 Customer Education and Residential Access

Utilities should attempt to educate the public prior to implementing a POU strategy. This education may include public hearings, water bill inserts, posters, or notices in print or on radio or TV. When presented with the facts, most people will happily provide the water utility with access to ensure their ongoing effectiveness.

To address the possibility that an individual or a group of individuals may refuse to provide utility personnel with the necessary access, the utility may need to convince the local government to pass an ordinance guaranteeing water utility personnel access to service treatment units. To meet the legal responsibility to provide water in compliance with all NPDWRs, the utility may also have to pass an ordinance that requires customers to use POU treatment units, and that provides the utility with the authority to shut off a customer's water if the customer refuses to allow installation and maintenance of, tampers with, bypasses, or removes the treatment unit.

To minimize the burden associated with gaining access to individual residences, POU sampling should be coordinated with routine maintenance. Reducing the number of house visits will reduce administrative costs and travel time, resulting in substantial cost savings as well reducing the disruption to the residents.

8.2.7 Residual Oxidant in Distribution System

In order to effectively use many sorbent type POU devices, the arsenic must be in its As(V) form as it is treated at the tap. RO type POU devices may also work more efficiently if arsenic is oxidized. This may require installation of a POU oxidation unit or centralized oxidation. If anoxic conditions occur in the distribution system, there is a potential for arsenic to reduce back to the As(III) state. This would drastically decrease the effectiveness of most of the sorptive type POU devices. Therefore, maintaining an adequate residual oxidant in the distribution system is important.

8.2.8 Waste Handling

The type of waste produced from a POU device will depend on the treatment employed. RO treatment will produce a continuous liquid waste stream (i.e., retentate) that should be suitable for disposal in an on-site or community sewerage system (see Section 2.4). Conversely, with column adsorption treatment, the only waste is exhausted media, which is produced on a periodic basis.

Because the solid residuals generated by POU units are collected from individual households, these wastes *may* be exempt from federal regulation as hazardous wastes, regardless of their toxicity. However, state regulations and each state's implementation of federal regulation can vary. In the case of liquid wastes, local wastewater treatment plants may

issue their own limits for the disposal of arsenic. It is anticipated that this waste will not exceed the TC characteristics and will be disposable in a municipal landfill. Additionally, POU manufacturers or vendors may also provide waste disposal services for the POU devices.

8.3 Device Certification

To meet the requirements of the SDWA, POU devices installed as part of a compliance strategy must be certified according the American National Standards Institute (ANSI) standards, if a standard exists for that type if device. RO POU devices must be certified as per ANSI/NSF 58 (2002) - *Reverse Osmosis Drinking Water Treatment Systems*. POU devices utilizing a sorption technology such as AA or an IBS must be certified as per ANSI/NSF 53 (2002) - *Drinking Water Treatment Units – Health Effects*.

Section 9
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Wang, Lili, Abraham Chen, and Keith Fields (2000). *Arsenic Removal from Drinking Water by Ion Exchange and Activated Alumina Plants*, EPA 600R00088, Prepared by Battelle under contract 68C70008 for U.S. EPA ORD, October 2000.

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Office of Water (4606M)
EPA 816-R-03-014
July 2003
www.epa.gov/safewater

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TECHNOLOGY ASSESSMENT PRESENTATION SLIDES

SURPRISE
ARIZONA

Water Design Standards and Technology Assessments

Workshop No. TA2: Water Treatment Technology Evaluation

September 30, 2009, 9:30 AM – 5:00 PM

carollo
Engineers...Working Wonders With Water™

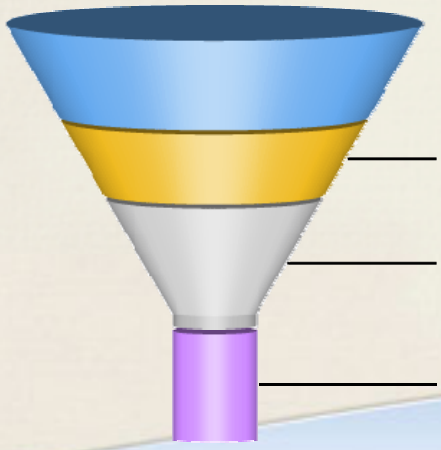
Water Treatment Technology Evaluation

METHODOLOGY

Filename.ppt

2

Principles for Identifying Technologies to Consider



Principle 1: Emerging Contaminants

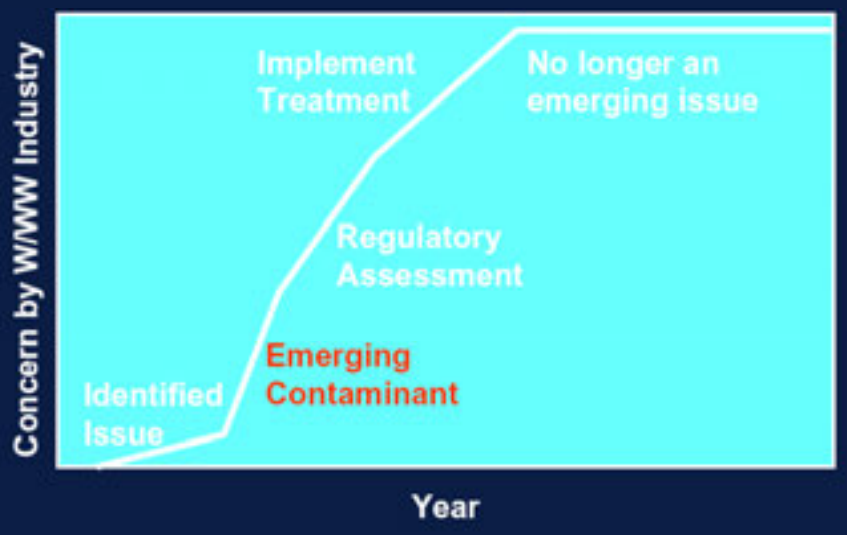
Principle 2: Technology Maturity

Principle 3: Removal Mechanism

Principle 4: Local Experience

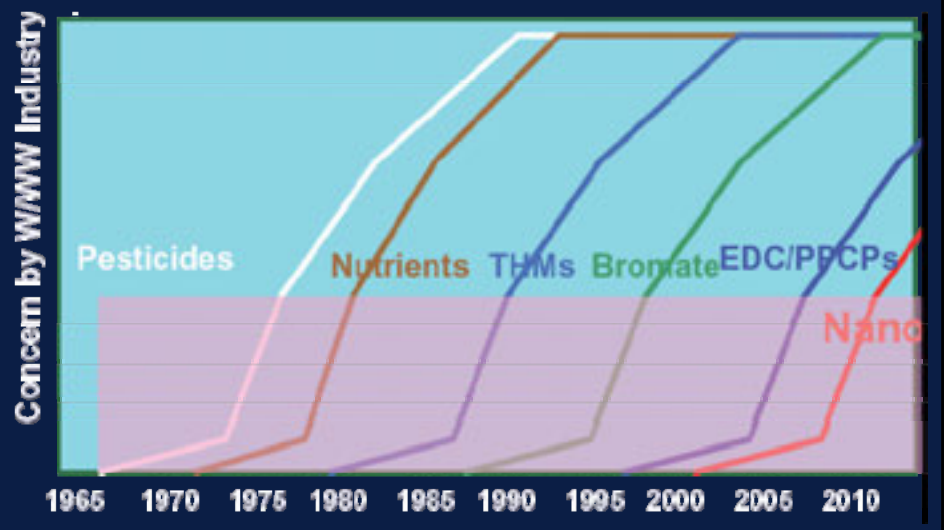
3

Stages of Concern for Pollutants



Source: Westerhoff, 2007

Periods of Concerns for Emerging Containments



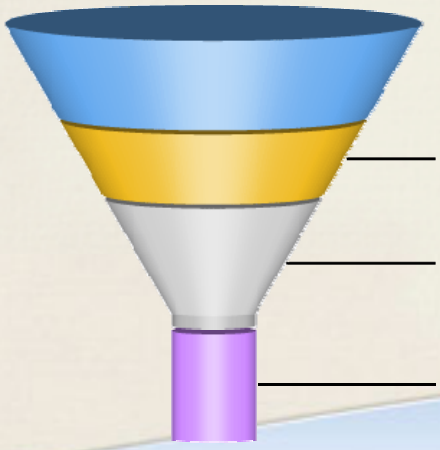
Source: Westerhoff, 2007

Principle 1: Processes selected are based on established treatment goals for the City of Surprise.

- Address Critical and Near term COCs
- Be prepared for potential and future COCs
  - Be proactive;
  - Do not preclude future options

6

Principles for Identifying Technologies to Consider



Principle 1: Emerging Contaminants

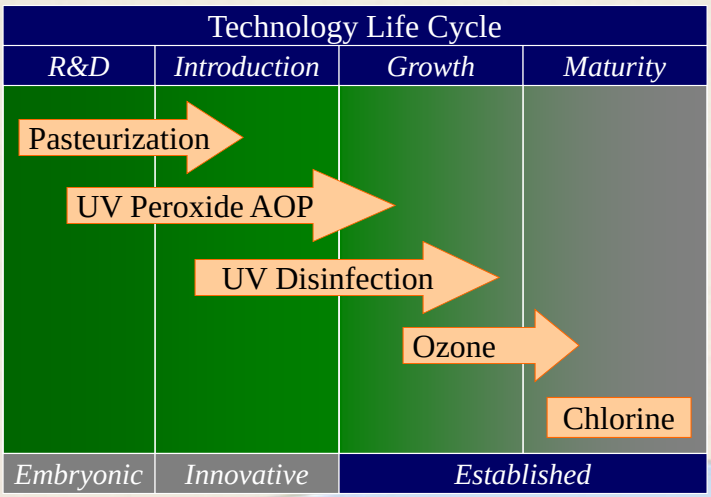
Principle 2: Technology Maturity

Principle 3: Removal Mechanism

Principle 4: Local Experience

7

Technology Life Cycle



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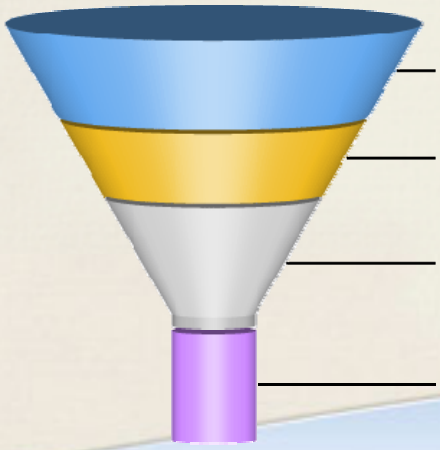
Principle 2: Select established processes.

- Innovative technologies proven at full scale may also be considered.
- Innovative applications of established process will also be considered.

9

Principles for Identifying Technologies to Consider



Principle 1: Emerging Contaminants

Principle 2: Technology Maturity

Principle 3: Removal Mechanism

Principle 4: Local Experience

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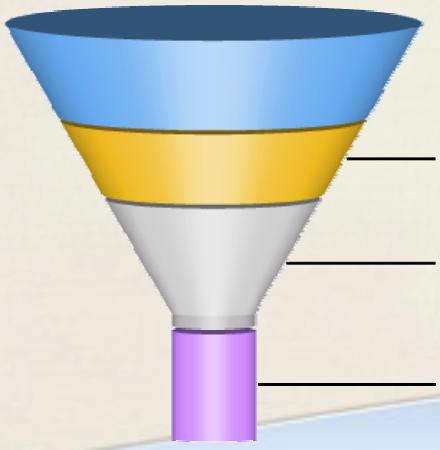
Vendors did a great job promoting commercial packages, but often confused the customers

Principle 3: Group technologies according to the contaminant removal mechanism.

- Focus on how it functions instead of the fancy names of the commercial packages
- This assessment may list manufacturers for consideration, but not for locking the City in.

Principles for Identifying Technologies to Consider



Principle 1: Emerging Contaminants

Principle 2: Technology Maturity

Principle 3: Removal Mechanism

Principle 4: Local Experience

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Principle 4: Include processes that have Arizona / Local experience or interests.

- Designed, built or operated by other utilities
- Researched, studied or being considered for Arizona applications

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Achieving the City's Water Treatment Goals Requires Multiple Treatment Categories

	Target COCs							
Treatment Categories	Arsenic	Fluoride	Nitrate	Virus	Total Coliform	TDS	Turbidity	Iron and Manganese
Pre-oxidation	X							X
Chemical Pretreatment	X	X					X	X
Filtration	X	X	X	X	X		X	X
Adsorption	X	X					X	X
Ion Exchange	X	X	X			X		X
Desalination	X	X	X	X		X	X	X
Disinfection				X	X			

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Water Treatment Technology Assessment

OXIDATION AND DISINFECTION

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Oxidation – Available Alternatives

1. Aeration (O_2)
2. Chlorine
   a. Gaseous Chlorine
   b. Liquid Chlorine (Bulk and Onsite)
3. Potassium Permanganate ($KMnO_4$)
4. Chlorine Dioxide
5. Chloramines
6. Ozone

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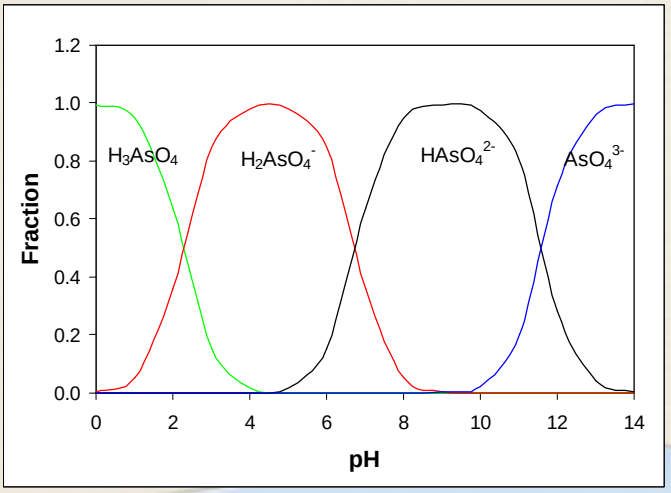
Why Oxidation: Acid-Base Chemistry of As(V)



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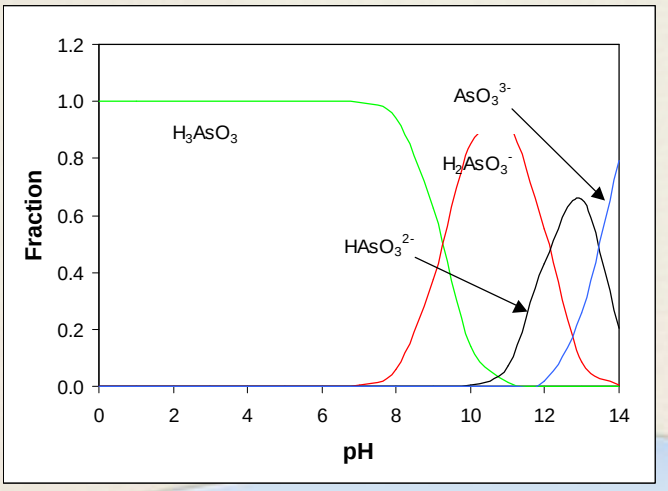
Why Oxidation: Acid-Base Chemistry of As(III)



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Benefits of Oxidation

1. **Enhance adsorption, sedimentation and filtration of Arsenic, Iron and Manganese**
2. Enhances Removal of T&O and color
3. Reduce chlorine demand and DBP formation (if chlorine is not used)
4. Destabilize colloidal material and organic compounds

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Oxidation Alternatives Comparison

Unit Operation	Selected for Treatment Train Ranking	Fe and Mn Oxidation	Arsenic Removal Improve-ment
Aeration / Stripping	Not Recommended	Slow. Not reliable	None
Chlorine	Recommended	Good for iron. Slow for manganese	Yes
Chloramines	Not Recommended	Ok for iron Slow for manganese	Not effective
Chlorine Dioxide	Not recommended	Good for iron and manganese	Slow
Potassium Permanganate	Recommended	Good	Yes
Ozone	Not Recommended	Excellent	Yes

Oxidation using Liquid Chlorine is Recommended for Practical Purpose

1. Better water quality at essentially no extra costs
   a. Virtually all technologies remove arsenic V better than arsenic III
   b. Residual disinfectant can also be used for oxidation

Exception: RO without pretreatment

Disinfection Alternatives

1. Gaseous Chlorine
2. Liquid Chlorine (Bulk)
3. Liquid Chlorine (Onsite)
4. Chloramines
5. UV*

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There is No Driver to Select UV for Your Groundwater Application

1. Still need residual disinfection
   a. Do not reduce chlorine dosage
2. Groundwater Supply
   a. No DBP concerns
   b. No *Cryptosporidium* and *Giardia* Concerns
3. No treatment goals for EDCs and emerging contaminants
   a. No need for advanced oxidation

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In Water, Gaseous and Liquid Chlorine are Essentially the Same

Gaseous Chlorine

Sodium Hypochlorite (Bulk)

Sodium Hypochlorite (Onsite Generation)

$$Cl_2 + H_2O \rightarrow HOCl + HCl$$

$$HClO \rightarrow H^+ + ClO^-$$

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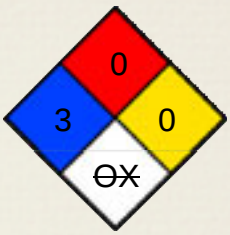
Disinfection - Gaseous Chlorine

- Gaseous form
- Available in cylinders, ton containers, 17-ton tank truck



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Gaseous Chlorine - Benefits and Challenges

Benefits:

- Long history of successful operation
- Readily available and economical chemical
- Experienced and trained personnel

Challenges:

- Operation and maintenance intense
- Safety concerns of accidental release during transportation and operation
- Require risk management plan (Clean Air Act Section 112(r): >2500 lb)

Sodium Hypochlorite (Bulk)

- 12.5% sodium hypochlorite is a hazardous material
- Referred as “Bleach”

Sodium Hypochlorite (Bulk) - Benefits and Challenges

Benefits:

- Safer to transport, store & handle than gaseous Cl_2
- Personnel experienced with chemical feed system
- Relatively easier to operate and maintain

Challenges:

- Higher chemical costs than gaseous chlorine
- Potential for air binding, plugging and mechanical malfunction
- Precipitation of calcium may result in solids in the solution feed lines
- Must be used in timely manner to minimize degradation (chlorate and chlorite)

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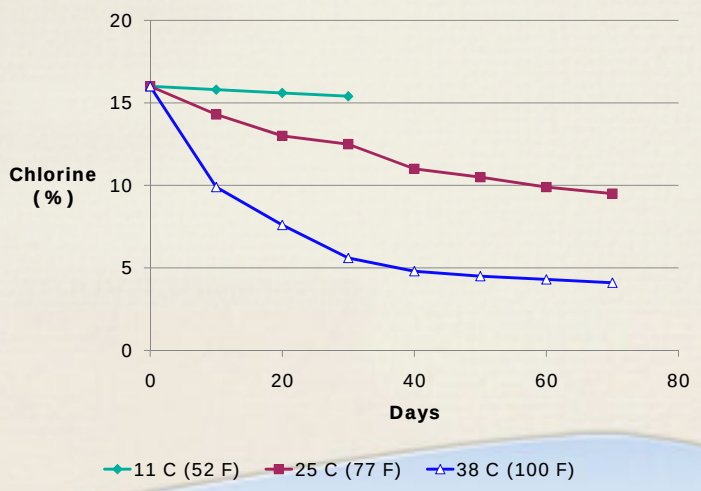
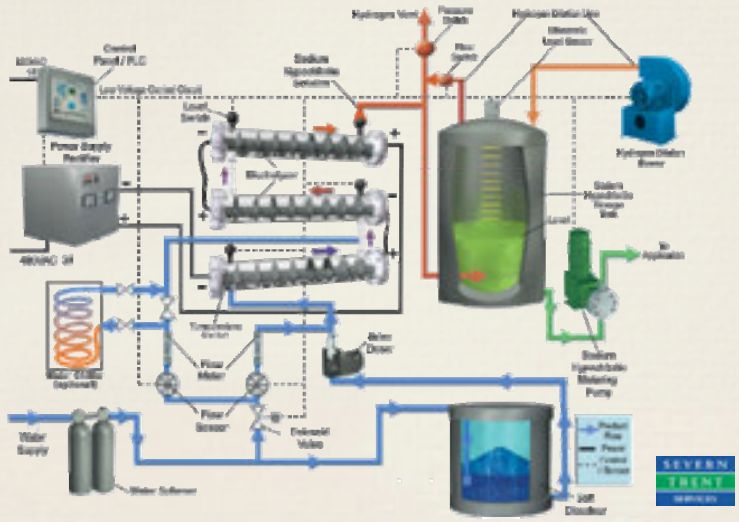
Sodium Hypochlorite Degrades, Especially under High Temperature



Building / climate control?

30

Sodium Hypochlorite Onsite Generation (OSG)



$NaCl + H_2O + 2e = NaOCl + H_2$

Salt + Water + Electrical Energy = Sodium Hypochlorite + Hydrogen

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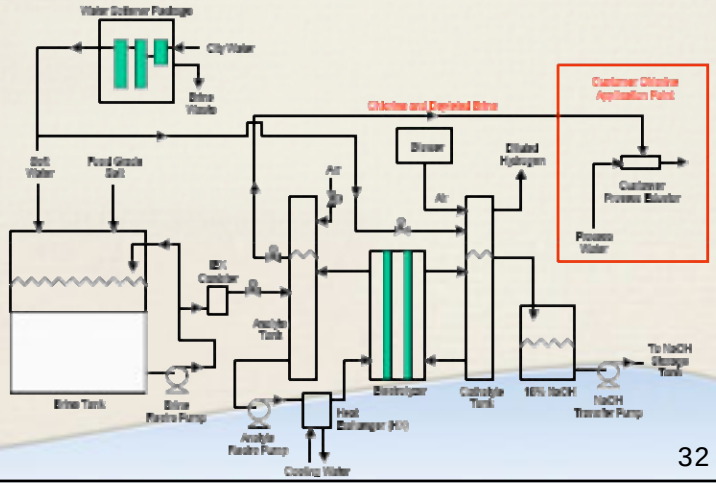
Onsite Chlorine Generation

Electrolytic Technologies Corporation

Klorigen™ M-Series

$2NaCl + H_2O + Power = Cl_2 + NaOH + H_2$

$Cl_2 + 2NaOH = NaOCl + NaCl + H_2O$ (Optional)



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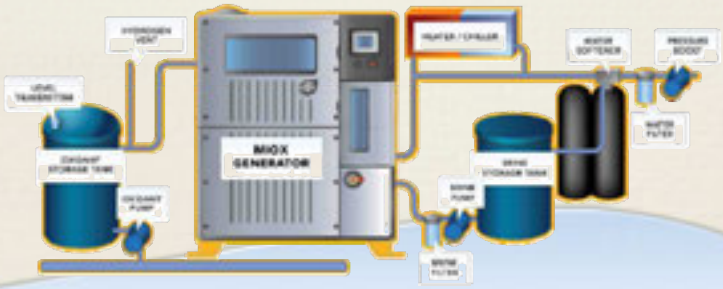
MIOX Onsite Hypochlorite Generation and Mixed Oxidant Solution Generation



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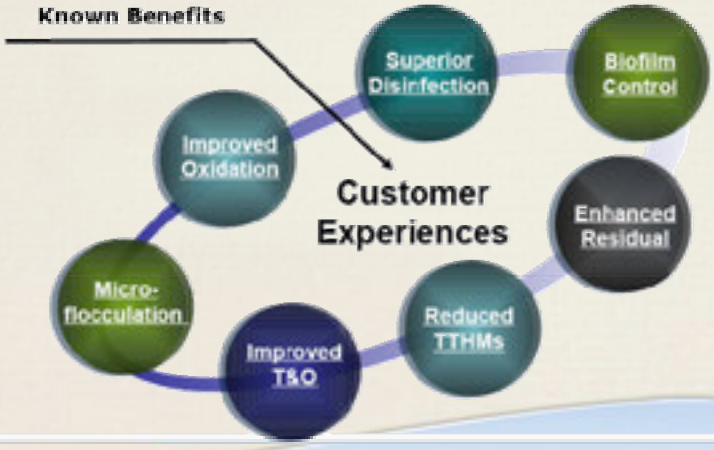
Manufacturers Claimed Superior Chemistry for Mixed Oxidants



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Onsite Generation – Benefits and Challenges

Benefits

- <1% Sodium Hypochlorite is a non-hazardous chemical
- Safer to store and handle than chlorine gas
- Less degradation
- On-demand production and flexible operation (produce extra during off-peak)
- Reduced operational costs
- Consistent solution strength
- Less truck traffic compared to bulk

Challenge

- High capital costs
- Replace electrolytic cells every 5 to 10 years
- High power consumption
- May require operation staff training
- Addition of TDS (10 – 14 mg/L increase) & sodium (5 – 6 mg/L)
- H_2 gas must be force vented and monitored

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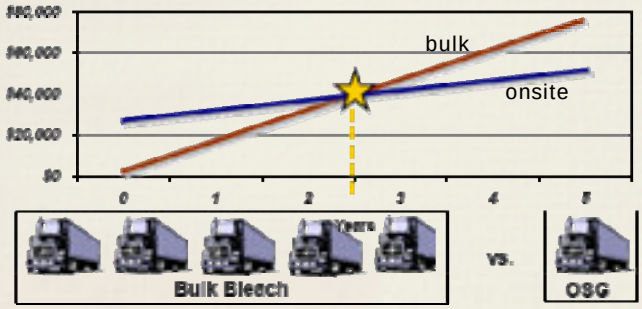
OSG Manufactures Claimed Payback Period as Short as 2 to 3 Years



- Size of Facility and Chlorine Usage
- Building? 100% Redundancy? Finance?

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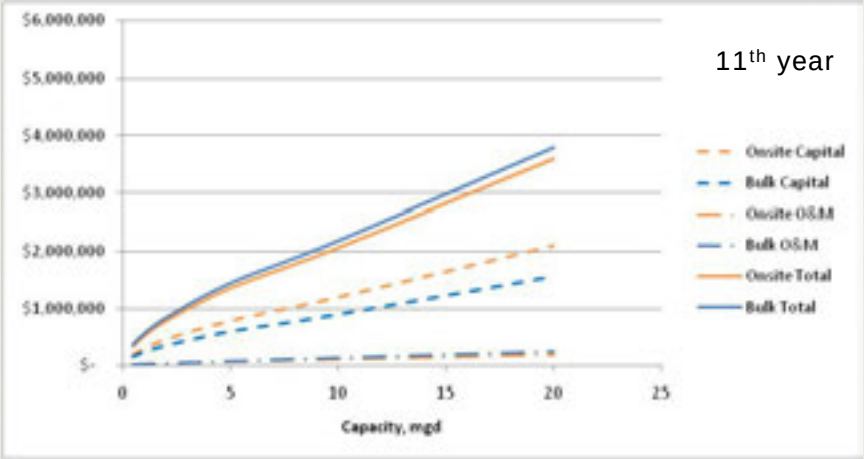
Payback Calculator



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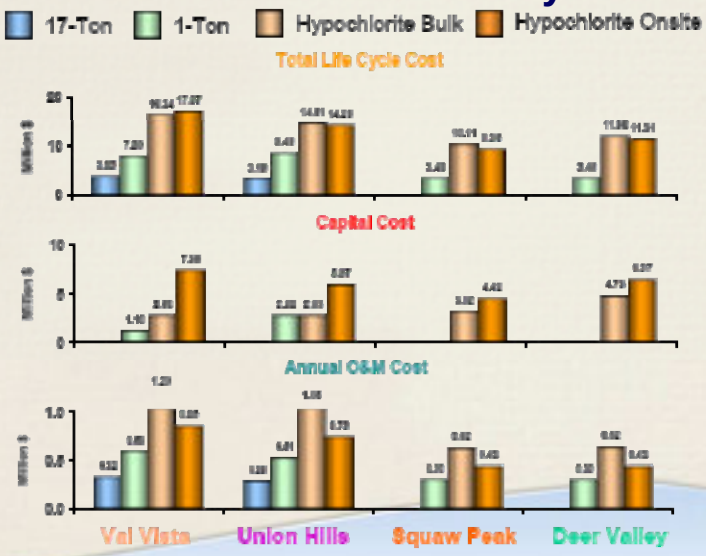
Example: City of Phoenix WTP Alternative Disinfection Study



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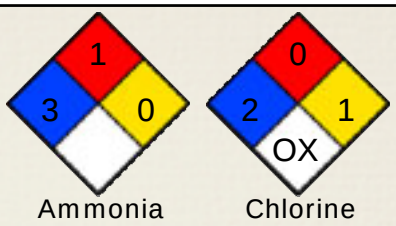
Chloramines



$NH_3 + HOCl = NH_2Cl + H_2O$

$NH_3 + 2HOCl = NHCl_2 + 2H_2O$

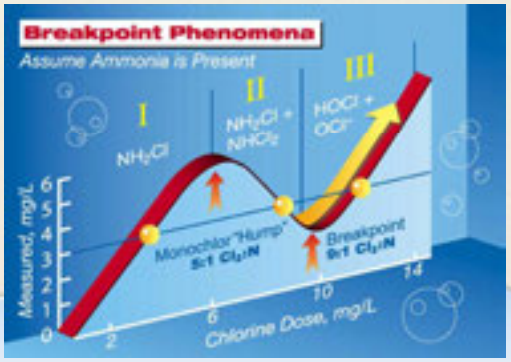
$NH_3 + 3HOCl = NCl_3 + 3H_2O$

Benefits

- Lower TTHM Formation (Not a main driver)
- Longer residual
- Less Chlorine Taste

Challenges

- Extra Costs
- Handle two hazardous chemicals
- Form other DBPs including NDMA



Ozone – Benefits and Challenges

Benefits

- Strong oxidant and disinfectant
- Lower TTHM Formation (Not a main driver)

Challenges

- Still need residual disinfection
- High capital and O&M costs
- Increased safety concern of liquid oxygen
- Higher O&M intensity
- Form Bromate (MCL 0.010 mg/L)

Consensus?

Recommendations for Disinfectant and Oxidant:

- Sodium Hypochlorite Bulk
- Sodium Hypochlorite Onsite

Water Treatment Technology Assessment

ARSENIC, FLUORIDE AND NITRATE

DRINKING WATER BEST AVAILABLE TECHNOLOGY (BAT)

1. Arsenic (40 CFR 141.62(c))
   a. Activated Alumina,
   b. Coagulation/Filtration (not BAT for systems < 500 service connections)
   c. Ion Exchange
   d. Lime Softening (not BAT for systems <500 service connections)
   e. Reverse Osmosis
   f. Electrodialysis
   g. Oxidation/Filtration (To obtain high removals, iron to arsenic ratio must be at least 20:1.)

DRINKING WATER BEST AVAILABLE TECHNOLOGY (BAT)

2. Nitrate (40 CFR 141.62(c))
   a. Ion Exchange,
   b. Reverse Osmosis
   c. Electrodialysis
3. Fluoride (40 CFR 142.61)
   a. Activated alumina absorption, centrally applied
   b. Reverse osmosis, centrally applied
   c. Primacy state variances (not BAT)
      - Modification of lime softening;
      - Alum coagulation;
      - Electrodialysis;
      - Anion exchange resins;

DRINKING WATER BEST AVAILABLE TECHNOLOGY (BAT)

4. **Total Trihalomethanes (TTHM):**

(1) Use of chloramines as an alternate or supplemental disinfectant or oxidant.

(2) Use of chlorine dioxide as an alternate or supplemental disinfectant or oxidant.

(3) Improved existing clarification for THM precursor reduction.

(4) Moving the point of chlorination to reduce TTHM formation and, where necessary, substituting for the use of chlorine as a pre-oxidant chloramines, chlorine dioxide or potassium permanganate.

(5) Use of powdered activated carbon for THM precursor or TTHM reduction seasonally or intermittently at dosages not to exceed 10 mg/L on an annual average basis.

DRINKING WATER BEST AVAILABLE TECHNOLOGY (BAT)

4. **Total Trihalomethanes (TTHM):**

Primacy state variances (not BAT)

- Introduction of off-line water storage for THM precursor reduction.
- Aeration for TTHM reduction, where geographically and environmentally appropriate.
- Introduction of clarification where not currently practiced.
- Consideration of alternative sources of raw water.
- Use of ozone as an alternate or supplemental disinfectant or oxidant.

Summary: BAT for Arsenic, Nitrate and Fluoride

Arsenic	Fluoride	Nitrate
RO	RO	RO
ED	ED	ED
AA	AA	
IX-As	IX-F	IX-N
Coagulation-Filtration (> 500 connections)	Alum Coagulation	
Softening-filtration (> 500 connections)	Modified Lime Softening	
Oxidation-Filtration (Fe:As > 20:1)		

BAT
Potential State Variances

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BAT Removal Efficiencies of Arsenic

Technology	Maximum Percent Removal (As V)
Ion Exchange	95
Activated Alumina	90
Reverse Osmosis	>95
Modified Coag/Filtration	95
Modified Lime Softening	80
Electrodialysis Reversal	85
Oxidation/Filtration (20:1 Fe/As)	80

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Evaluated Treatment Technologies

Arsenic	Fluoride	Nitrate
RO	RO	RO
ED	ED	ED
AA	AA	
IX-As	IX-F	IX-N
Coagulation-Filtration (> 500 connections)	Alum Coagulation	Biological Filtration
Softening-filtration (> 500 connections)	Modified Lime Softening	
Oxidation-Filtration (Fe:As > 20:1)		
GFH Adsorption*		
Iron Modified Media		
Coagulation + MF/UF*	Coagulation + MF/UF*	
Greensand Filters		
Pellet Softening	Pellet Softening	

BAT
Variances
Additional

Reasons for not listed as BAT: No full scale history or lack of published data

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Water Treatment Technology Assessment

ADSORPTION

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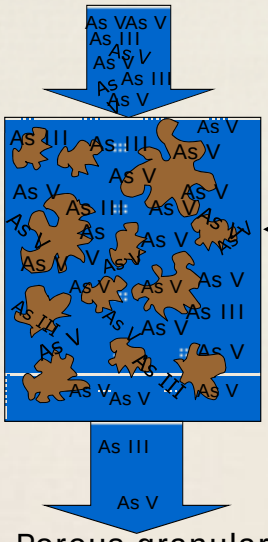
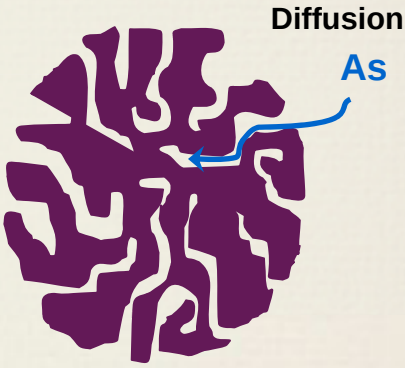
Adsorption Technology



Fix Bed Process

Porous granular media with ion exchange properties

Accessible Area of Granular Media



> 99% of surface for removal is internal

Source: M. Edwards, June 2003

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Examples of Adsorbent Media

GFO Bayoxide E33

Modified activated alumina

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Adsorptive Media Listed in NSF/ANSI STD 61

Company	Base Material	Name	Material
Alcan (4)	Aluminium	AAFS - 50	Mod AA
Alcoa (2)	Aluminium	CPN	AA
Apyron	Aluminium	Aqua-Bind	Mod AA
Engelhard	Aluminium	ARM 100	AA
Engelhard	Iron	ARM 200	Iron Oxide
ADI	Iron	G2	Iron based
SMI	Iron	SMI III	Iron/sulfur
US Filter	Iron	GFH	Iron Hydroxide
Bayer AG	Iron	E 33	Iron Oxide
WRT	Zeolite	Z – 33	Mod Zeolite
Magnesium Elektron	Zirconium	Isolux	Zirconium Hydroxide

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Adsorptive Media Listed in NSF/ANSI STD 61

Company	Base Material	Name	Material
ATS (MA)		A/I Complex 2000	
Hydroglobe, Inc	Titanium	MetSorb	Titanium Oxide
Dow Chemical	Titanium	ADSORBSIA	Titanium Oxide
Purolite	Resin	ArsenX	Mod w/Fe
ResinTech	Resin	ASM-10HP	Mod w/Fe

Activated Alumina System - New Hampshire

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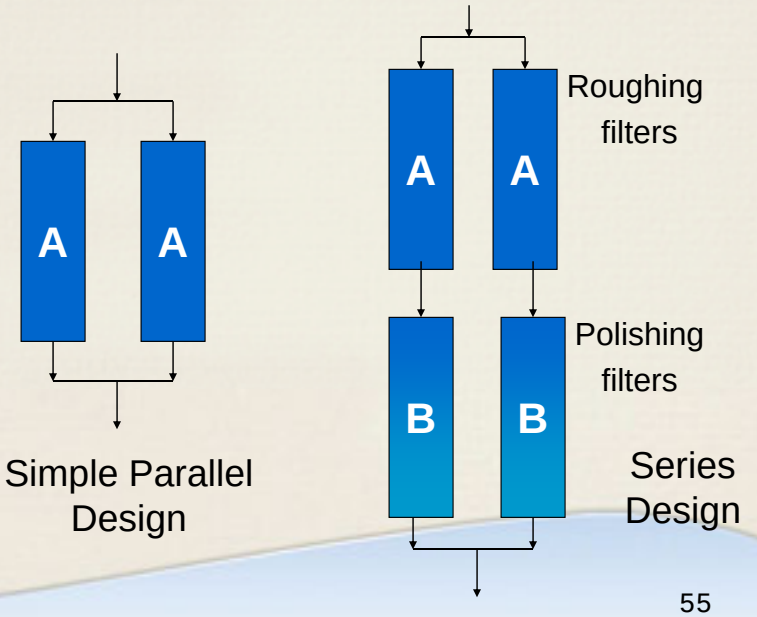
Adsorptive Media System Configuration



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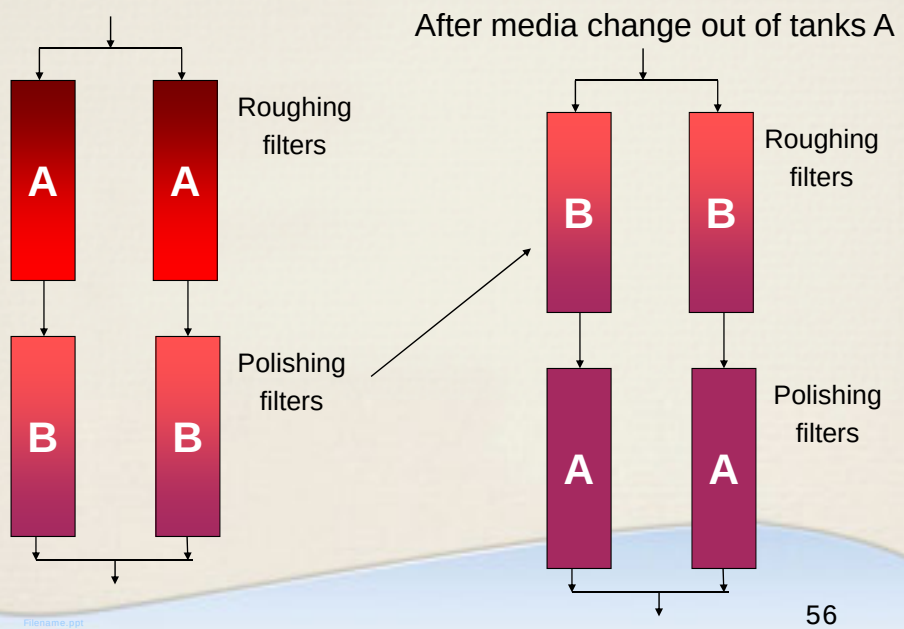
Adsorptive Media System Configuration



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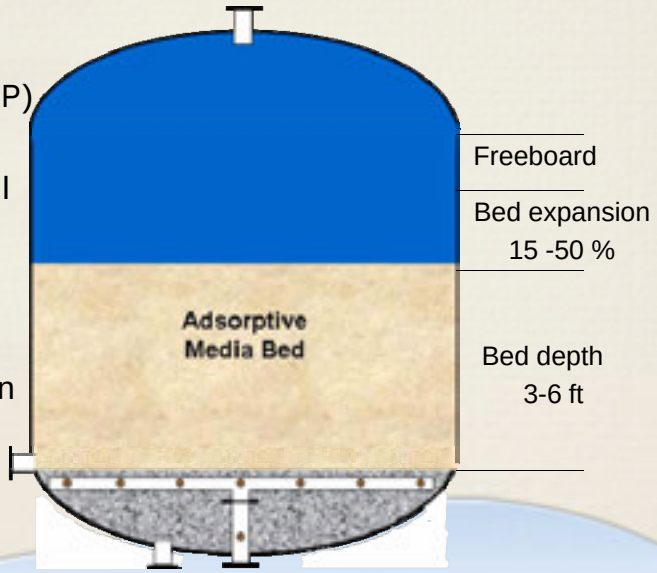
Adsorptive Media Pressure Tank

Material

- Fiberglass (FRP)
- Carbon Steel
- Stainless Steel

Media
EBCT
3 – 10 min



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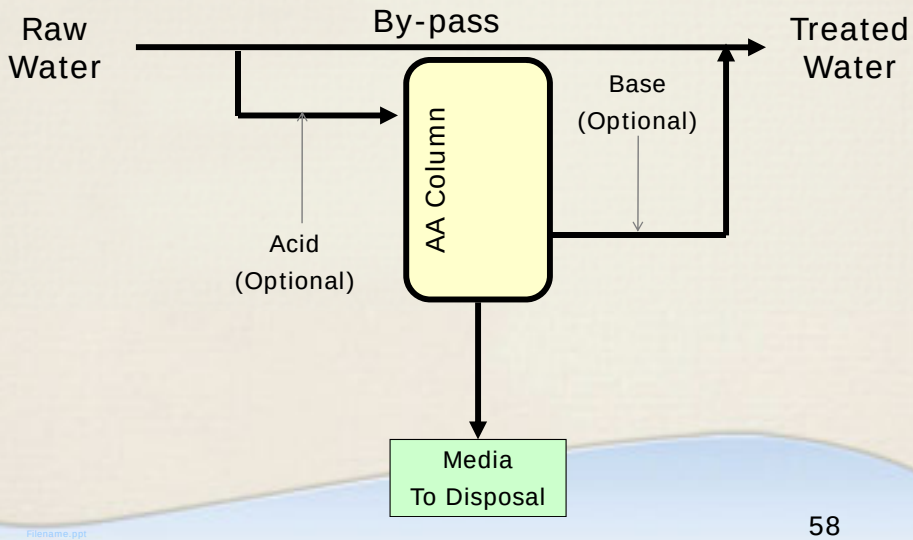
Activated Alumina Blending and Bypass



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Adsorption - Benefits and Challenges

Benefits

- Highly selective for arsenic and fluoride
- Relatively insensitive to TDS and sulfate
- Low arsenic in treated water (2-3 ug/L) at low EBCT (3 to 10 minutes)
- Reliable and simple operation
- Reasonable prices and widely used
- Relatively small footprint
- Many adsorption media available
- > 99% recovery
- Residual disposal usually not a major issue

Adsorption - Benefits and Challenges

Challenges

- Removal capacity impacted by water chemistry such as pH and competitive contaminants
- pH adjustment may be required
- Media replacement

Activated Alumina Key Issues

- Effective but pH sensitive
  - High removals over a broad range of pH
  - Shorter run lengths at higher pH
- Regenerated Option
  - Use strong bases and acid
  - Regeneration removes 50 – 70% capacity
  - Brine disposal is difficult
- Disposable Option
  - Cheaper than regeneration
  - Optimal pH of 6 or natural pH
  - Spent media disposed of in a non-hazardous landfill
  - No strong acids or bases handling

Activated Alumina Residuals

1. Liquids
   a. Backwash and rinse water
   b. Spent regenerant (not for the disposal mode)
2. Solids
   a. Media

Terms of the Trade

1. RCRA – Resource Conservation and Recovery Act
2. OSHA – Occupational Safety and Health Act
3. TCLP – Toxicity Characteristic Leaching Procedure
4. TBLL – Technically Based Local Limits
5. TTLC – Total Threshold Limit Concentration
6. WET – Waste Extraction Test
7. STLC – Soluble Threshold Limit Concentration

Activated Alumina Residuals

- Activated Alumina Residuals often passes Toxicity Characteristic Leaching Procedure (TCLP) (around < 50 µg/L)
- Current toxicity characteristic (TC) regulatory level for designating arsenic as a hazardous waste under the Resource Conservation and Recovery Act (RCRA) is 5 mg/L (5000 µg/L) listed in 40 CFR 261.24(a).

RCRA

1. Subtitle C – Hazardous Waste Management
   a. 40CFR Part 261 – Identification and Listing of Hazardous Waste
      - Subpart C – Characteristics of Hazardous Waste
      - Subpart D – Lists of Hazardous Wastes
2. Subtitle D – State or Regional Solid Waste Plans
   a. 40CFR Part 257—Criteria for Classification of Solid Waste Disposal Facilities and Practices
   b. 40CFR Part 258—Criteria for Municipal Solid Waste Landfills

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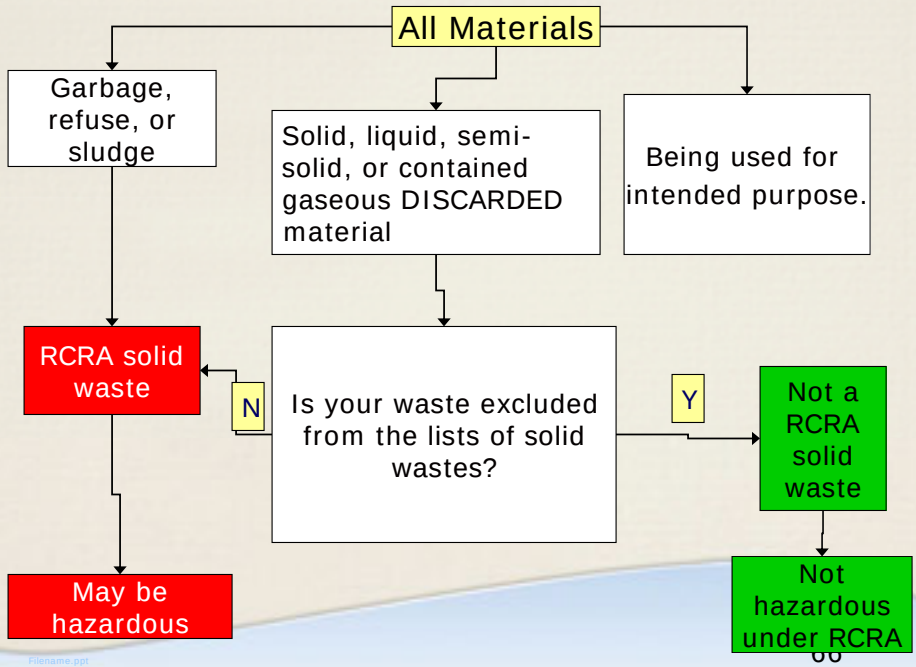

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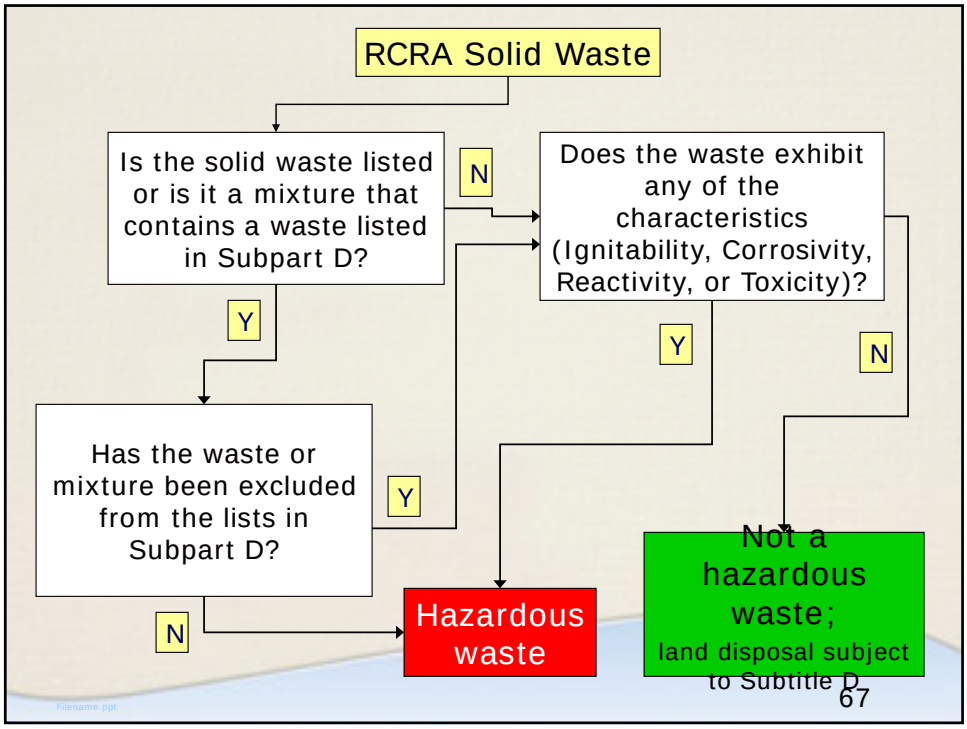

Waste Identification

1. Hazardous or non-hazardous?
   a. Knowledge of the waste generation process
   b. Toxicity Characteristic Leaching Procedure (TCLP) or Waste Extraction Test (WET)
   c. Exemption for small quantity generators
2. Mixed Waste?
   a. Hazardous waste and > 0.05% uranium or thorium by weight (totaling <15 lbs.)

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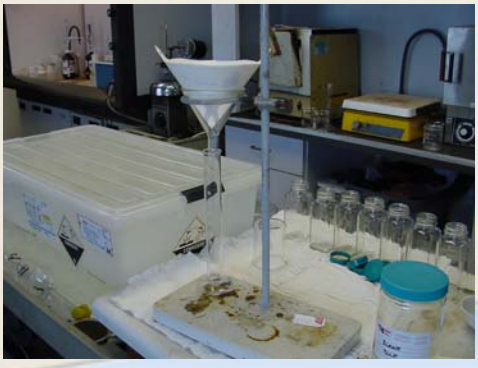
RCRA Regulatory Tests

1. Paint Filter Liquids Test
2. TCLP
   a. Arsenic is one of the eight metals regulated under RCRA
   b. Arsenic > 5.0 mg/L = Hazardous

Paint Filter Liquids Test

a. Determines if “free” liquids are present
b. Wastes containing free liquids banned from disposal in municipal and hazardous waste landfills



Toxicity Characteristic Leaching Procedure

a. Predicts if hazardous components of a waste are likely to leach out
b. Acetic acid extractant
c. Regulatory levels established for
   - 8 metals
   - 32 organics
d. Exceeding regulatory levels causes designation as hazardous waste

Water Quality Interferences with Activated Alumina Adsorption

Parameter	Problem Level
Chloride	250 mg/L
Fluoride	2 mg/L
Silica	30 mg/L
Iron	0.5 mg/L
Manganese	0.05 mg/L
Sulfate	720 mg/L
Dissolved Organic Carbon	4 mg/L
Total Dissolved Solids	1,000 mg/L

Media Selection Consideration - Activated Alumina

- Selectivity: OH^- > $\mathbf{H_2AsO_4^-}$ > $Si(OH)_3O^-$ > $\mathbf{F^-}$ > $HSeO_3^-$ > TOC >SO_4^{2-} > H_3AsO_3
- Two sides
  - Competition with Fluoride (close to double the capacity)
  - Dual removal of Arsenic and Fluoride

Filename.ppt 73

Media Selection Consideration - Granular Ferric Hydroxide

- Not a BAT due to lack of published data
- Becoming more popular and cost effective
- Recommended over AA if only Arsenic no Fluoride (Based on Scottsdale and Tucson case studies)
- Very likely require pH adjustment

Filename.ppt 74

Waste Extraction Test (California Only)

a. Predicts if hazardous components of a waste are likely to leach out
b. Citric acid extractant
c. Regulatory levels established for
   - 19 metals
   - 18organics
d. More aggressive than TCLP for inorganics
e. Exceeding regulatory levels causes designation as hazardous

Co-contamination

1. Typical multiple contaminants where there is elevated Arsenic
2. Some contaminants of concern:
   a. Chromium (Cr6)
   b. Uranium (U)
   c. Nitrate (NO3)
   d. Vanadium (V)

Waste Type: Mixed Waste

1. Contains both hazardous waste and source. . . or byproduct material subject to the Atomic Energy Act
2. Also regulated by RCRA

>0.05% U/Th by weight (totaling <15 lbs.)	+	Hazardous Waste	=	Mixed waste Subject to license from NRC or Agreement State

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Summary

1. Is it a waste?
2. Is it a Hazardous Waste?
   a. Yes If listed or demonstrates hazardous characteristics
3. How can you dispose of the waste?
   a. Non-hazardous
      - Many options
   b. Hazardous
      - Options more limited and expensive

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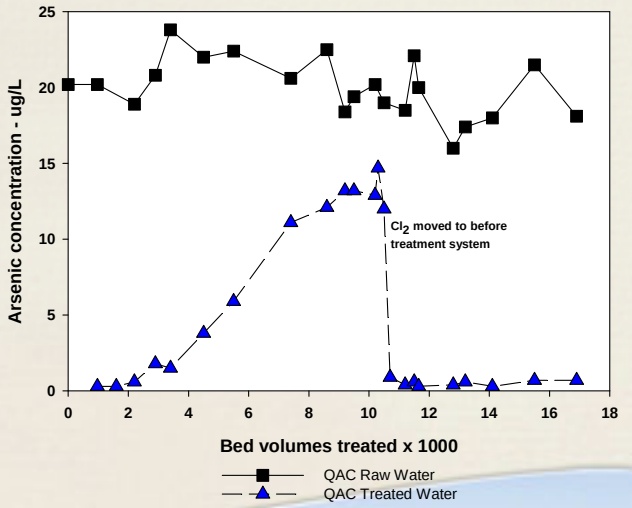
Queen Anne's County

Adsorptive Media (E33) Treatment System



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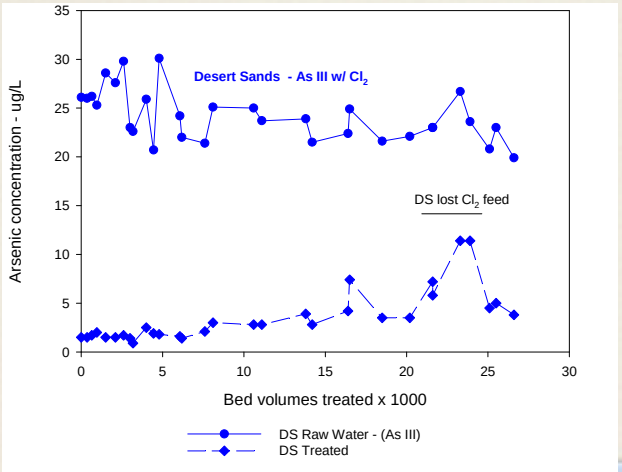
Desert Sands

Adsorptive Media (E33) Treatment System



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pH Adjustment

Arsenic Demonstration Program

Bow, NH – Acid/Cauatic	7.5 – 6.5 – 7.8
Rollinsford, NH – CO_2	8.2 to 7.2
Valley Vista, AZ – Acid	8.4 to 6.9
Nambe Pueblo, NM – CO_2	8.3 to 7.3
Taos, NM – CO_2	9.5 -
Bunni, TX – CO_2	8.0 -
Wellman, TX – CO_2	8.2 -
Tohono O'Odhan – CO_2	8.2 -

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Adsorptive Media Treatment

Flow gpm	Media	Design	Total Capital Investment (TCI)	Equipment Cost	Eq Cost % of TCI
70	G2	Series	$154,700	$102,600	66
37	AAFS50	Series	$228,309	$122,646	54
45	E33	Series	$90,757	$66,235	73
100	E33	Parallel	$106,568	$82,081	77
145	E33	Parallel	$139,251	$112,211	80
300	E33	Parallel	$211,000	$129,500	62
320	E33	Parallel	$153,000	$112,600	73
350	GFH	Parallel	$232,309	$157,646	68
640	E33	Parallel	$305,000	$218,000	71

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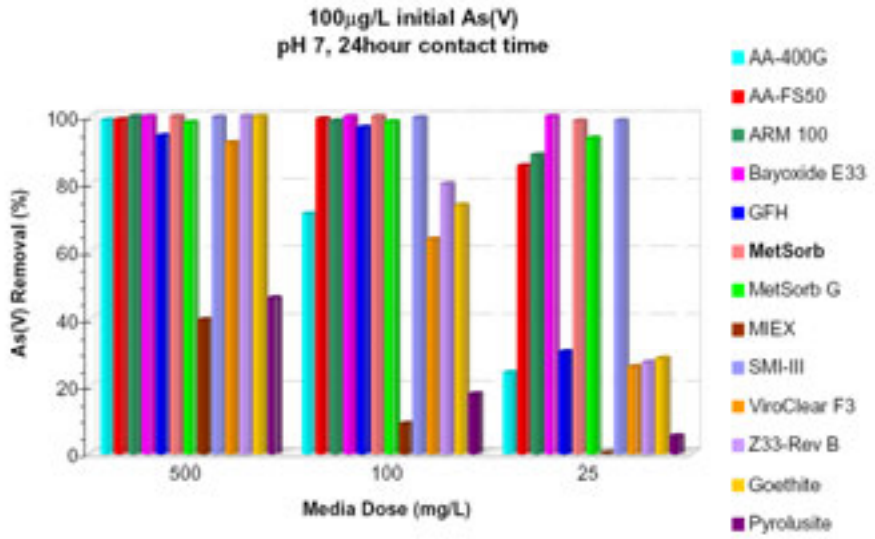
Feed Water Quality Impacts…

- Adsorption Capacity and Media Life
- Selection of Media
- Number / Size of Vessels and lbs of Media (Capital Costs & Layout)
- Replacement Frequency (O&M Costs)

Amy et. al. Studied Impacts of Water Quality on Adsorption Media Performance

- AA-400G (activated alumina (AA))
- AA-FS50 (iron impregnated AA)
- MIEX (amagnetized ion exchange resin)
- Bayoxide E33 (granular ferric oxide (GFO))
- Granular Ferric Hydroxide (GFH)
- Metsorb (titanium dioxide)
- Z33-Revision B (iron modified zeolyte)
- ARM 100 (alumina based, with proprietary promoters)
- Sulfur Modified Iron Version III (SMI)
- ViroClear Bauxsol F3 (Bauxite Clay)
- Geothite (α-FeOOH)
- Pyrolusite (β-MnO2)

Amy et. al. Studied Impacts of Water Quality on Adsorption Media Performance



Physical/Chemical Properties of Adsorbents

Adsorbent	Property				
	Grain Size (mm or mesh)*	Bulk Density (g/mL)	pH_{zpc}	Surface Area (m^2/g) (BET)	Mineral Identity (by XRD)
AA-FS50	28-48 mesh	0.75 (dry)	7.28	246	Aluminum oxide Hydrate (Boehmite)
E33	0.5 – 2.0 mm (10-35 mesh)	1.19 (wet)	8.28	119	Iron oxide hydrate (Goethite)
GFH	0.32 - 2.0 mm	1.19 (wet)	7.57	242	Iron oxide (Akaganeite)**
Metsorb G	16 – 50 mesh	0.78 (dry) 0.88 (wet)	4.68	166	Titanium oxide (Anatase)
Z33	100-140 mesh	0.88	4.79	36.9	Calcium aluminum silicate hydrate (Heulandite)
SMI	n/a	2.15	n/a	4.46	n/a

*10 mesh = 0.1 inches = 0.254 cm = 2.54 mm
**Traces of Hematite and Geothite also identified in contrast to previous studies

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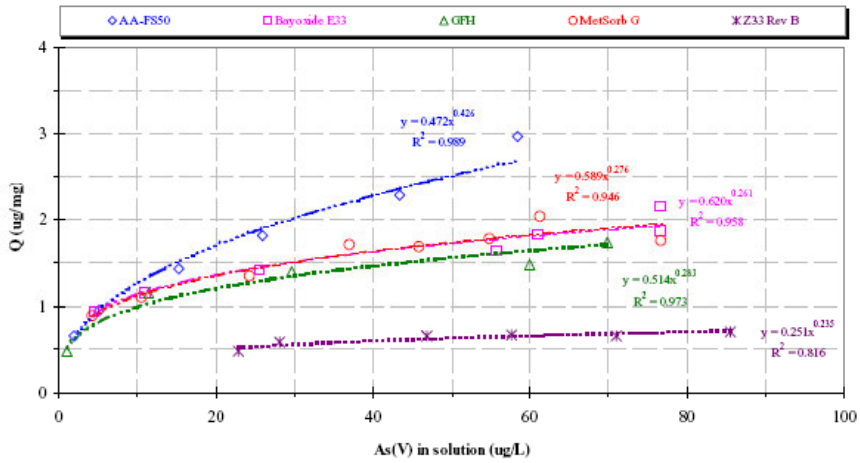
As(V) Adsorption Isotherms @ pH 7.0
(Single Solute)



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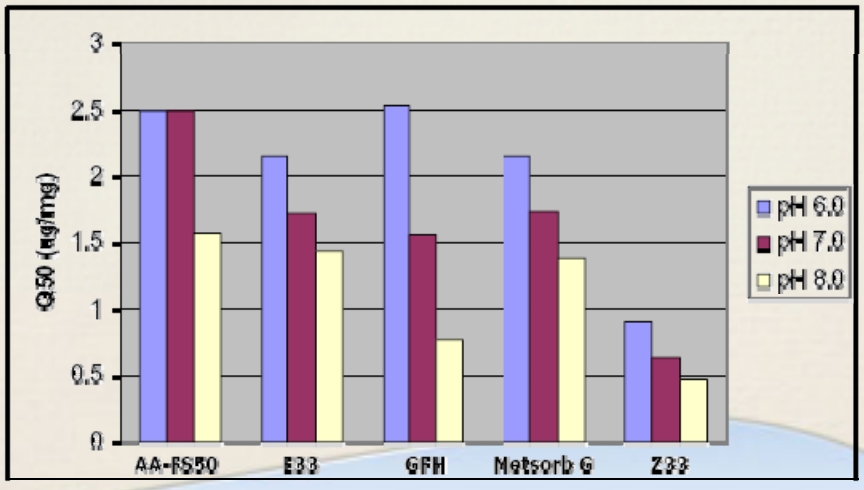
As(V) Adsorption: pH Effects on Q_{50}
(Q_{50} in equilibrium with C = 50 ug/L)



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Concentrations of Interferents based on U.S. Co-Occurrence Survey

Component*	Units	50 Percentile Concentration	75 Percentile Concentration
Phosphate	ug/L as PO_4^{3-}	125	250
Silicate	mg/L as SiO_2	13.5	22
Vanadate	ug/L as V	18	30

*Others: Fluoride, Sulfate, Carbonate

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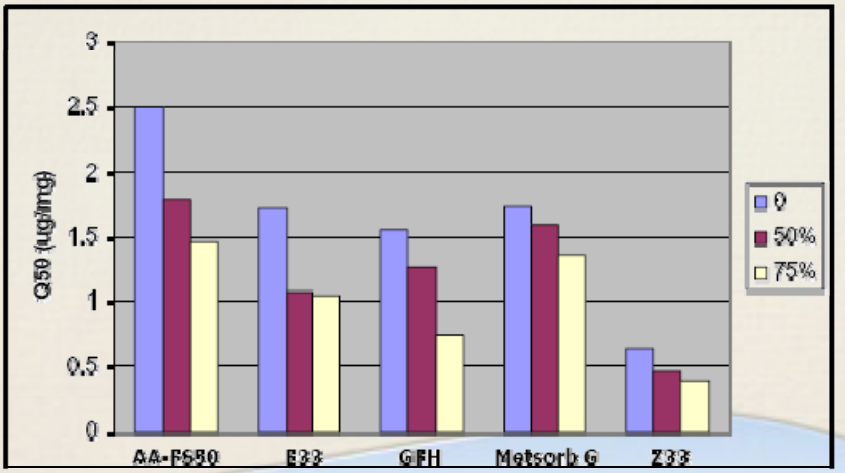
As(V) Adsorption: PO_4^{3-} Effects @ pH 7.0



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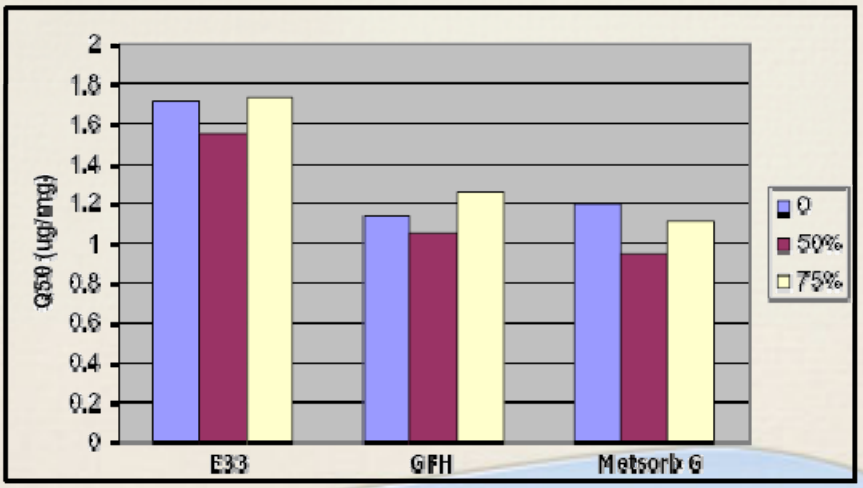
As(V) Adsorption: SiO_2 Effects @ pH 7.0



Monomeric vs. Polymeric Silica?

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In Increasing Order of pH Dependency

- Bayoxide E33 (GFO)
  - **Slight** pH effect
  - Significant impacts by phosphate and vanadium
  - Some silica effects
- MetSorb G (TiO_2)
  - Interferent effects were less at lower pH
  - Decrease in performance with phosphate, silica, and vanadium
- AA-FS50
  - **Moderate** decrease in capacity as pH increased
  - Significant decrease in capacity in the presence of fluoride
  - Small impact by phosphate
- GFH
  - Rapid decrease in performance as pH increased
  - Decrease with phosphate, silica and vanadium
- Z33
  - Lowest capacity (lowest specific surface area)
  - Decreased as pH increased
  - phosphate had a significant effect

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Water Treatment Technology Assessment

ION EXCHANGE

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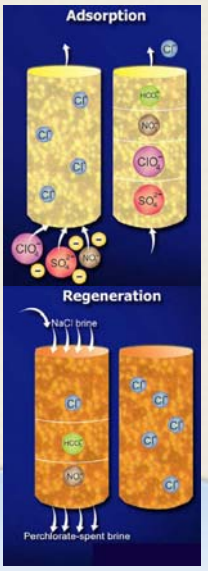
Ions Held Electrostatically on Resins are Exchanged with Ions of Concerns

- **Cation Exchange** (e.g. water softening)
  - $2\ (R\text{-}Na) + Ca^{2+} = R_2\text{-}Ca + 2\ Na^{+}$

    R = Resin site
- **Anion Exchange** (e.g. arsenic removal)
  - $R\text{-}Cl + H_2AsO_4^{-} = R\text{-}H_2AsO_4 + Cl^{-}$
- Will only remove ionic species
- Regenerate resin with concentrated NaCl brine



Anion Exchange Ion Exchange Resins Include Two Classes

- Weak-base anion (WBA)
- Strong-base anion (SBA)
  - SBA resins are used for arsenic removal because they tend to be more effective over a larger pH range than WBA resins
  - Does not remove uncharged As(III) when pH under 9.0 (need oxidation)

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Selectivity Sequence for SBA Anion Exchange

Typical Sequence: SO_4^{2-} > $\mathbf{NO_3^-}$ > $\mathbf{HASO_4^{2-}}$ > NO_2^-, Cl^- > $H_2ASO_4^-$, HCO_3^- >> $Si(OH)_4$, H_3ASO_4 > $\mathbf{F^-}$ >OH^-

- High sulfate (>150 mg/L) and TDS levels (>500 mg/L) can significantly reduce arsenic removal efficiency
- High Fe(III) in feed water can affect arsenic removal by forming Fe(III)-arsenic complexes, which cannot be removed by IX resins
- Depending on water quality, removing Fluoride may require a different type of resin

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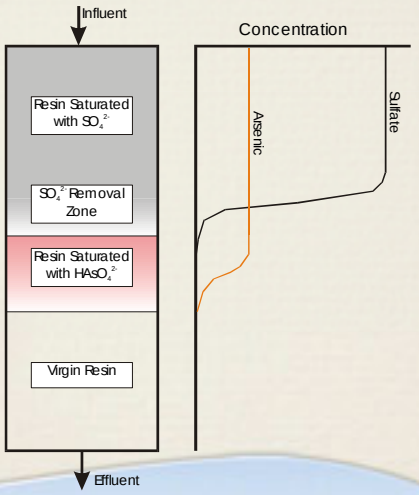
Concentration Profiles in IX Column Can Result in Chromatographic Peaking

- All SO_4^{2-} is removed before $HAsO_4^{2-}$ is removed
- Can result in **chromatographic peaking:**
  - SO_4^{2-} elutes $HAsO_4^{2-}$ from resin
  - Effluent As concentrations are much higher than influent concentrations



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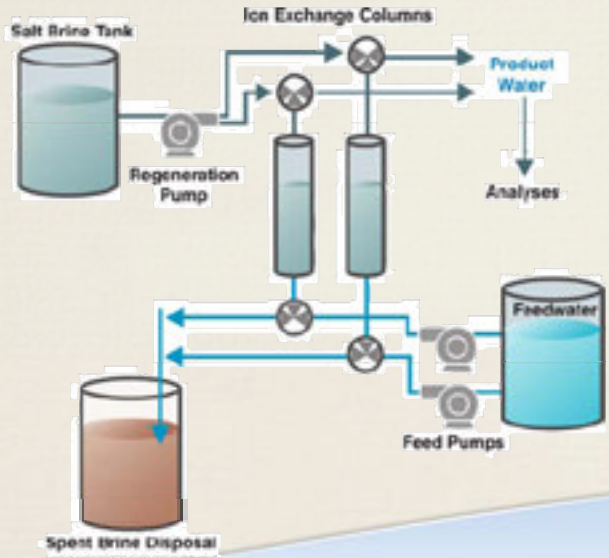
Typical Ion Exchange System



- Operation
- Regeneration
  - Backwash (optional)
  - Brine Rinse
  - Final Rinse

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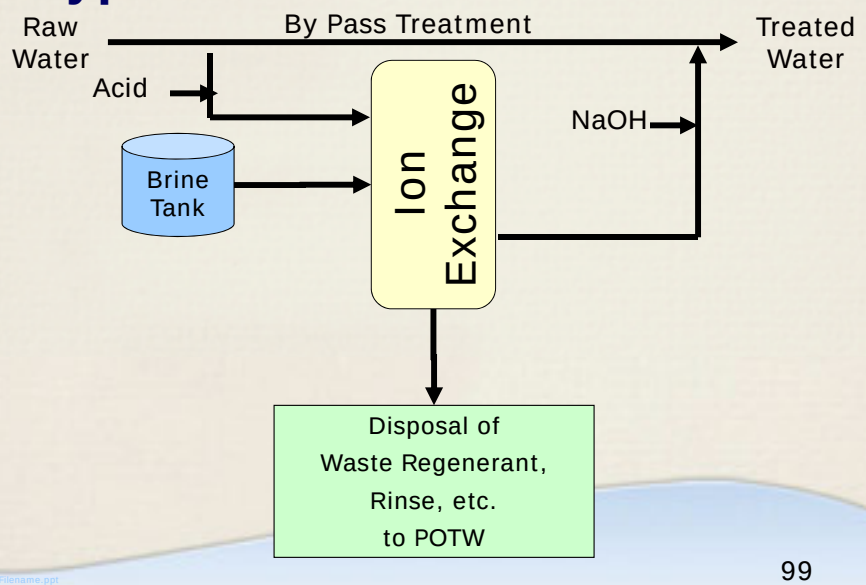
Ion Exchange Blending and Bypass



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Ion Exchange - Benefits and Challenges

Benefits

- Reliable and simple operation
- Low arsenic in treated water at low EBCT (1.5 to 5 minutes)
- Reasonable prices
- Relatively small footprint
- Widely used
- Competitive resin market
- 95 – 98 % recovery

Challenges

- Not effective when high TDS / Sulfate
- Require frequent regeneration
- Brine disposal may be an issue
- Potential of chromatographic peaking
- Excessive oxidant (> 0.1 mg/L free chlorine) may degrade resin
- May require pretreatment

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Many IX Resins and Package Systems are Available

US Filter

Basin Water

Calgon Carbon

Other Suppliers: DOW, Purolite, Layne Christensen, Loprest, H&T, Rohm & Hass, Resintech, Sybron-Bayer

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Selecting the Right IX Resins Require Better Defined Feed Water Quality

- Modeling inputs
- Supplier will need to know WQ to determine exchange capacity
- Bench and pilot testing may be required for complicated applications

DOW CADIX® Computer Assisted Design for Ion eXchange

Purolite® A520E – IX Resin for Nitrate

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INDION FR-10 – IX Resin for Fluoride

1. Feed 10mg/L reduced to < 1 mg/L
2. Flowrate did not affect removal capacity
3. Preferable pH range is 6 to 9. Maximum fluoride removal capacity at neutral
4. Not suitable for water having nitrates
   a. With nitrate volume throughput of 9L;
   b. Without nitrate, the exhaustion 45L
5. Regenerated with 250 g/L alum and the regeneration efficiency is 82% in continuous column operation and 51% in batch operation.

Ion Exchange Residuals

- Liquids
  - Backwash and rinse water
  - Brine (Typically 3 to 5 bed volumes of brine wasted per generation)
- Solids
  - Resin
- Large facility may practice brine reuse / recycle
- Small systems are much more likely to dispose brine directly to a POTW instead of recycling it.
- Must meet Technically Based Local Limits (TBLL)

Commercially Available Resins

Category	Rohm & Hass	Sybron-Bayer	Purolite	Dow	Resintech
Regenerable Resin	IRA 458 and	ASB2 Type II M500 & M600 Type 1	A-850,	Dowex 21K-XLT	SBACR1 PA resin
NSF Certification	Yes	-	Yes	Yes	FDA approved
Full-scale Regenerable Applications	City of La Verne, CA, Southern California Water Company, CA	City of Pomona, CA-	LPVCWD, CA-		-

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Table 1.9 Summary of Available Vendors of Packaged Ion Exchange Systems
Well No. 28 Nitrate Treatment
City of Garden Grove

Criteria	US Filter	Calgon Carbon	Basin Water	Layne Christensen	Loprest	H&T
System Process	Regen	Regen	Regen	Regen	Regen	Regen
CDPH Acceptance	Yes	Yes	Yes	Yes	Yes	Yes
Spent Brine Service	NA	Brine treatment	Off-site Brine disposal	Off-site Brine disposal	NA	Brine treatment
Spent Resin Service	Yes	Yes	Yes	Yes	Yes	NA
Full-Scale Lease Option	Available	Available	Usually Required	NA	NA	NA
Pilot System	Available - 6 gpm	Available	Available - 4-5 gpm	Available	Available	Available
Full-Scale Regen	City of Fresno, CA	La Puente, CA	Pomona, CA	Ontario, CA	Mira Loma, CA	Decatur, IL

Note:
NA: Not Available, H&T: Hungerford and Terry.

DRAFT

EBCT

EBCT—2 to 10 minutes

Surface loading rate

The lower the EBCT and the higher surface loading rate

- The higher the unit flow rate
- The smaller the size of the vessels

Ion Exchange – Arsenic Removal

1. > 95% removal
2. Recommended BAT for Arsenic when Sulfate < 50 mg/L (final rule, was < 200 mg / L in the proposed rule)
3. Regenerate more frequently than Adsorption
4. Brine can be sewer discharged, but limited by technically based local limits (TBLLs) for arsenic or TDS

IX - Arsenic

1. Case 1: hydraulic loading rate 4 gpm/ft2; EBCT 3.7 minutes; Filox™ column 22.5-inch-deep Purolite A-300 anionic resin bed (The Purolite Company, Bala Cynwyd, PA) is a strongly basic gel IX resin in chloride form.
2. Case 2: LAT-32 IX tank; hydraulic loading rate to the filter is 3.7 gpm/ft2; EBCT is 5.6 min.
3. Case 3: hydraulic loading rate to each tank is 5.0 gpm/ft2 and the EBCT is 4.3 minutes.

Selective IX for Fluoride

1. Fluoride is a very low selectivity anion so it can not be removed from water without first removing all of the higher selectivity anions like chloride or sulfate.
2. table of selectivity data
3. Fluoride can be selectively removed. Dow is in the process of developing a high capacity, beaded alumina for this application.
4. Chelating resin is more selective than an anion-exchange resin for fluoride removal.

IX Fluoride Removal

1. Under acidic conditions, fluoride is present as HF and can be removed from solution with an acid absorber like DOWEX™ M-43 resin.
2. Under neutral to basic conditions, DOWEX 21K XLT resin has the strong base functionality needed to split the salt.
3. For streams that have a high organic content and are prone to surface fouling, DOWEX MARATHON™ MSA strong base anion exchange resin is recommended.

Fluoride Removal

1. Filtration through activated alumina reduced the fluoride concentration in water. The sorption capacity of alumina was 4.5 g/kg and volumetric capacity 3.95 g/L.
2. The coagulant consumption for fluoride removal was 80 mg $Al_2(SO_4)_3$ per 1 mg F^-
3. At 5 ppm 50% efficiency; cannot lower to 2 ppm.
4. $2Ca(OH)2+2HF+H2SO4=CaF2+CaSO4{\cdot}2H2O+2H2O$ lower F to 10 to 12 ppm (2 ppm cannot be achieved using precipitation)

Ion Exchange Resin Manufacturer

Siemens Water Technologies Corp. - Warrendale, PA
Distributor, Manufacturer, Custom Manufacturer, Service Company
http://www.water.siemens.com/en/products/ion_exchange/cation_anion_specialt...
Company Profile: Supplier of ion exchange resin for industrial, municipal and high purity systems. Including USFilter, Dowex, Purolite, Sybron and other leading brand name resins at regional distribution centers.
Klenzoid Equipment Co. - Wayne, PA
Distributor
http://www.klenzoidequipment.com/Products_Hub.html
Company Profile: Distributor of ion exchange resin: anion, cation, mixed bed, nuclear; softener, demineralizer, condensate & ultrapure grades. Reverse osmosis membranes, filter media, bulk bags, resin analysis. Supplying many industries including pulp & paper, utilities, manufacturing, chemical, pharmaceutical &...
Brand Names: Bayer, Sybron, Thermax, Rohm & Haas, Dow, Purolite
Res-Kem Corp. - Media, PA
Distributor, Manufacturer, Custom Manufacturer, Service Company
http://www.reskem.com/pages/resin.php
Company Profile: Manufacturer, Distributor Of Water Treatment Equipment & Supplies For Industrial, Institutional, Commercial Applications. Ion Exchange Resins Include; National Brands, Cation, Anion, Mixed Bed, EDM & Semi-Conductor Grades, Activated Carbon
WaterProfessionals ® - Multiple Locations
Distributor, Manufacturer, Custom Manufacturer, Manufacturers' Rep, Service Company
http://www.waterprofessionals.com/ultrapure/ion_exchange.html
Company Profile: Ion exchange resins for softening & demineralization. Cation, anion & mixed bed. Ultrapure electronic grade, pre-rinsed to 18 megohms, low TOC. Ion- selective resins for heavy metals, arsenic. Resin analysis, computer modeling of treated water throughput & composition on waste stream. Automatic...
Brand Names: WaterProfessionals, WaterProfessionals, General Electric
CEI-Carbon Enterprises, Inc. - Circleville, OH
Distributor, Manufacturer, Service Company
http://www.ceifiltration.com/filtration.asp?p=other
Company Profile: Manufacturer of filtration media including sand, gravel, anthracite, activated carbon, & garnet. AWWA, NSF & food chemical codex approvals, service work. Other products: greensand, calcite, magnesium oxide, ion exchange resins, pumice & activated alumina.
Daico Water Management - Valrico, FL
Distributor, Manufacturer, Custom Manufacturer
http://www.daicowater.com/ro-components.html
Company Profile: Custom manufacturer & distributor of ion exchange resins.
Brand Names: Rohm & Haas, Dow, Pulsafeeder
Mil-Spec Industries Corp. - Roslyn Heights, NY
Manufacturer, Custom Manufacturer
http://www.mil-spec-industries.com
Company Profile: Ion exchange resins. Manufacturer & supplier special chemicals, explosives, propellants, ammunition, pyrotechnic & ordnance components, military & law enforcement equipment. Intelligence surveillance & electronic warfare (EW) defense systems, radar, demilitarization & EDO products. Worldwide...
Aquatech International Corp. - Canonsburg, PA
Distributor, Manufacturer, Custom Manufacturer
http://www.aquatech.com
Company Profile: Manufacturer & distributor of WATERTRAK™, featuring water treatment components such as filtration, demineralization, RO & EDI.

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PUROLITE FerrIX™ A33E – IX Resin for Arsenic

Specific service flow rate	Typical 20 - 24 BV/H up to 32 BV/h (2.5 to 3 gpm/ft3 up to 4 gpm/ft3)
Arsenic operating capacity	0.5 - 4.0 g As/l (Depending on raw water composition and operating conditions)
Recommended contact time	2.5 - 5 minutes (Typical 3 minutes)
Bead Size Range	0.30 - 1.20 mm
Shipping Weight (approx.)	790 - 820 g/l (43.0 - 51.0 lbs/ft3)
Temp Limit (Stability)	80 C (176 F)

BASIC FEATURES:

Application - Arsenic Removal Resin

Polymer Structure - Polystyrene cross-linked with divinylbenzene

Appearance - Brown spherical beads

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Purolite® A520E – IX Resin for Nitrate

Mean Size Typical	0.60 - 0.85 mm
Moisture Retention, Cl^- Form	50 - 56%
Specific Gravity	1.07 g/ml
Temp Limit, Cl^- Form	100 C (212 F)
Total Capacity, Cl^- Form	0.90 eq/l (19.65 kGr/ft3)
Uniformity Coefficient (max.)	1.70
Shipping Weight (approx.)	675 - 705 g/l (42.2 - 44.1 lbs/ft3)

BASIC FEATURES:

Application - Nitrate Removal

Polymer Structure - Macroporous polyacrylic crosslinked with divinylebenzene

Appearance - Spherical beads

Functional Group - Type 1 Quaternary Ammonium

Ionic Form as Shipped - Cl^-

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Water Treatment Technology Assessment

BIOLOGICAL FILTRATION

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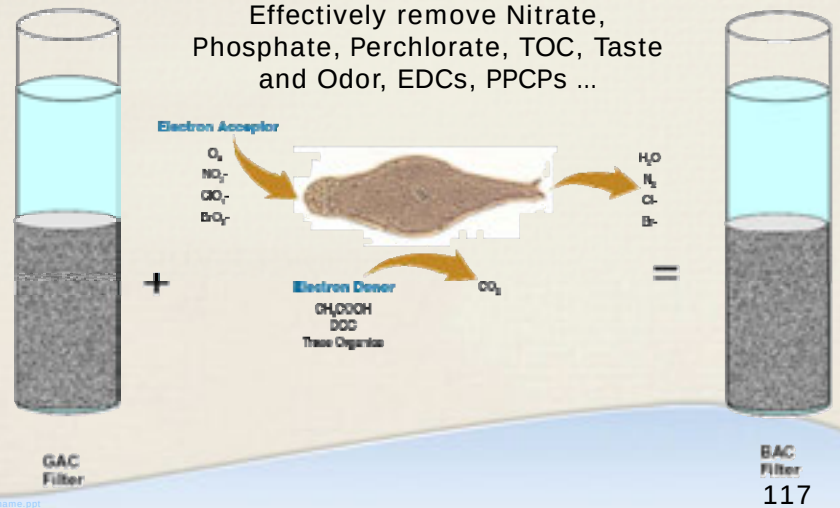
Biological Filtration is Simple and Robust

Effectively remove Nitrate, Phosphate, Perchlorate, TOC, Taste and Odor, EDCs, PPCPs …



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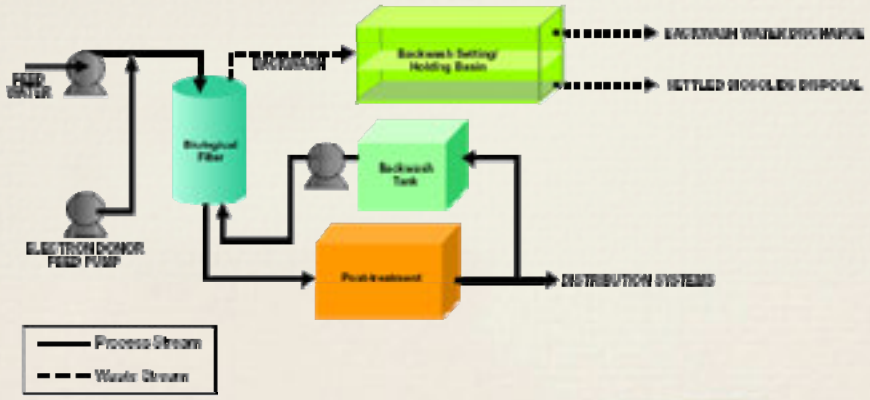
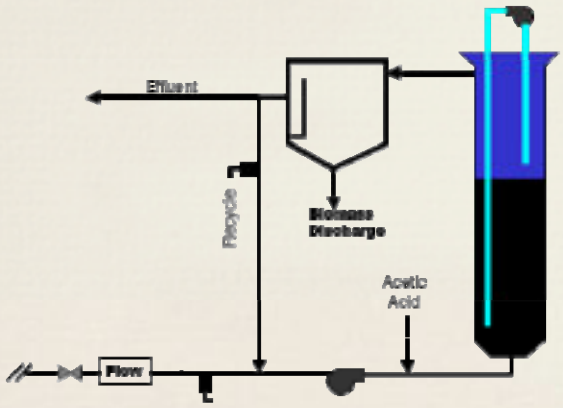
Biological Filtration Process Flow Diagram

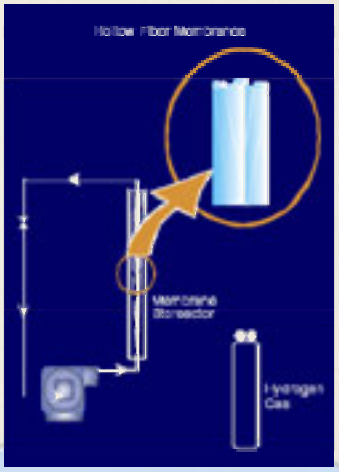


118

Besides Fixed Bed, Fluidized Bed or Membrane Biofilm Reactors (MBfRs) also Have Applications



(a). Schematic of Fluidized Bed Biological System



(a.) Schematic of Membrane Biofilm Reactor System

119

Biological Filtration - Benefits and Challenges

Benefits

- **"Green technology": No Brine (Producing N_2, H_2O & biomass)**
- Simple, established technology (used for DW in Europe since 1983)
- Gaining popularity
- High removal and high efficiency
- Very Robust
- Low O&M costs compared to IX and RO with brine management options
- Broad contaminant application

Challenges

- Perceptions regarding biological safety
- Use of high dose of acetic acid for high nitrate low TOC GW

Water Treatment Technology Assessment

DESALINATION

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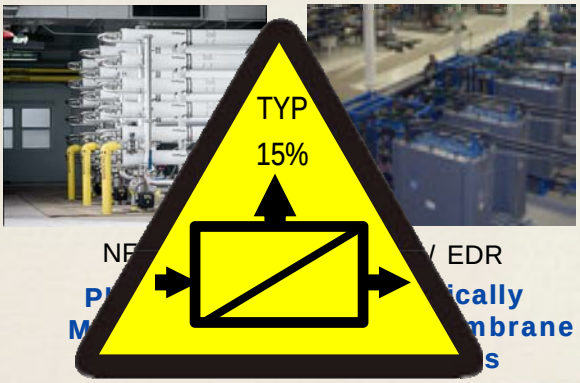
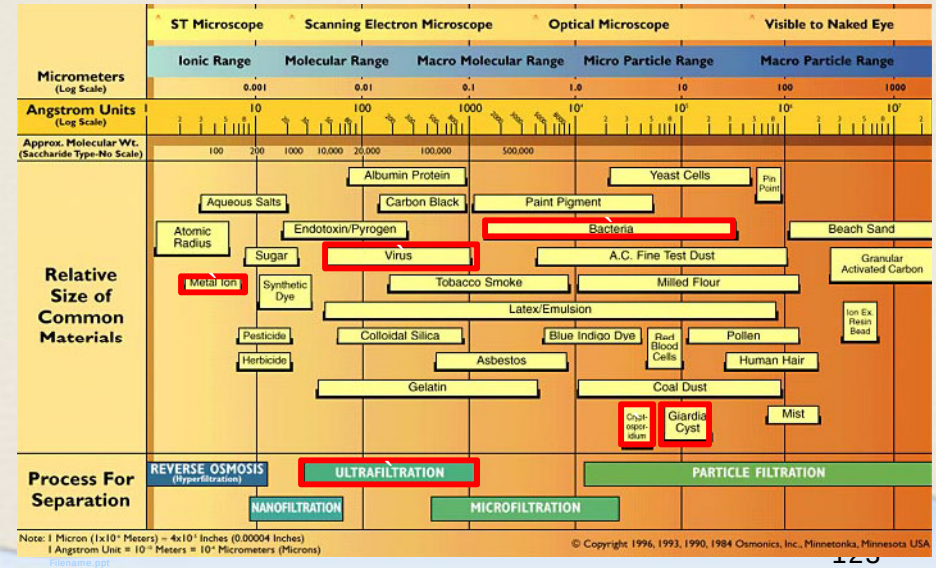
Desalting Technologies Can Be Categorized into Three Types of Processes

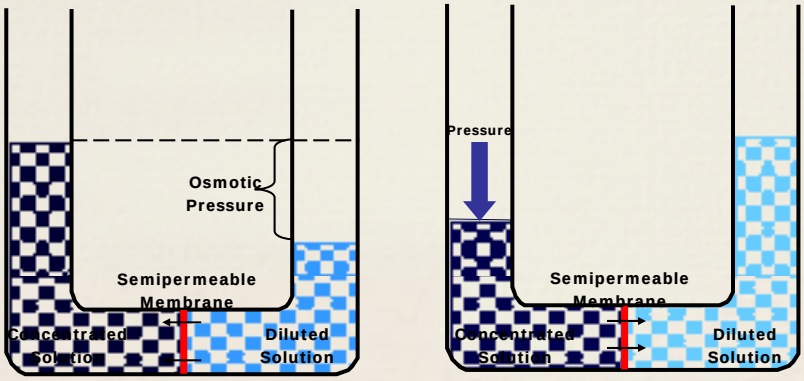


122

RO is the finest degree of filtration on the filtration



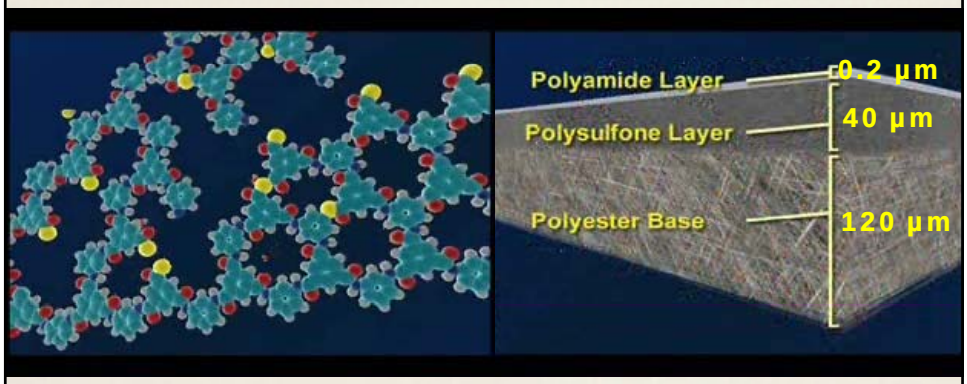
Applied pressure in excess of osmotic pressure reverses water flow direction



Osmosis Reverse Osmosis

Rule of Thumb: OP of 100 mg/L TDS = 1 psi

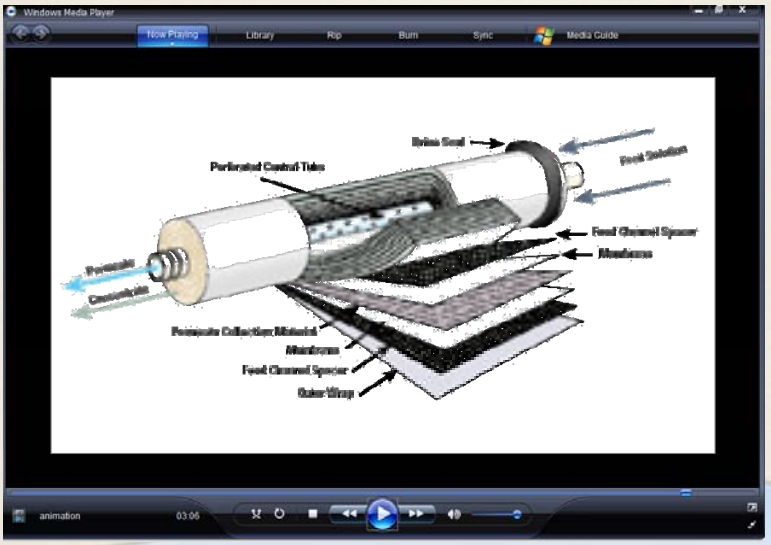
NF / RO Membrane Do Not Have Pores



Thin Film Composite Polyamide

125

NF / RO Membrane is Typically Spiral Wound



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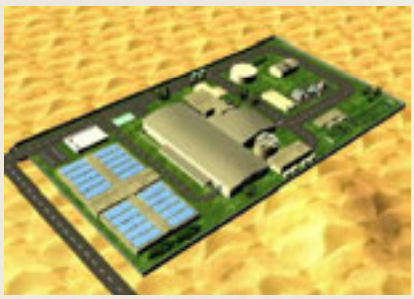
Four Main NF / RO Manufacturers Take 90+% of the Market

	TORAY	DOW	HYDRANAUTICS	KOCH MEMBRANE SYSTEMS
MUNICIPAL RO PRODUCT	**TM810 & 820** TM710 & 720 TMG10 & G20 TMH10 & H20 *TML20*	**SW30;** **SW30HR;** **SW30HRLE;** **SW30XLE** BW30 XLE; LP; LE; *TW30 (4040, 400); TW30LP*	**SWC** CPA ESPA *LFC*	**TFC-SS & SW (4", 8", MM);** **TFC-HF;** TFC-XR TFC-HR TFC-ULP TFC-S
DESIGN TOOL	TorayDS	ROSA6.1	IMSdesign.exe	ROPRO 8.0

127

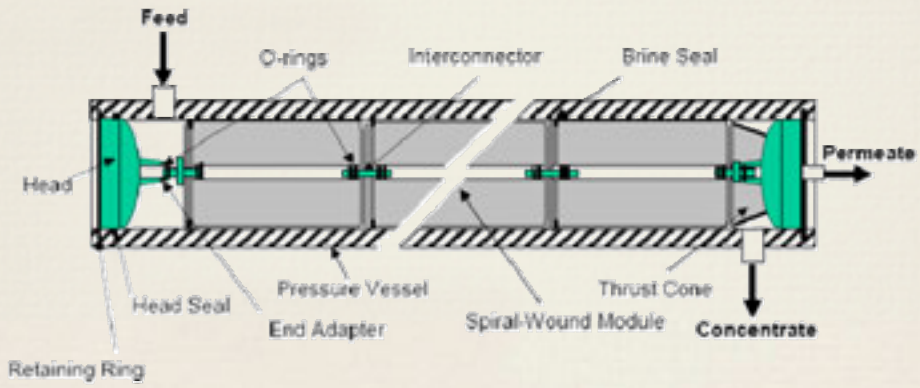
Arrayed-Rack Design Makes NF / RO Space Efficient



World's largest desalination plant (**86 MGD**) in Ashkelon, Israel produces 13% of the country's domestic consumer demand on a plant footprint of **980' X 820'** (300 m X 250 m).

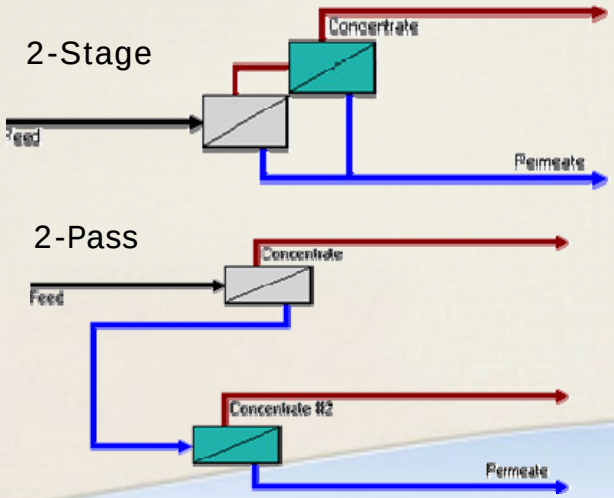
128

Each Pressure Vessel Contains up to 8 Membrane Elements



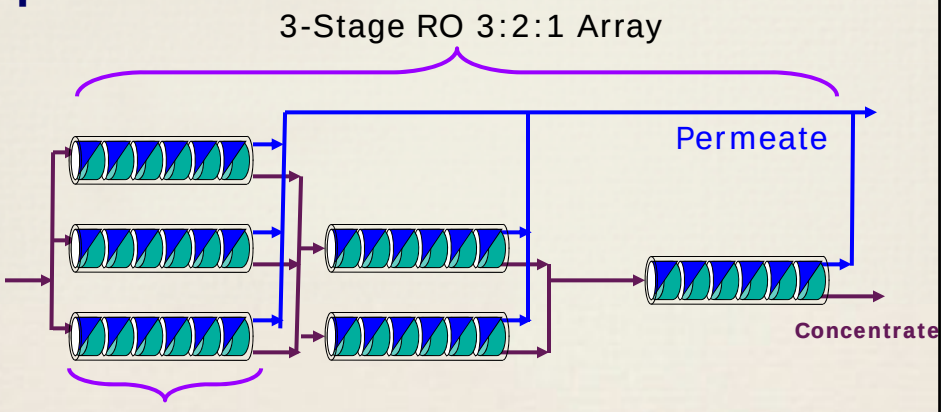
129

Various Configurations for Multi-Stage and Multi-Pass Systems Exist



130

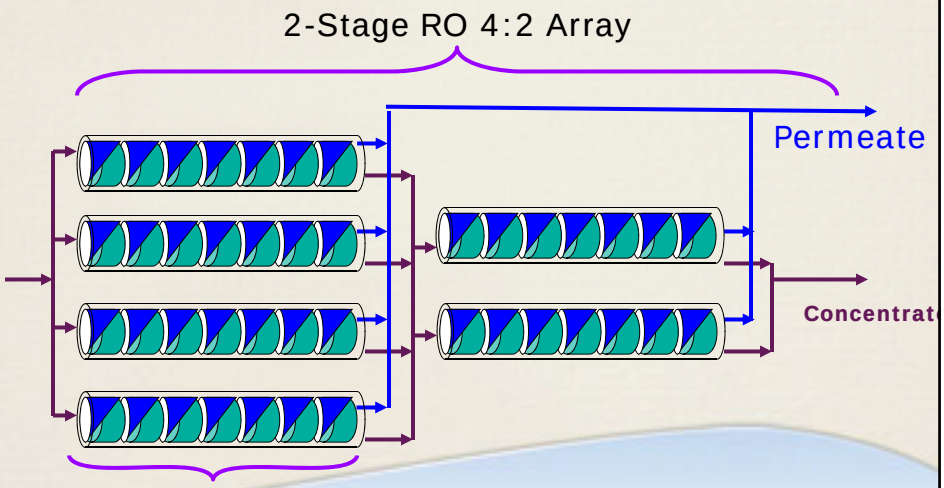
3:2:1 is a Typical Three-Stage RO Array Design, often w/ Six Elements per Vessel



6 elements per vessel, 85% recovery

131

Two-Stage Seven-Element-per-Vessel 4:2 RO Array Saves up to 15% Costs



7 elements per vessel, 85% recovery

132

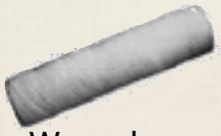
For Large Plants, 16” and 18” Elements are Avaialble.

133

Cartridge Filters Protects RO Membranes

Melted-blown

Housing

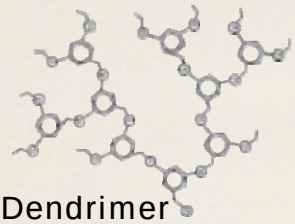


Wound

Pleated

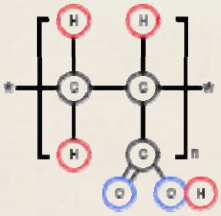
134

Various Antiscalant Chemicals are Available to Control Inorganic Scaling

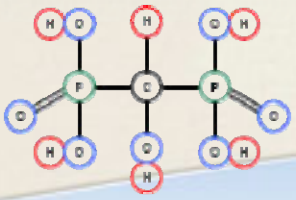


Dendrimer

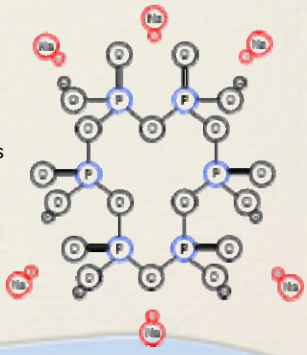
Suppliers:
GE Betz-Dearborn / Agro Scientific
Lubrizol / Noveon
PWT
King Lee
Avista Technologies
Nalco Chemical Company
Applied Membranes, Inc.
Solutia, Inc. (Dequest)
American Water Chemicals



polyacrylate



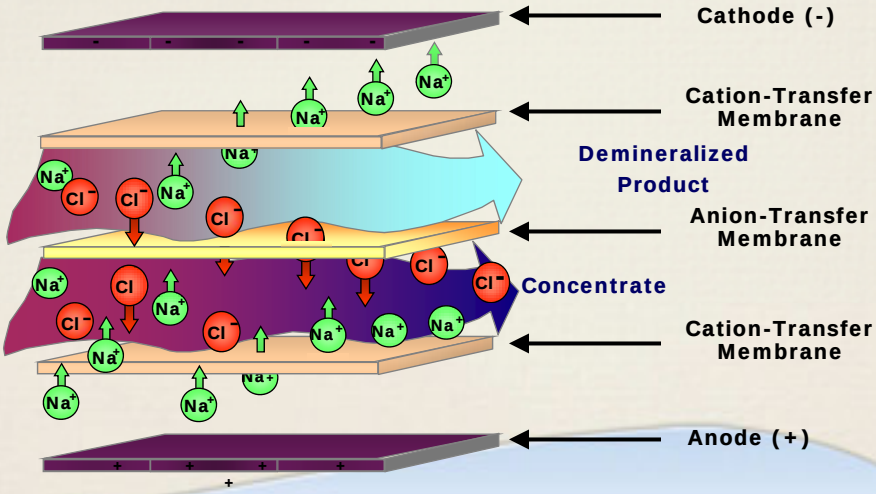
phosphonate



sodium hexametaphosphate

135

ED / EDR Consists of Many Electrodialysis Cell Pairs



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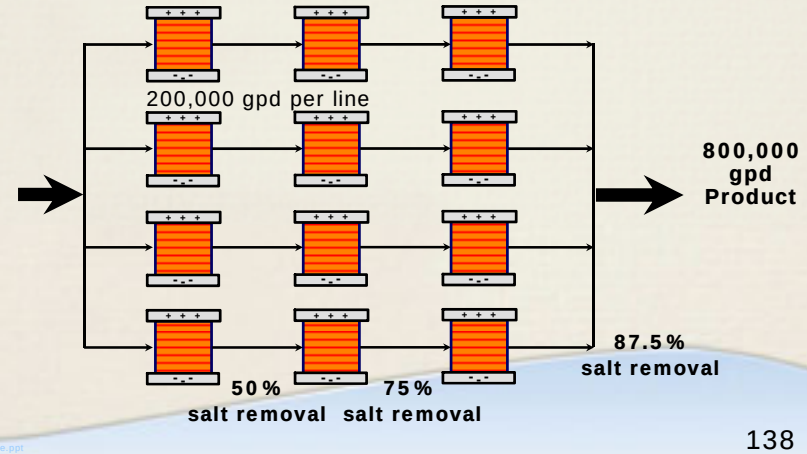
Electrodialysis Reversal (EDR) Versus ED

1. Self-cleaning reversal technique breaks up polarization films in the system 3 to 4 times per hour, preventing scale
2. Automatically cleans electrodes with acid formed during anodic operation
3. Eliminates need for continuous chemical pre-treatment
4. Membranes are resilient, durable – many plants report continued use of original membranes
5. Sole sources versus a few players

137

Multiple EDR Stages and Trains Cover Range of Capacities and Salt Removal

Example: 4 Line, 3 Stage System



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EDR Stack

Checking for "Hot Spots"

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NF/RO is Recommended over ED/EDR Because of Better Water Quality, Economics and Services

	NF / RO	ED	EDR
Chlorine	0.5 ppm, <10 min	1 mg/L	
SDI	SDI ≤ 3	SDI ≤ 12	
TOC	TOC Removal / Fouling	No TOC removal, No fouling	
Silica	Silica fouling	No Silica Fouling Concern	
TDS Range	<40,000 mg/L (Limited by fouling and 600 psi)	No limitation*	< 8,000 mg/L (polarity reverse energy and time)
	RO more economic > 10,000 mg/L (energy)		
Manufacture	Hydranautics, DOW, TORARY, KOCH, etc.	Eletrosynthesis, Eurodia, Electrolytica, GE, etc.	GE IONICS
Cleaning	Typ 4 to 6 month	Typ 3 month	Less frequent

Desalination (NF/RO) – Benefits and Challenges

Benefits

- Efficient remove Arsenic, Nitrate, Fluoride, Coliform, Virus … in one step
- Finest degree of filtration produce the BEST water quality
- Very reasonable price with sewer discharge option
- Post-treatment may not be necessary because of blending
- Very low fouling concerns for groundwater application at 85% recovery
- 95% recovery with intermediate concentrate stabilization

Challenges

- If sewer discharge is not an option, brine management can be cost prohibitive

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NF / RO is an Option only When Brine Can Be Disposed of at Low Costs

- Recommend to consider NF/RO w/ Sewer Discharge as one of the Top 3 Trains
  - Relatively small facilities
  - Low TDS => Low percentage of flow to be treated => Less brine and salt loading
  - Technical and economical feasibility to be analyzed in conceptual level evaluation (blending analysis tool)

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Water Treatment Technology Assessment

BRINE MANAGEMENT
(OPTIONAL PRESENTATION)

Sewer disposal may be a short-term solution, but…

1. Requires Pretreatment Permit
2. Impacts WWTP's APDES permit
3. Biological inhibition starting at 2000 - 2500 mg/L
4. Take up hydraulic capacity of sewer system
5. Requires large dilution flow
6. Impacts reuse potential

91st Ave WWTP

Dust control may use some concentrate, but…

1. Concentrate Quality
   a. Best if primarily $CaCl_2$ and/or $MgCl_2$
2. Sustainability concerns
   a. Groundwater contamination
3. Limited market
   a. Volume of concentrate greatly exceeds demand

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Deep well injection is ideal, but not for Arizona

Deep injection well (Florida)

1. Injection of brine into a confined underground aquifer
   a. TDS > 10,000 mg/L
2. Sustainability Concerns
   a. Contamination drinking water sources
3. No known aquifers in Arizona capable of receiving brine continuously from a desalination plant

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Beneficial reuse as cooling water at PVNPGS opens many doors

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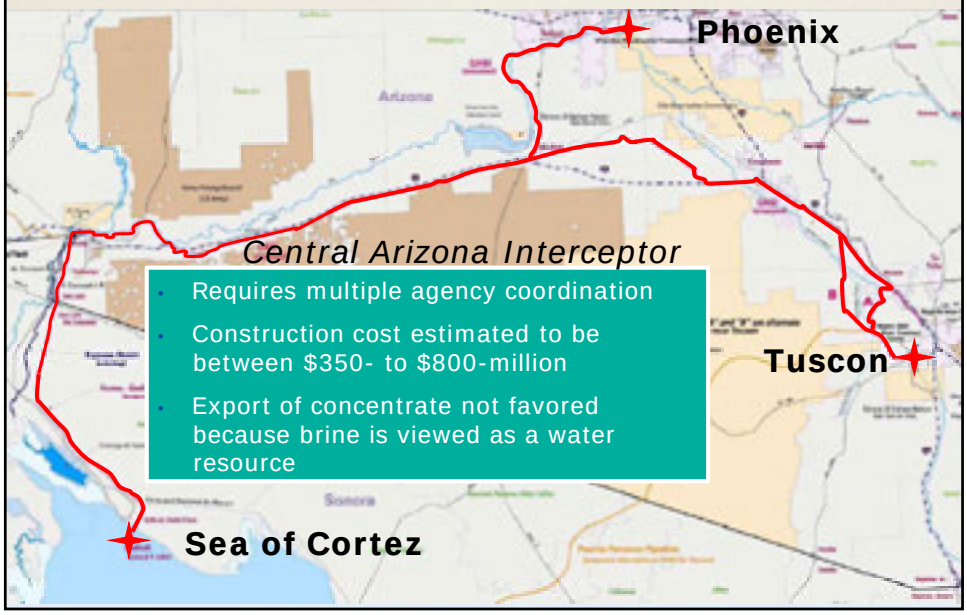
CASS evaluated surface water discharge, but it didn't fly



- Requires multiple agency coordination
- Construction cost estimated to be between $350- to $800-million
- Export of concentrate not favored because brine is viewed as a water resource

Evaporation pond sounds like a perfect match for Arizona, but…

Double Lined Ponds with Leachate Collection System

Fences & Bird Netting

- Requires lots of land!
- More manageable with reduced concentrate volume
- APP Permit requires a double liner system (linear life 20 yrs)
- Require environmental mitigation
- Loading Rate
  - 2.5 gpm / acre
  - Annual net loss of water ~85 in/yr
  - Evaporation efficiency = 70%
  - Storage = 20%

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Wetlands creation using halophyte may be part of the solution

1. Use of halophytes for wetland and habitat restoration
2. Environmental Concerns
   a. Exposure to toxic constituents in concentrate
   b. Endangered Species
   c. Maintenance
   d. Liner and leachate collection
3. Permitting coordination
   a. Groundwater
   b. Surface water: WET

Phoenix Tres Rios

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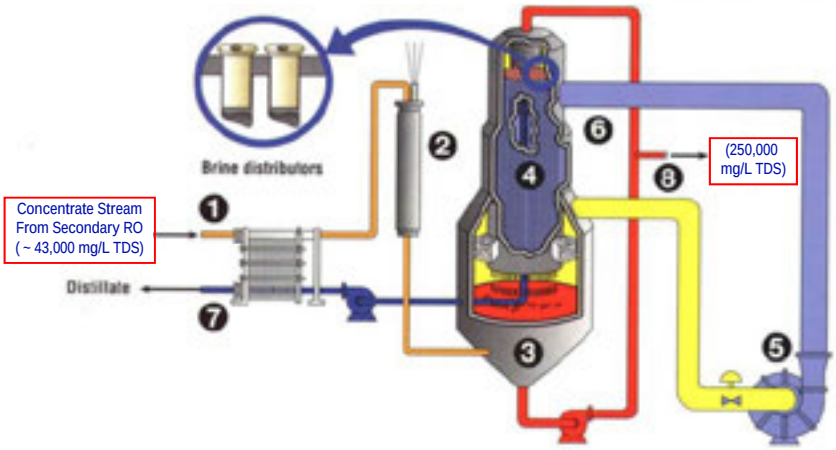
Technologies are available to enhance evaporation pond efficiency

Photos: Erik Jorgensen, USBR

1. Solar Bee
   a. Minimizes pond size by mixing pond's thermocline to enhance evaporation
   b. Enhanced evaporation
      - 1.6 x during day
      - 1.8 x during night
   c. Pond size
      - 5 gpm / acre
   d. Not applicable when using vapor compression brine concentrator (220°F brine)

151

Vapor Compression Brine Concentrator (MVRE) is Part of a Proven ZLD Train



Vapor Compression Brine Concentrator works, but…

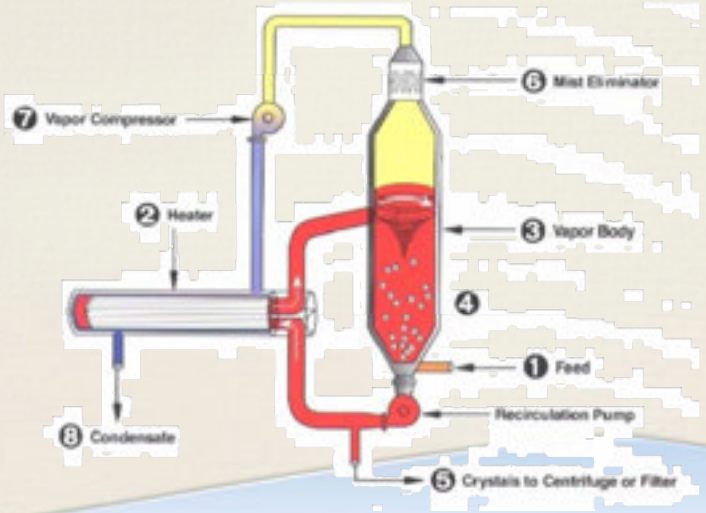
1. 85 to 90-ft tall
2. Maximum size = 250 gpm
3. About $8-million for a 250 gpm system
4. Requires 60 to 100 kW-hr per 1,000 gallons of concentrate

Intel – Chandler, AZ

Deuel Vocational Institution, CA

153

Crystallizer achieves ZLD and produces crystallized salt



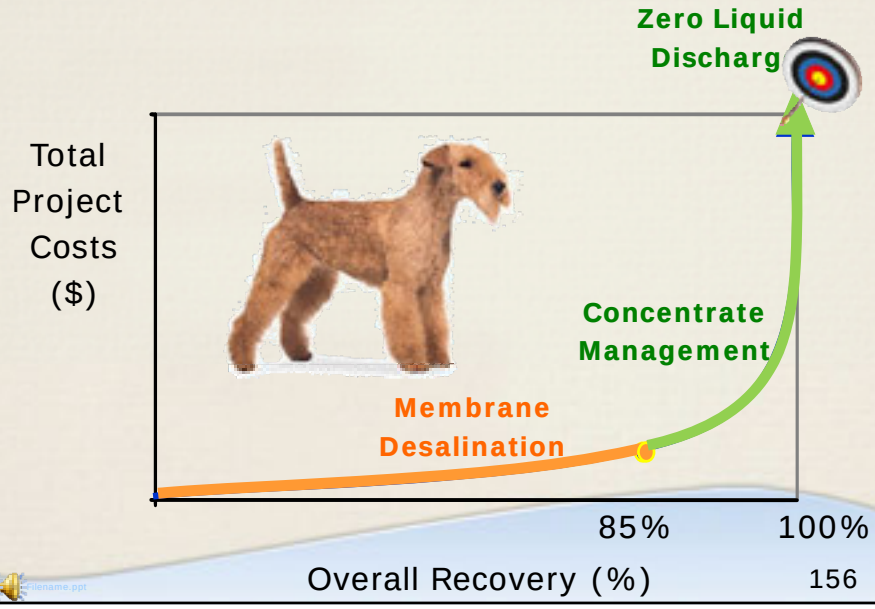
154

Crystalizer works, but takes a lot of energy

1. 65 to 75 ft tall
2. Flows: 2 to 50 gpm
3. About 80 to 120 kW-hr per 1,000 gallons of brine

155

Concentrate disposal is "the tail that wags the dog" for desalination projects



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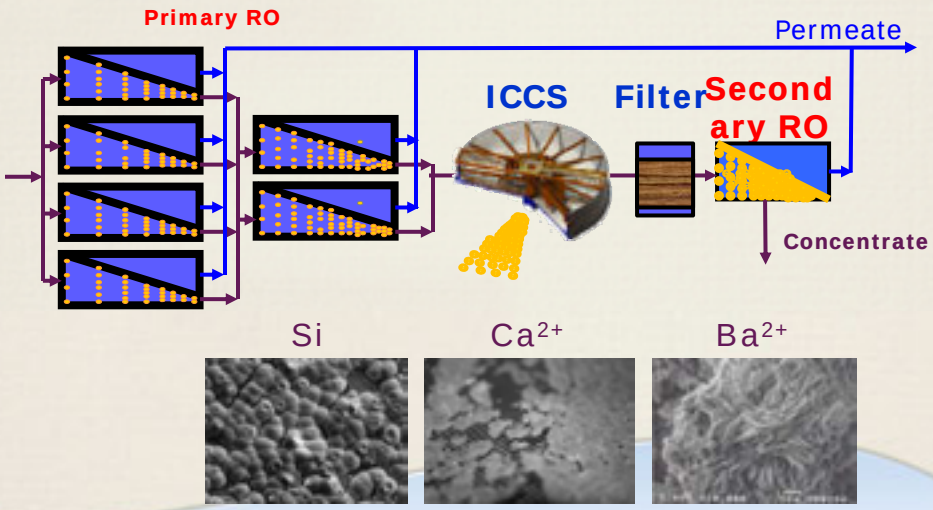
Concentrate management is complicate, involving multiple steps

157

Intermediate Concentrate Chemical Stabilization (ICCS) Removes Scale Forming Constituents that Limit Recovery



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ICCS Used Conventional or Pellet Lime Softening

CONVENTIONAL SOFTENING

- An economic way of concentrate volume reduction proven at bench & pilot scale
- Low rate (1.75 gpm/sf) = large foot print
  - Requires open tank = energy loss
  - Residuals require drying ponds or mechanical dewatering

PELLET SOFTENING

- Fluidized bed using sand & lime
- High rate (35 gpm/sf) = small footprint
- Can be operated in a pressure vessel = save energy
- Residuals easily dewatered by gravity

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Water Treatment Technology Assessment

CHEMICAL ENHANCED FILTRATION

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Chemical Enhanced Filtration – Applicable Alternatives

1. Coagulation – Flocculation + Filtration
   a. + Granular Media Filtration
   b. + Membrane Filtration
2. Enhanced Coagulation + Filtration
3. Enhanced Lime Softening + Filtration
4. Oxidation + Filtration
5. Oxidizing Filters (Greensand)

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Chemical Enhanced Filtration – How it works

1. Involves the addition of chemicals
   a. Coagulation - aluminum salts, iron salts, polymer, PACL, etc.
   b. Lime Softening - lime, soda ash caustic soda, etc.
2. Coagulation/Flocculation - Rapid and gentle mixing to initiate the formation of floc
3. Softening – Enhance solids contact
4. Oxidation – high iron concentration in the feed water or on the media (Fe:As > 20:1)
5. Particles are removed through either direct filtration or sedimentation + filtration

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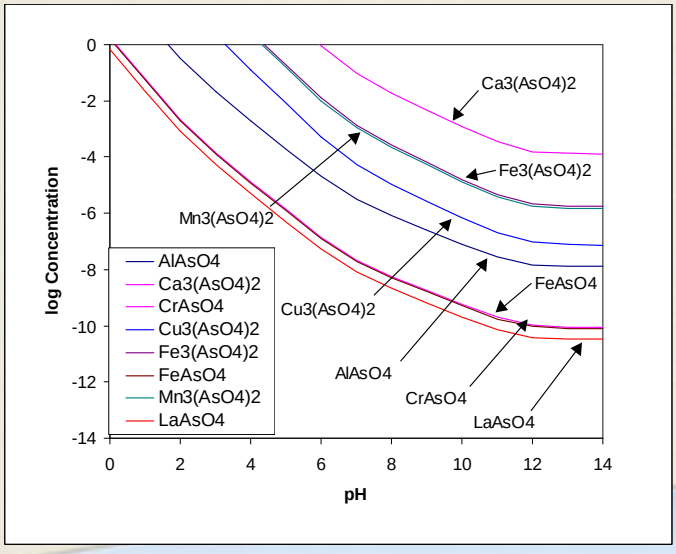
Enhanced Coagulation Can be Considered as a Process Optimization of Coag + Filter

- Defined by the EPA
- Compliance strategy for the D/DBP Rules
- Achieved in most cases by
  - Increasing coagulant doses
  - Adjusting the pH
  - Optimization of type of coagulants
- Always an option if coagulation is selected.
- May not be necessary for Groundwater Application.

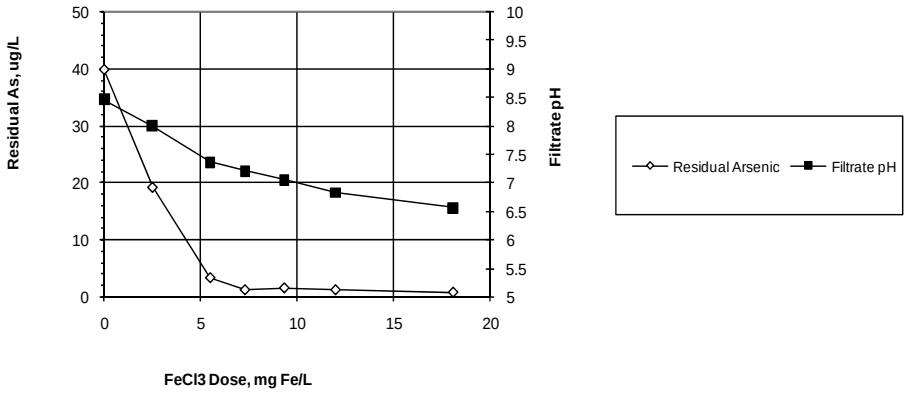
3

Solubility of As(V) Species



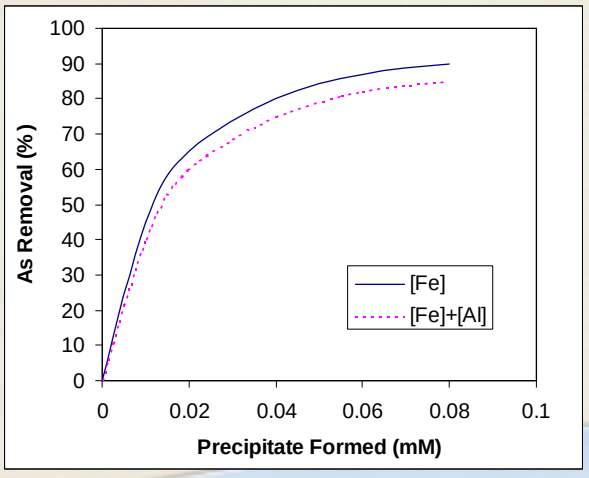
164

Arsenic Removal using $FeCl_3$ are Well Documented



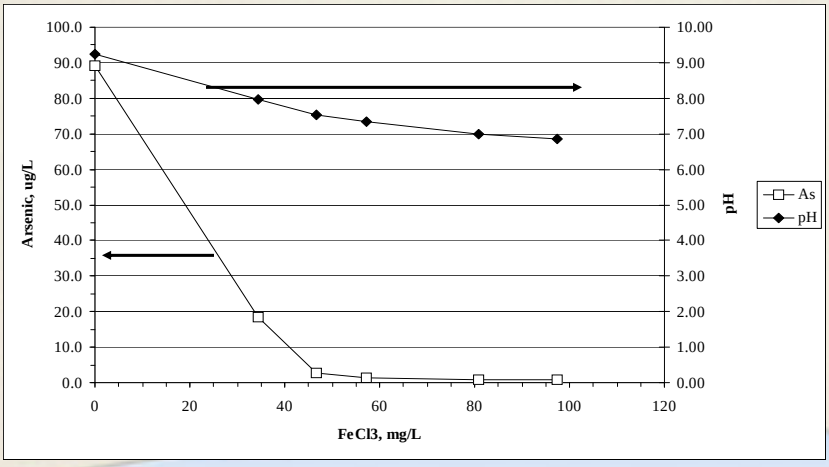
165

As Removal by Conventional Trt. - 2



166

Ambient pH: $FeCl_3$ vs As Leakage, NAS Fallon



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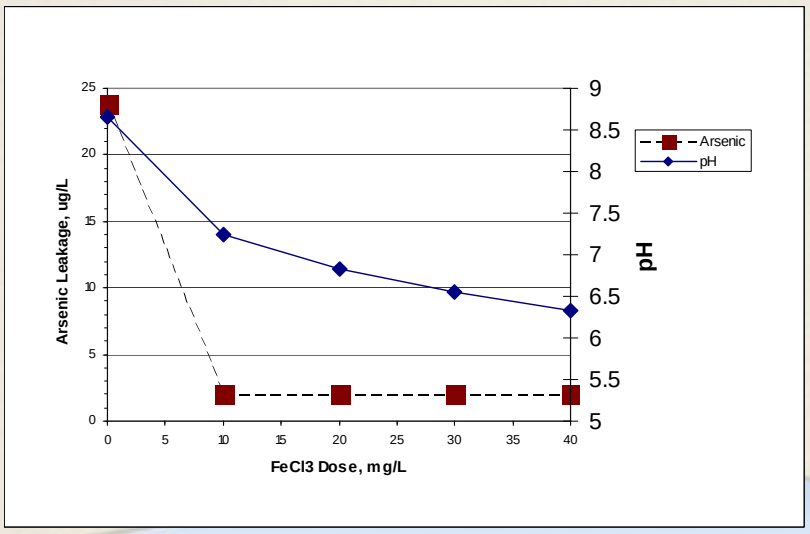
El Paso Jar Testing



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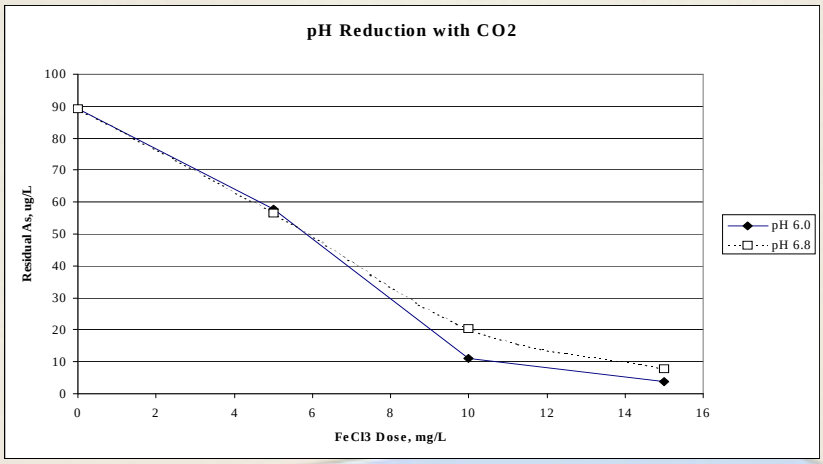
pH Adjustment with CO2, NAS Fallon, NV



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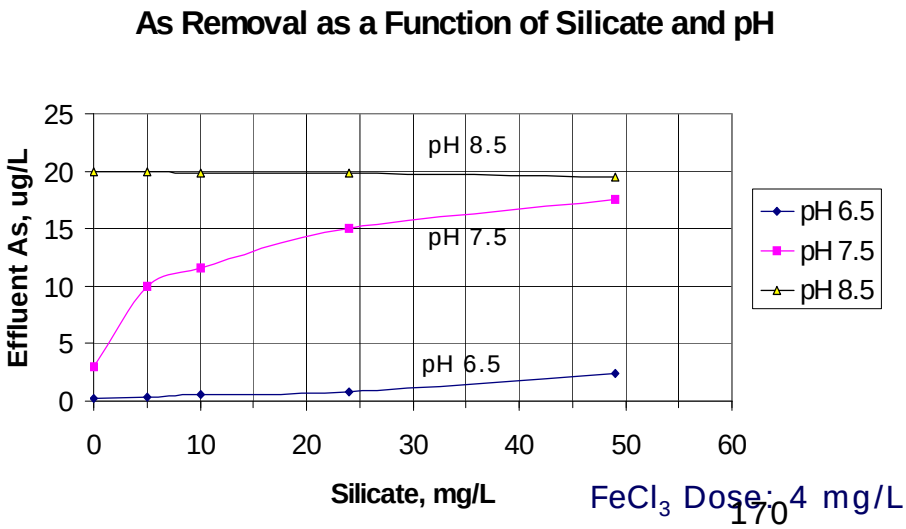
Silica Impacts Arsenic Removal at pH 7.0 and above



$FeCl_3$ Dose: 4 mg/L

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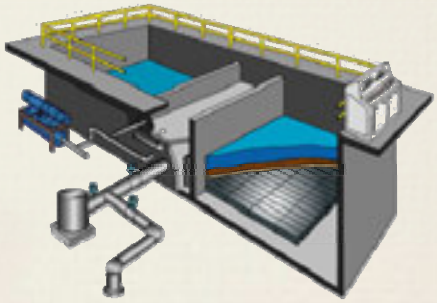
Coagulation – Arsenic Removal

1. Below a pH of approximately 7, removals with alum or ferric sulfate/chloride are similar.
2. Above a pH of 7, removals with alum decrease dramatically (at a pH of 7.8, alum removal efficiency is about 40%).
3. Other coagulants are also less effective than ferric sulfate/chloride.
4. Systems may need to lower pH or add more coagulant to achieve higher removals.

Coagulation – Fluoride Removal

- High removal efficiency at high concentration (15 ppm feed down to 5 ppm)
- Cannot drop fluoride to < 2 ppm
- Good pretreatment to reduce ion exchange / RO costs

Conventional Granular Media Filters



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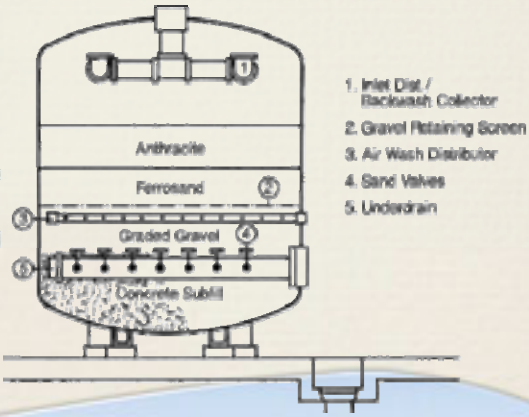
Granular Media Filters using Pressure Vessles



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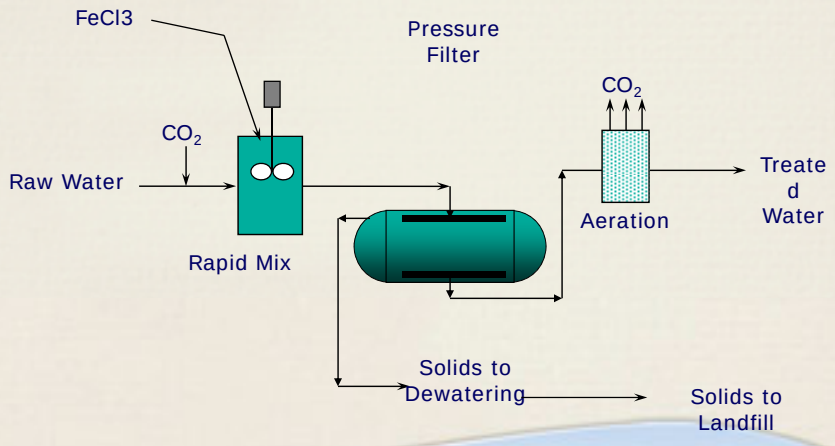
Schematic of Coagulation / Filtration



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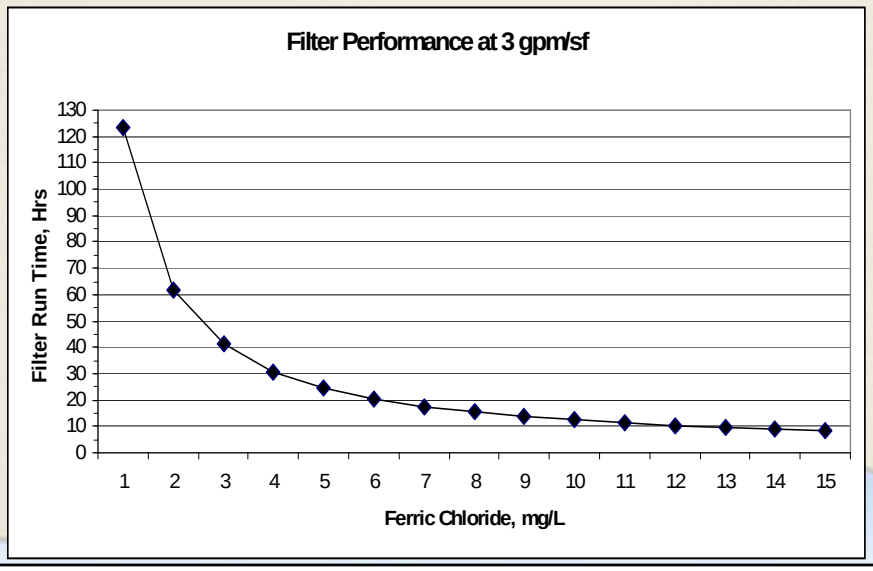
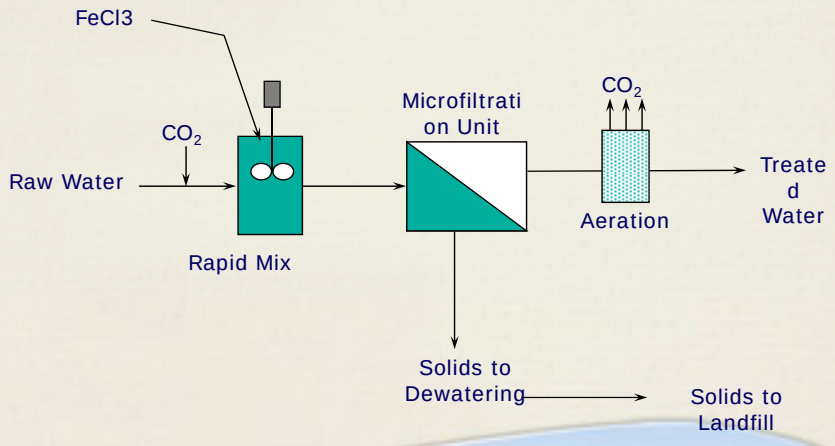
Direct Filtration Performance (Based on 0.1 lbs Solids / sf)

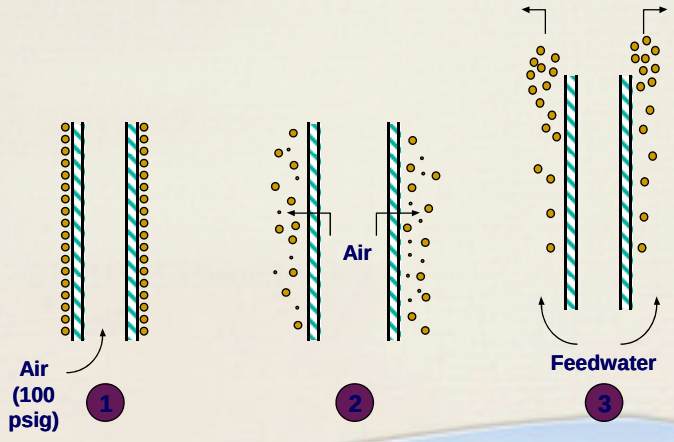


MF Process Operates in Direct Filtration Mode



177

Solids are Removed from Module by an Air-Water Backwash



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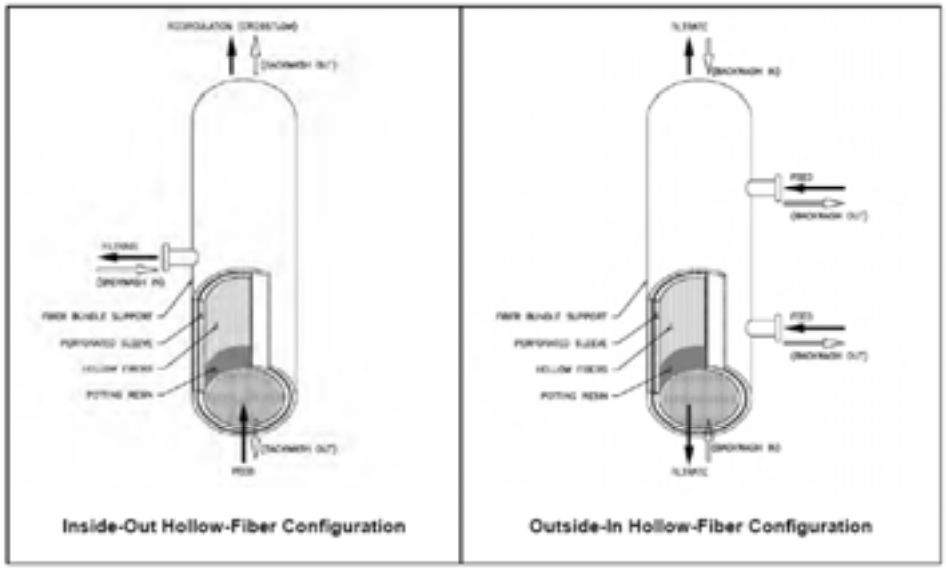


179

Membrane Filtration

- Microfiltration or Ultrafiltration: 0.1 µm
- Immersed or pressurized
- Inside out or outside in

180

Coagulation + Granular Media Filtration – Benefits and Challenges

Benefits

- Remove multiple contaminants, including iron, Mn, Arsenic and Fluoride
- Established technology
- Very robust. Easy to operate.
- Cost effective way to reduce high concentrations of As and F
- Good for large facilities
- Efficiency can be enhanced
- Residual are relatively easy to treat

Challenges

- Effluent Arsenic and Fluoride are not as Low as IX and AA
- Handle large volume of chemicals
- Generate large volume of residuals

181

Coagulation Assisted Microfiltration – Benefits and Challenges

Benefits

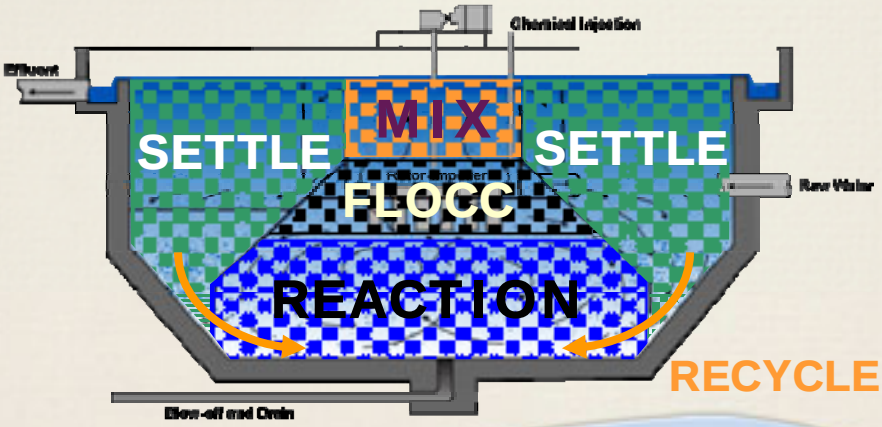
- Remove multiple contaminants, including iron, Mn, Arsenic and Fluoride
- Cost effective way to reduce high concentrations of As and F
- Good for large facilities
- Membrane filtration produce better water quality than GMF

Challenges

- Effluent Arsenic and Fluoride are not as Low as IX and AA
- Larger volume of residuals compared to GMF backwash wastes; Harder to treat.
- Handle CIP chemicals and CIP wastes
- Higher costs than GMF
- Less published data compared to Coag + GMF

182

Enhanced Lime Softening - Full Scale Solids Contact Clarifier Improves Chemical Precipitation



183

Conventional Lime Softening

CONVENTIONAL SOFTENING

- Remove hardness and heavy metals
- Can also remove organics and colloidal material
- Low rate (1.75 gpm/sf) = large foot print
- Requires open tank = energy loss
- Residuals require drying ponds or mechanical dewatering

184

Pellet Softening

PELLET SOFTENING

- Fluidized bed using sand & lime
- High rate (35 gpm/sf) = small footprint
- Can be operated in a pressure vessel = save energy
- Residuals easily dewatered by gravity

Lime Softening – Arsenic Removal

1. Modified Lime Softening (LS), operated within the optimum pH range of greater than 10.5 is likely to provide a high percentage of As removal.
2. Systems operating lime softening at lower pH will need to increase the pH to achieve higher removals of arsenic.

186

Softening – Fluoride Removal

- High removal efficiency at high concentration
- Cannot drop fluoride to < 2 ppm
- Good pretreatment to reduce ion exchange / RO costs

Softening – Benefits and Challenges

Benefits

- Remove multiple contaminants, including Arsenic and Fluoride
- Established technology
- Very robust
- Cost effective way to reduce high concentrations of As and F
- Good for large facilities
- Can be enhanced using pellet softening
- Residual are relatively easy to treat

Challenges

- Effluent Arsenic and Fluoride are not as Low as IX and AA
- Intensive O&M
- Require high pH
- Handle large volume of chemicals
- Generate large volume of residuals

Oxidation / Filtration – Arsenic Removal

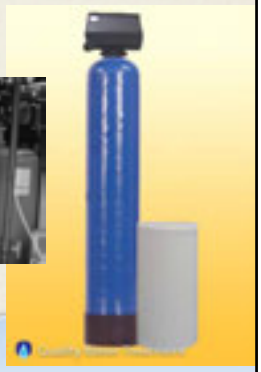
- Convert the As(III) to As(V)
- No ion competition
- Arsenic is co-precipitated with the iron
- 80% removal > 20:1 iron to arsenic ratio (50% removal at 7:1)

189

Greensand Filter

Benefits

- Removes Arsenic, iron & manganese
- Low maintenance.
- Proven technology used over decades.
- Low costs



Challenges

- Arsenic removal highly dependant on iron concentration
- EPA study

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SURPRISETREE™ WATER MODEL REPORT

SURPRISE ARIZONA

carollo

Water Treatment Technology Assessment
Groundwater Supply Treatment Evaluation
Surprise Tree™

Date: 3/8/2010

Project Information

Facility Name:	Sierra Verde Well 1 Water Supply Facility	
Facility Size:	< 5 mgd	
Estimated Construction Time:	2010	
Life Cycle Length (years):	20	
Estimated Operation Time:	2011	to 2030
Location:	Surprise, AZ	
RS Means 300-City Location Factor:	0.89	
Inflation Rate:	5%	
Interest Rate:	5%	

Water Quality Inputs

	Well WQ	Standards	Other
(1) Arsenic (mg/L)	0.012	0.01	0.008
(2) Fluoride (mg/L)	1	2	4
(3) Nitrate (mg/L)	2	10	8
(4) Sulfate (mg/L)	77	250	200
(5) Sodium (mg/L)	82	-	150
(6) Chloride (mg/L)	55	250	150
(7) Iron (mg/L)	0.2	0.3	0.24
(8) Managnese (mg/L)	0.03	0.05	-
(9) TOC (mg/L)	1	-	2
(10) TDS (mg/L)	360	500	700
(11) Turbidity (NTU)	1	-	1

Warnings and Considerations:

(1)	Arsenic >80% of MCL!	Arsenic > MCL!!	Arsenic Treatment
(2)			
(3)			
(4)	High Sulfate!!! IX may be interfered.		
(5)			
(6)			
(7)			Fe:As < 20:1
(8)			
(9)			
(10)			
(11)			

* Above warnings may contain blank rows.

EXAMPLE

Water Treatment Technology Assessment

Groundwater Supply Treatment Evaluation

Surprise Tree™

Date: 3/8/2010

Scenario Number: 1

Scenario Description: Arsenic Treatment

Weighting Factors

Air Quality	6
O&M Costs	9
Capital Costs	8.8
Process Robustness	7.9
Maturity of Technology	6.9
City of Surprise Farmilarity	4.1
Mainteance Intensity	6.4
Operation Flexibility	6.5
System Complexity	5
Footprint	4.6
Regulatory	5.9
Saftety	6.8
Residuals	6.6
Versatility	6.5
Expandability	6.5

Decision Making Weighting

Capital Costs	0%
O&M Costs	0%
Life Cycle Costs	0%
Performance	0%
Implemention	100%

EXAMPLE

Water Treatment Technology Assessment

Groundwater Supply Treatment Evaluation

Surprise Tree™

Date: 3/8/2010

Disclaimer:

1) Costs presented above are for relative technology alternative evaluation. They shall NOT be used for CIP planning or construction purpose.

2) This is an Order-of-Magnitude (Feasibility Study) cost estimate. According to the American Association of Cost Engineers (AACE), the cost estimate accuracy is +50% to -30%. The costs shall not be misused in lieu of preliminary design or detailed design cost estimates.

3) Costs do not include preliminary and final design expenses, permitting costs, land acquisition costs for well sites, well development costs, construction admin & inspection costs, commissioning costs, and associated contingency on these costs.

4) Capital costs are expressed in $/gpd, costs to build a 1 gpd facility. O&M costs are expressed in $/1000 gallon, costs to produce 1000 gallon of water. Life cycle costs are expressed in $/1000 gallon, costs to produce one thousand gallon of water including amortized capital costs.

5) Costs are based on EPA Cost Curves (multiply a validation factor) and Carollo internal cost estimating database, validated using recent completed similar projects.

6) Adjustment by users are allowed. Users are responsible for the accuracy of the adjusted costs and the validation of all costs once adjusted.

EXAMPLE

SURPRISE
ARIZONA

Water Treatment Technology Assessment
Groundwater Supply Treatment Evaluation
Surprise Tree™

carollo
Engineers...Working Wonders With Water™

Date: 3/8/2010

			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	**Oxidation**	Chlorine	100	100	46	64	88	100
2	**Oxidation**	Potassium Permanganate	90	40	100	100	83	90
1	**Arsenic**	Granular Ferric Hydroxide or Iron Modified Media	100	92	21	28	83	100
2	**Arsenic**	Coagulation + Granular Media Filtration	96	59	46	50	81	96
3	**Arsenic**	Ion Exchange Arsenic	93	50	9	13	71	93
4	**Arsenic**	Activated Alumina	93	83	33	41	83	93
1	**Fluoride**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	**Fluoride**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	**Fluoride**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	**Nitrate**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
2	**Nitrate**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
3	**Nitrate**	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
1	**Disinfection**	Liquid Chlorine Bulk	100	54	48	50	100	100
2	**Disinfection**	Liquid Chlorine Onsite	81	30	74	55	100	81

EXAMPLE

COST REFERENCES

United States
Environmental Protection
Agency

Office of Water
(4606)

EPA 815-R-00-028
December 2000
www.epa.gov/safewater

Technologies and Costs for Removal of Arsenic from Drinking Water

TECHNOLOGIES AND COSTS FOR REMOVAL OF ARSENIC FROM DRINKING WATER

TARGETING AND ANALYSIS BRANCH
STANDARDS AND RISK MANAGEMENT DIVISION
OFFICE OF GROUND WATER AND DRINKING WATER
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C.

December 2000

INTERNATIONAL CONSULTANTS, INC.
4134 Linden Avenue
Dayton, Ohio 45432

MALCOLM PIRNIE, INC.
432 North 44th Street, Suite 400
Phoenix, Arizona 85008

THE CADMUS GROUP, INC.
135 Beaver Street
Waltham, Massachusetts 02452

Under Contract with the USEPA No. 68-C6-0039
Delivery Order 13

Figure 3-1
Pre-oxidation - 1.5 mg/L Chlorine
Capital Costs

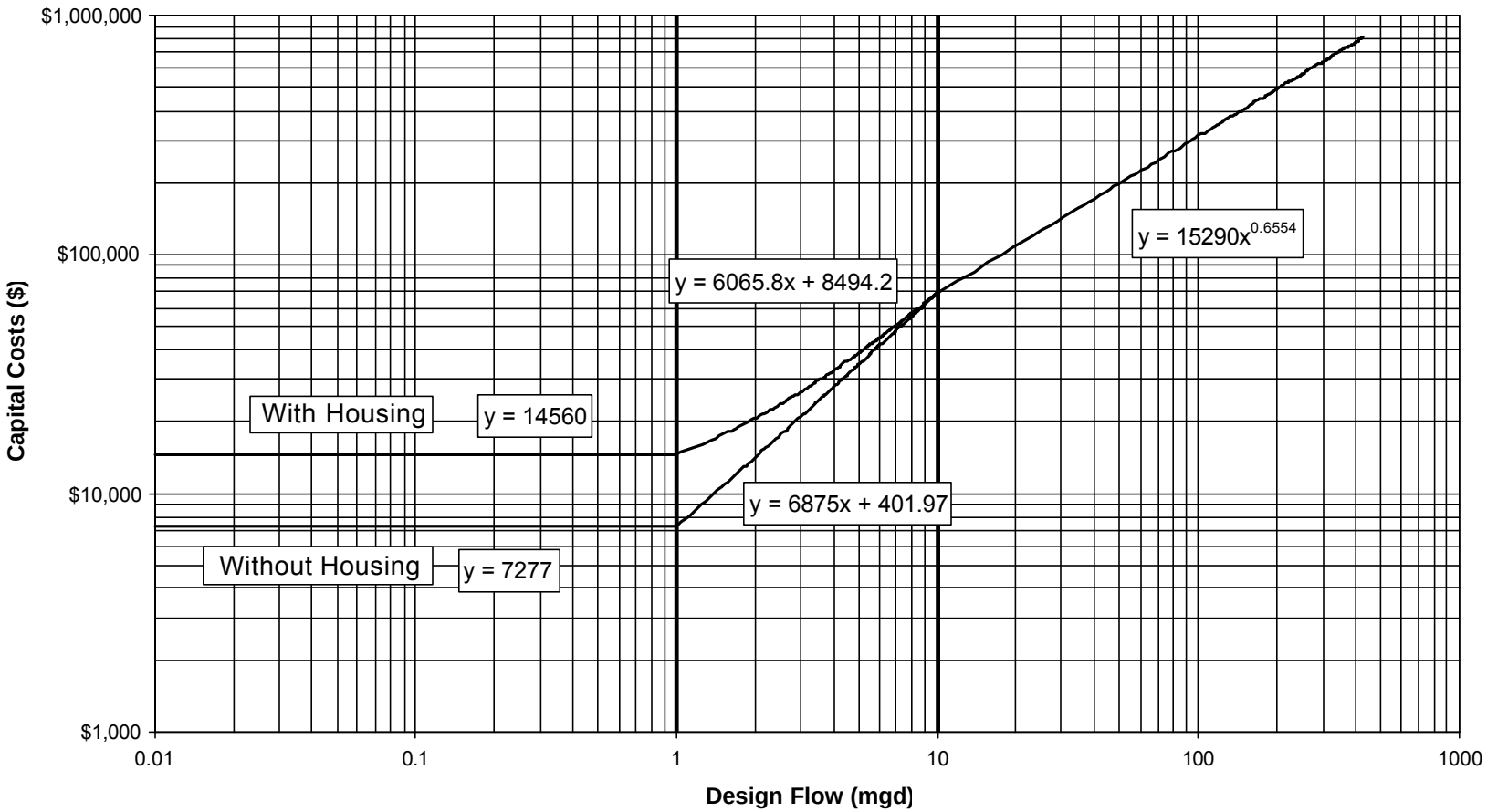


Figure 3-2
Pre-oxidation - 1.5 mg/L Chlorine
O&M Costs

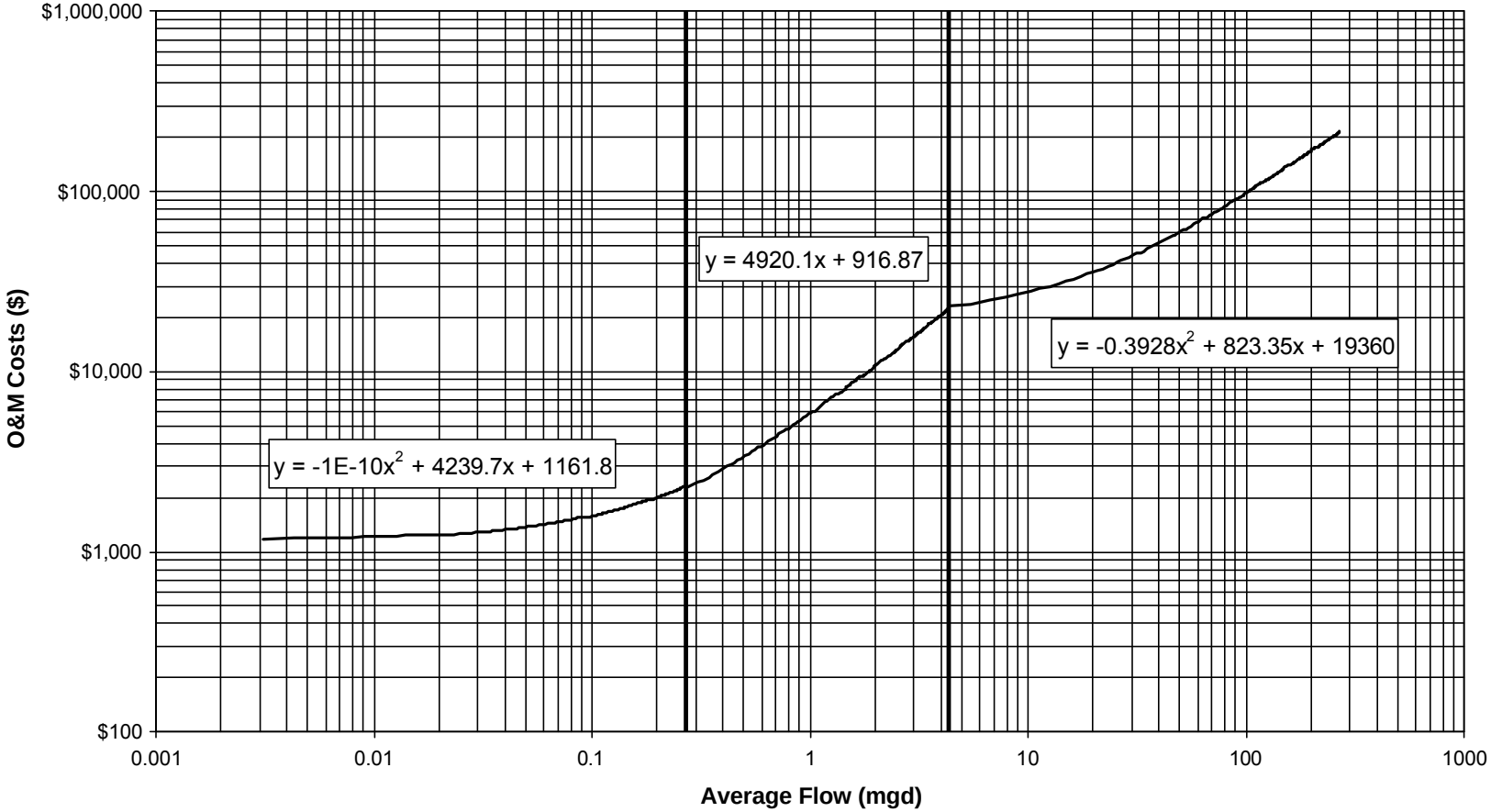


Figure 3-3
Enhanced Coagulation/Filtration
Capital Costs

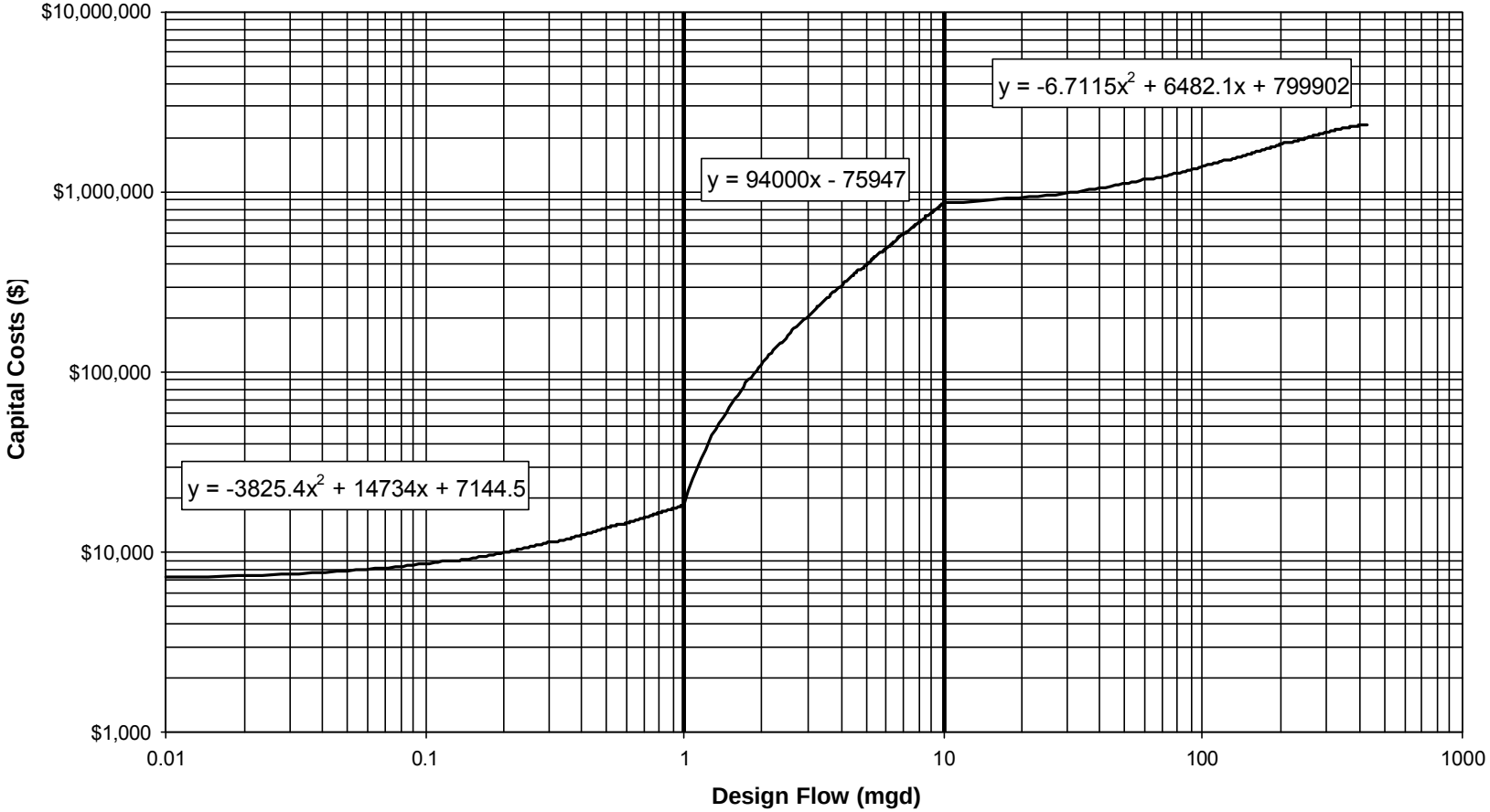


Figure 3-4
Enhanced Coagulation/Filtration
O&M Costs

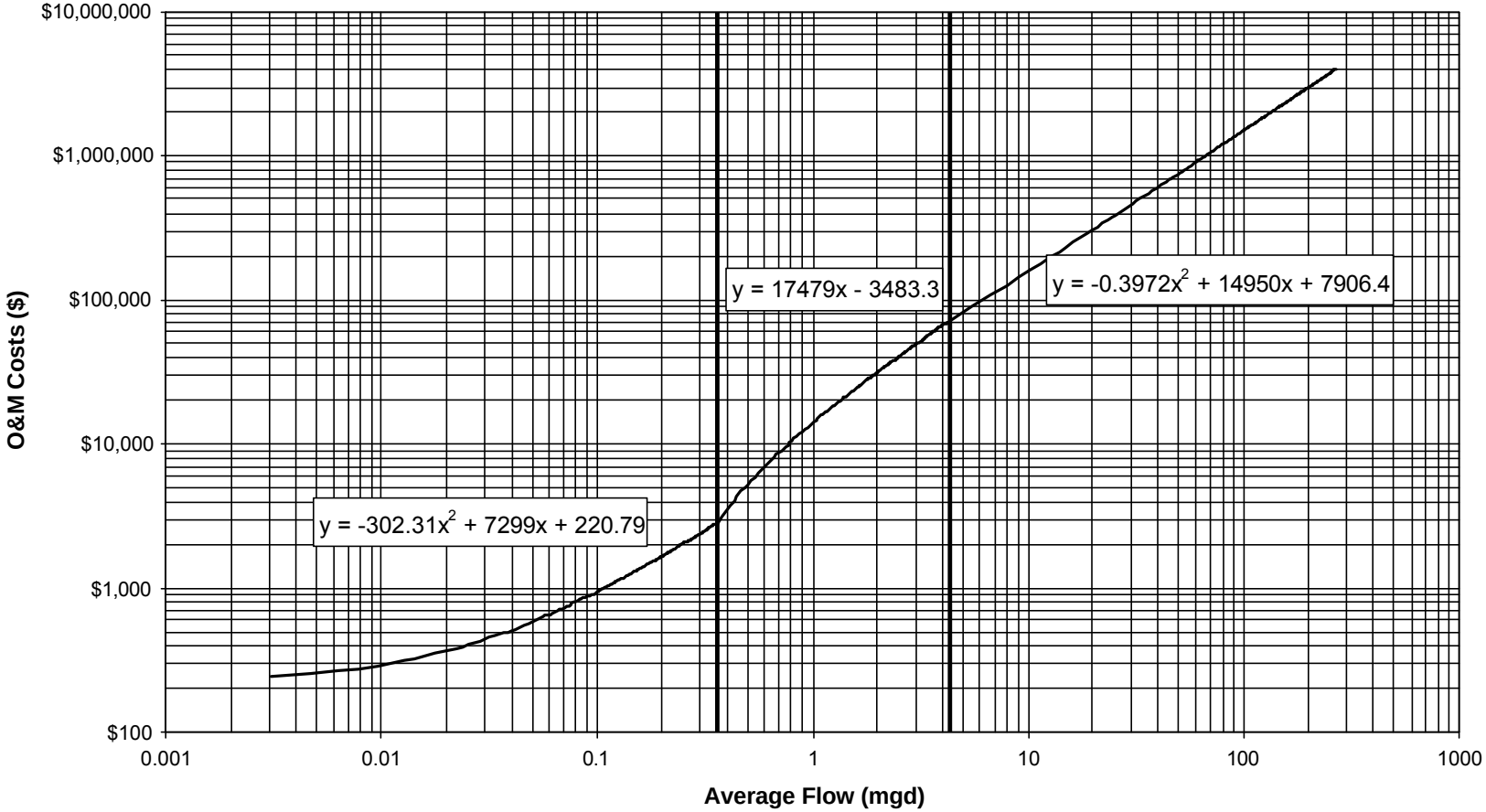


Figure 3-5
Coagulation Assisted Microfiltration
Capital Costs

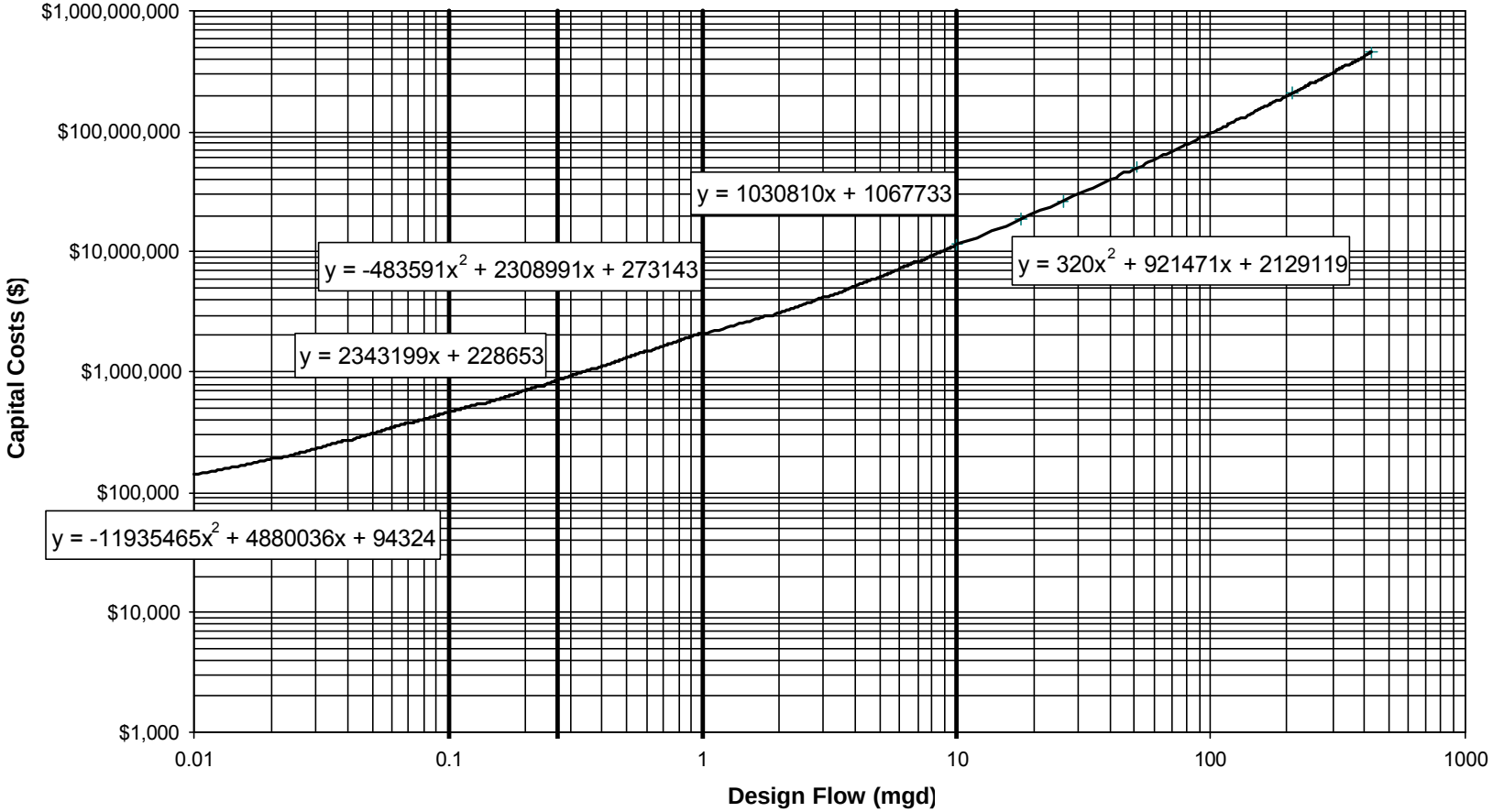


Figure 3-6
Coagulation Assisted Microfiltration
O&M Costs

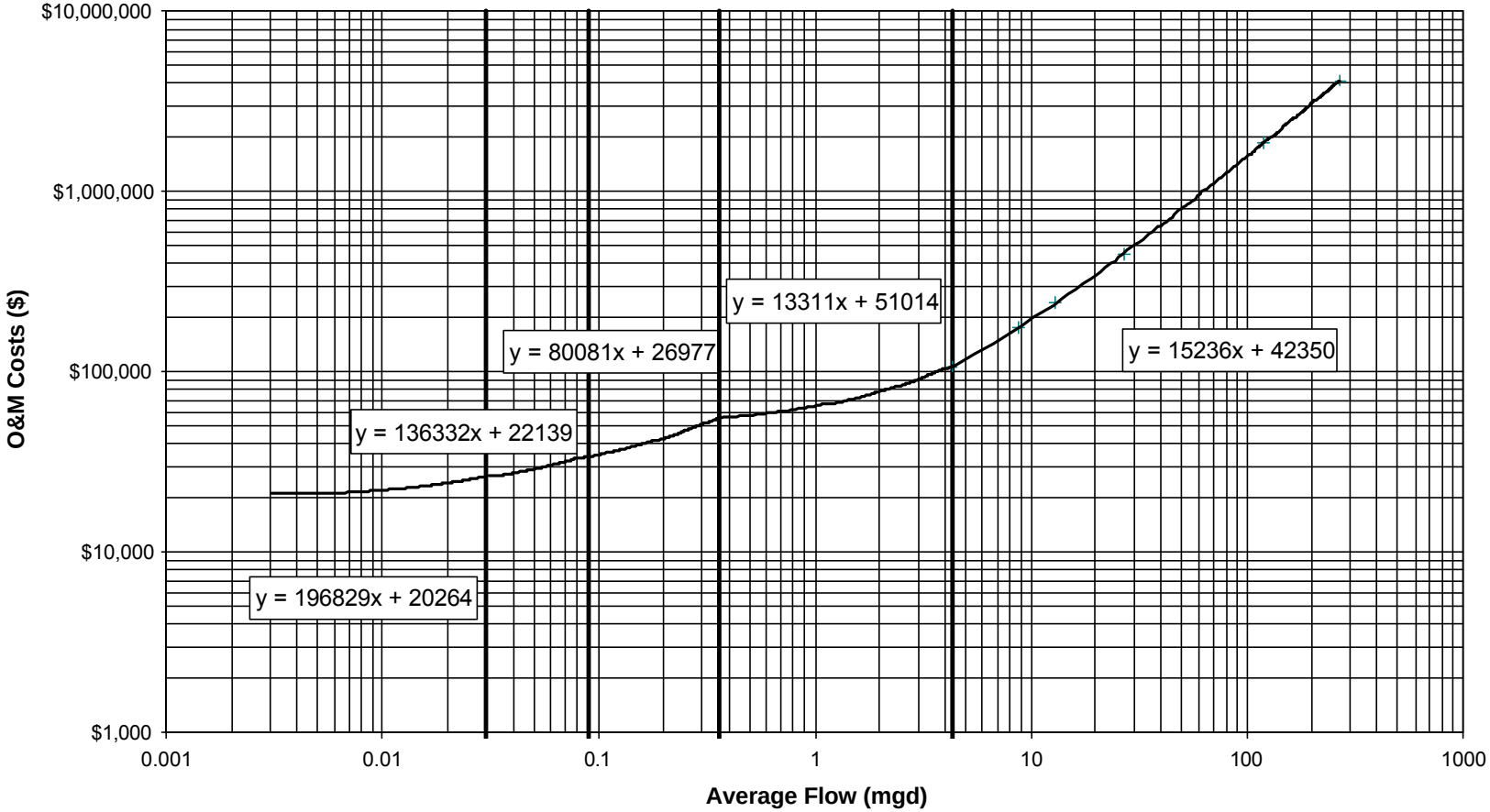


Figure 3-7
Enhanced Lime Softening
Capital Costs

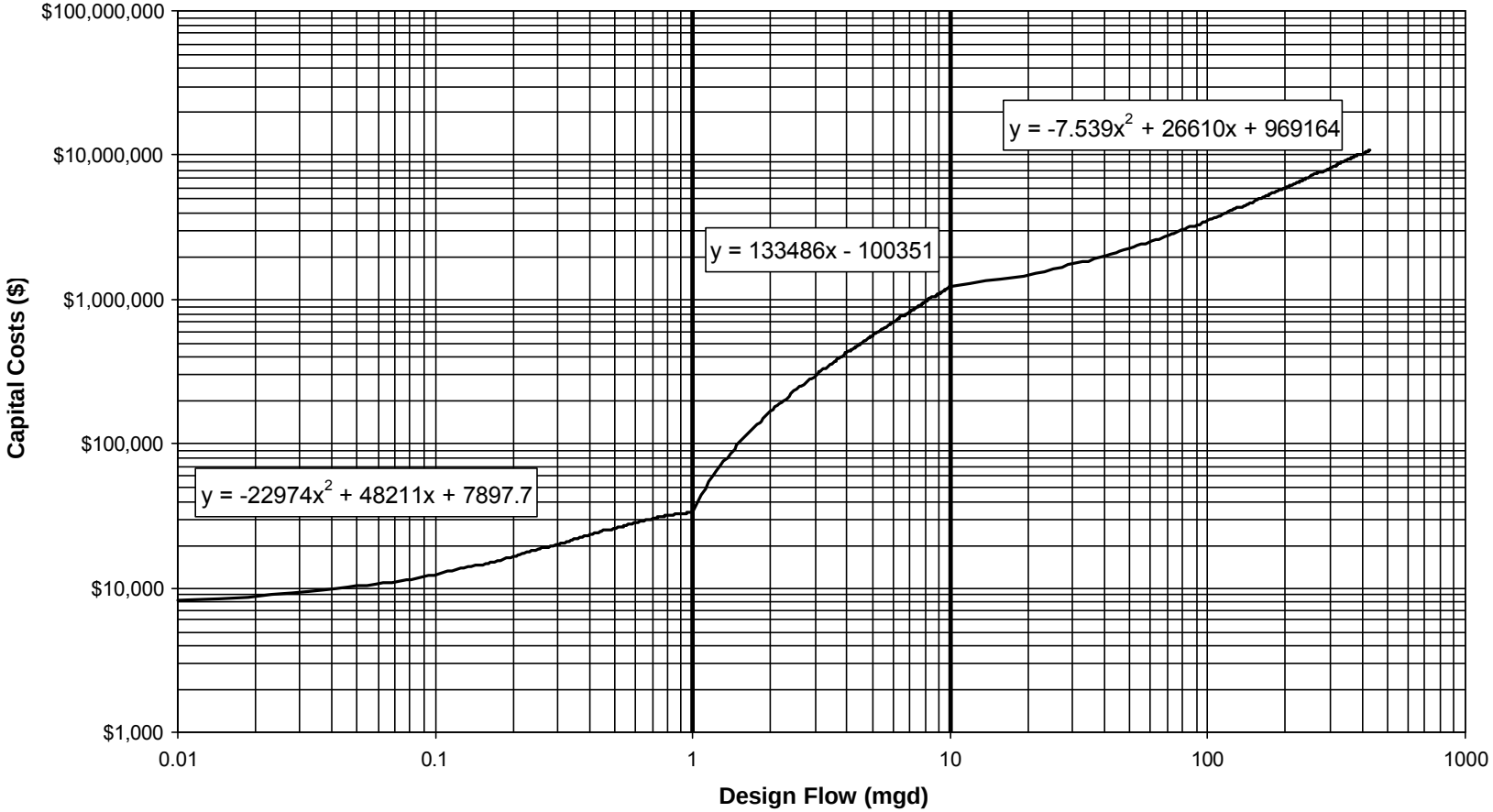


Figure 3-8
Enhanced Lime Softening
O&M Costs

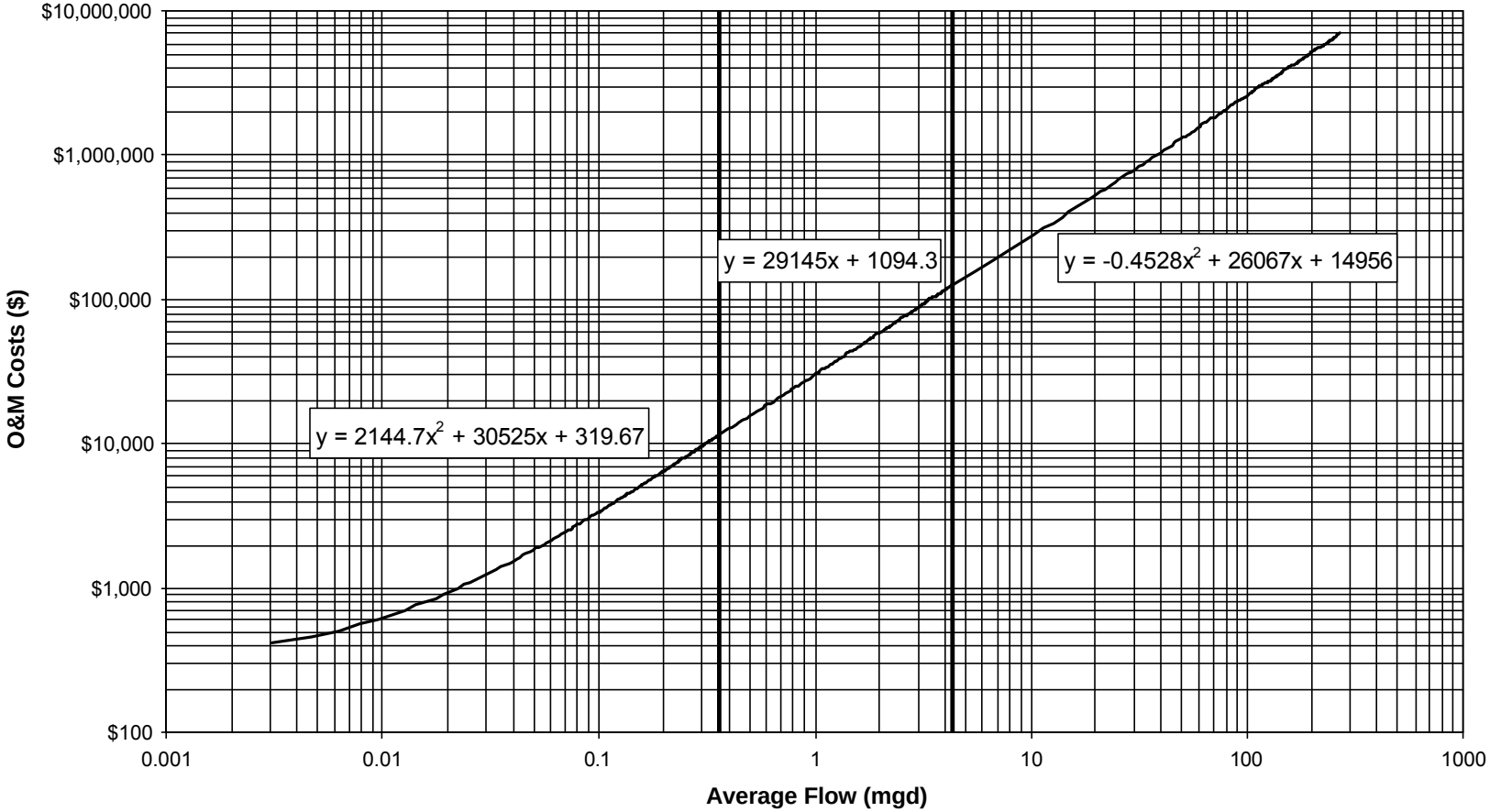


Figure 3-9
Activated Alumina
Capital Costs

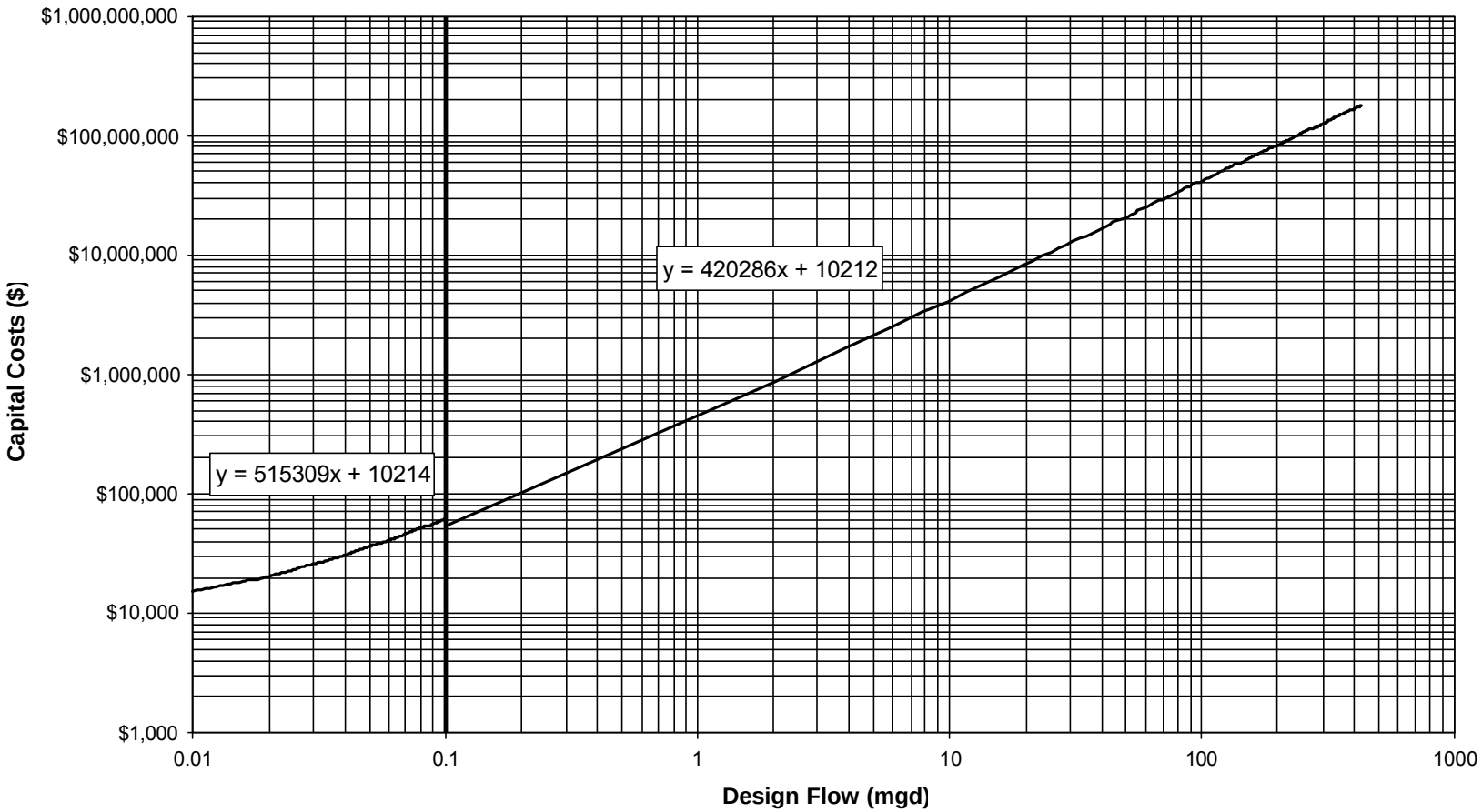


Figure 3-10
Activated Alumina (pH 7 - 8)
O&M Costs

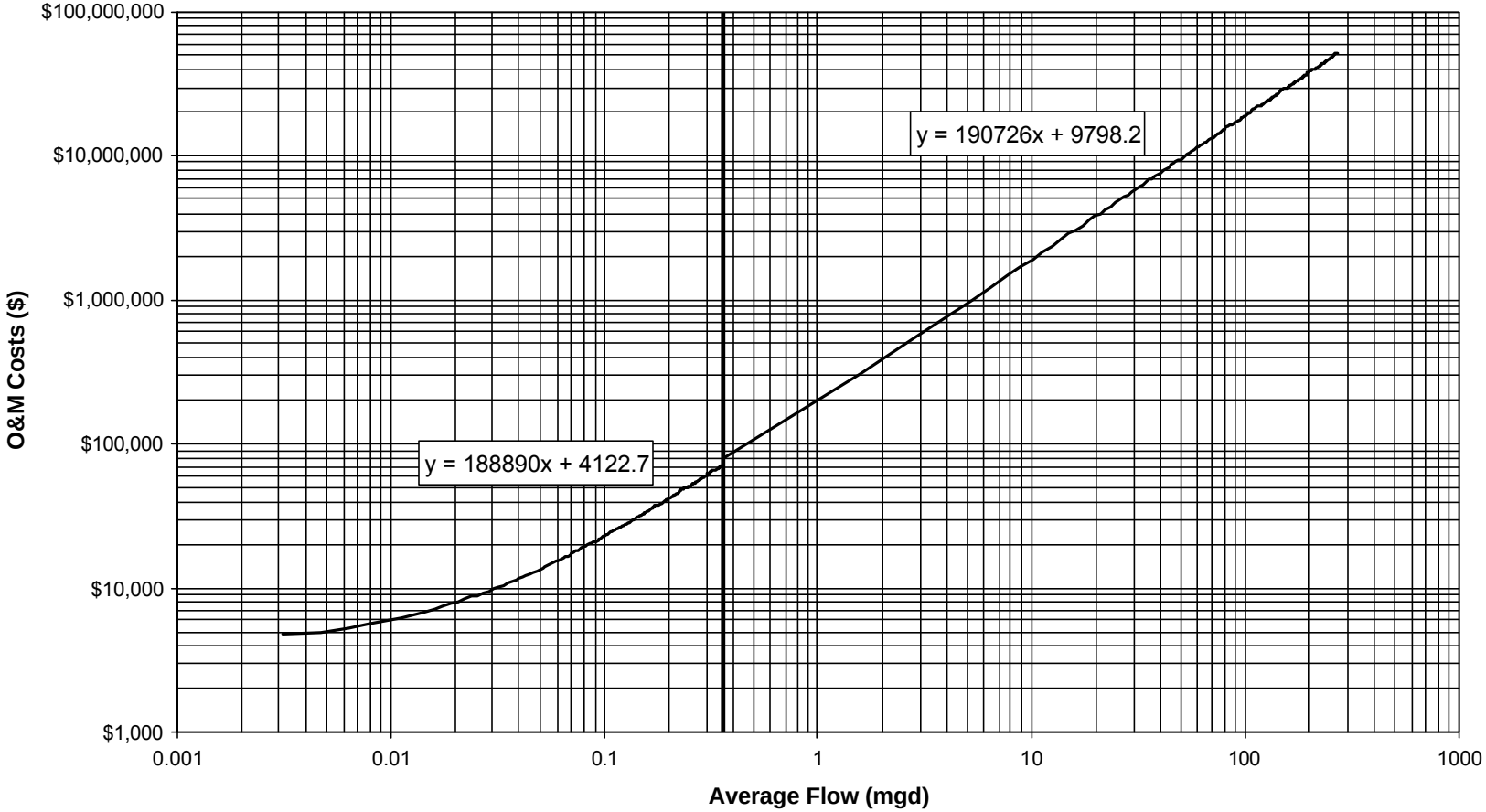


Figure 3-11
Activated Alumina (pH 8 - 8.3)
O&M Costs

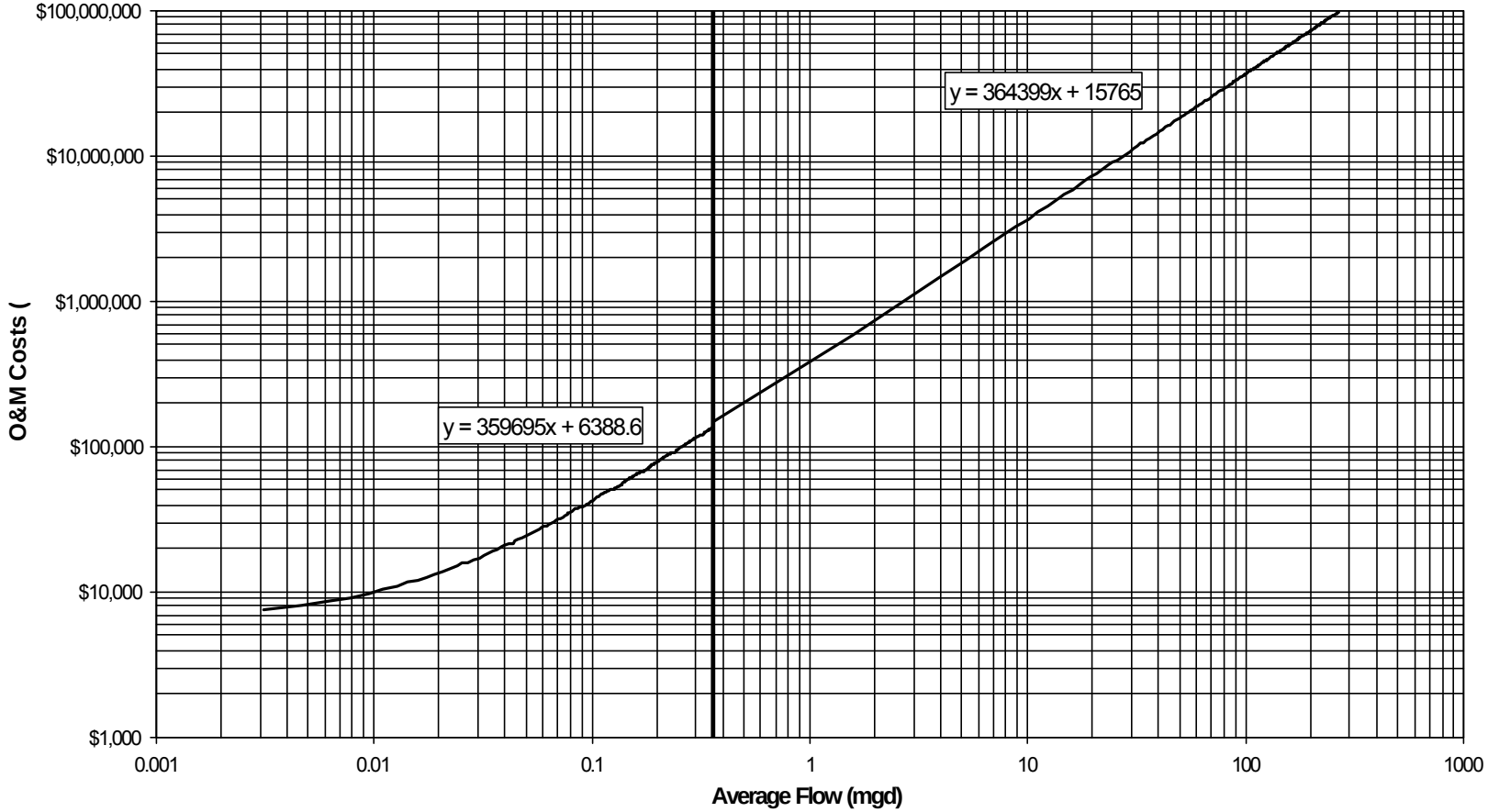


Figure 3-12
Activated Alumina (pH Adjusted to 6.0)
Capital Costs

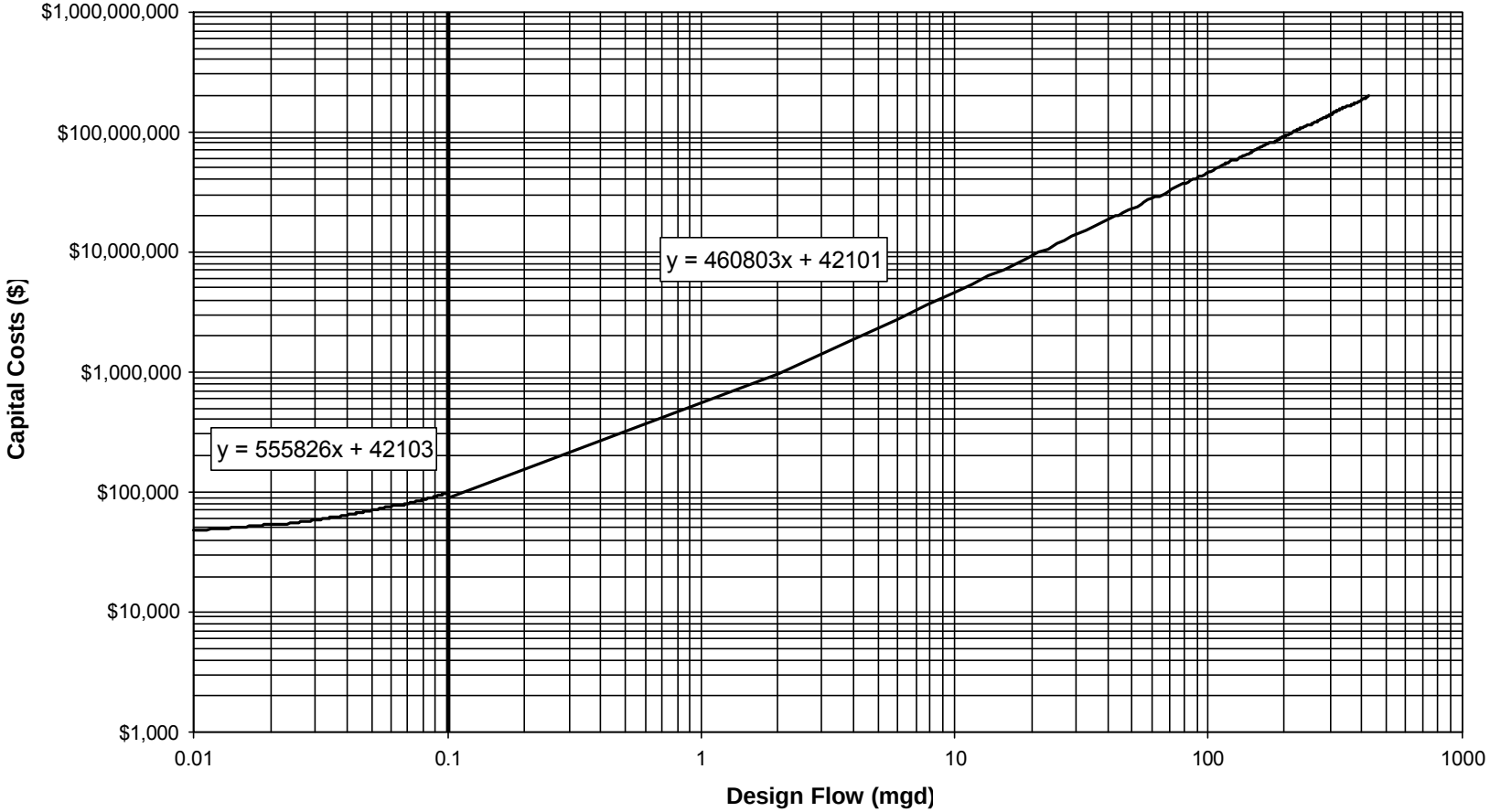


Figure 3-13
Activated Alumina (pH Adjusted to 6.0 - 23,100 BV)
O&M Costs

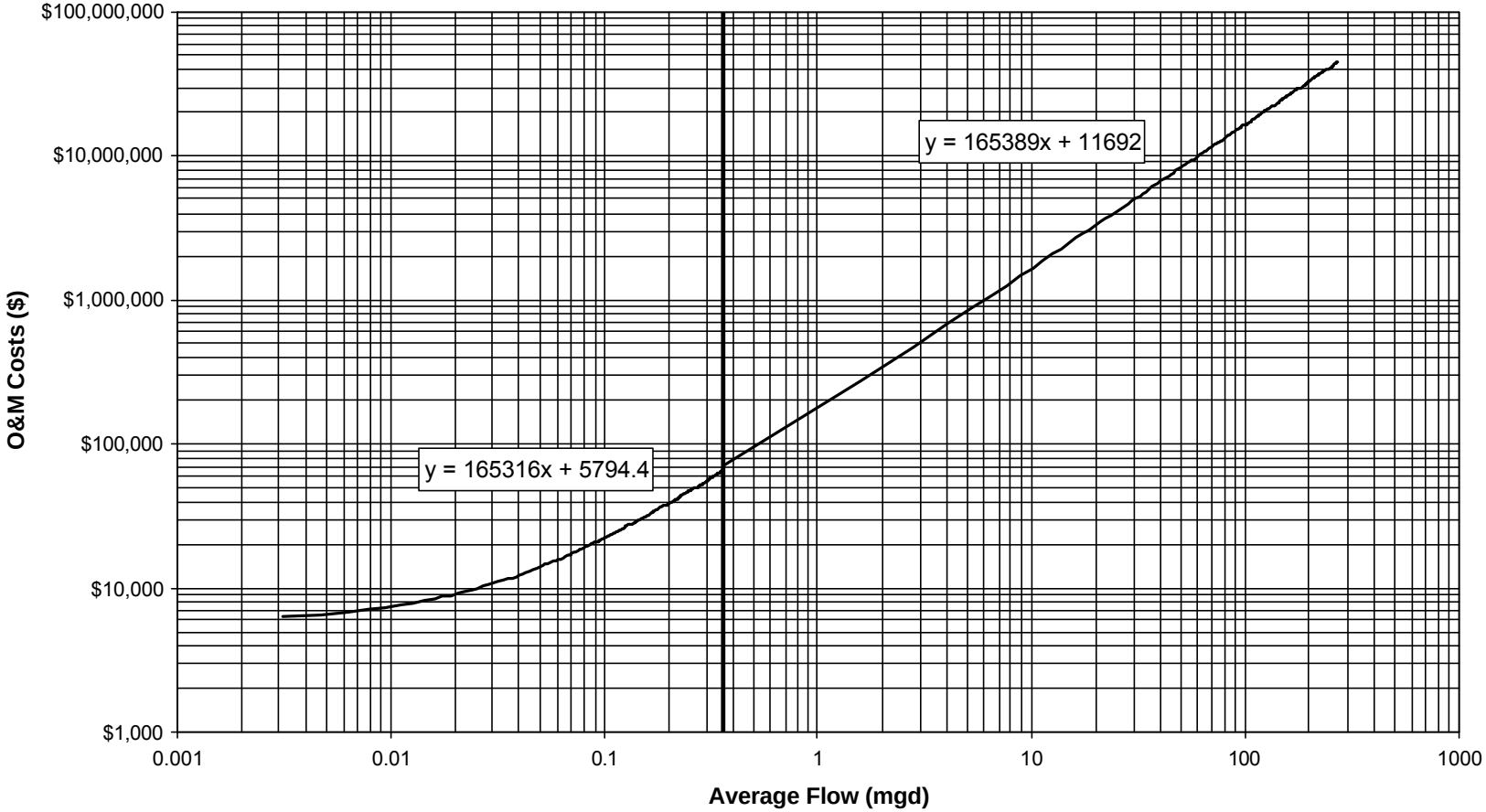


Figure 3-14
Activated Alumina (pH Adjusted to 6.0 - 15,400 BV)
O&M Costs

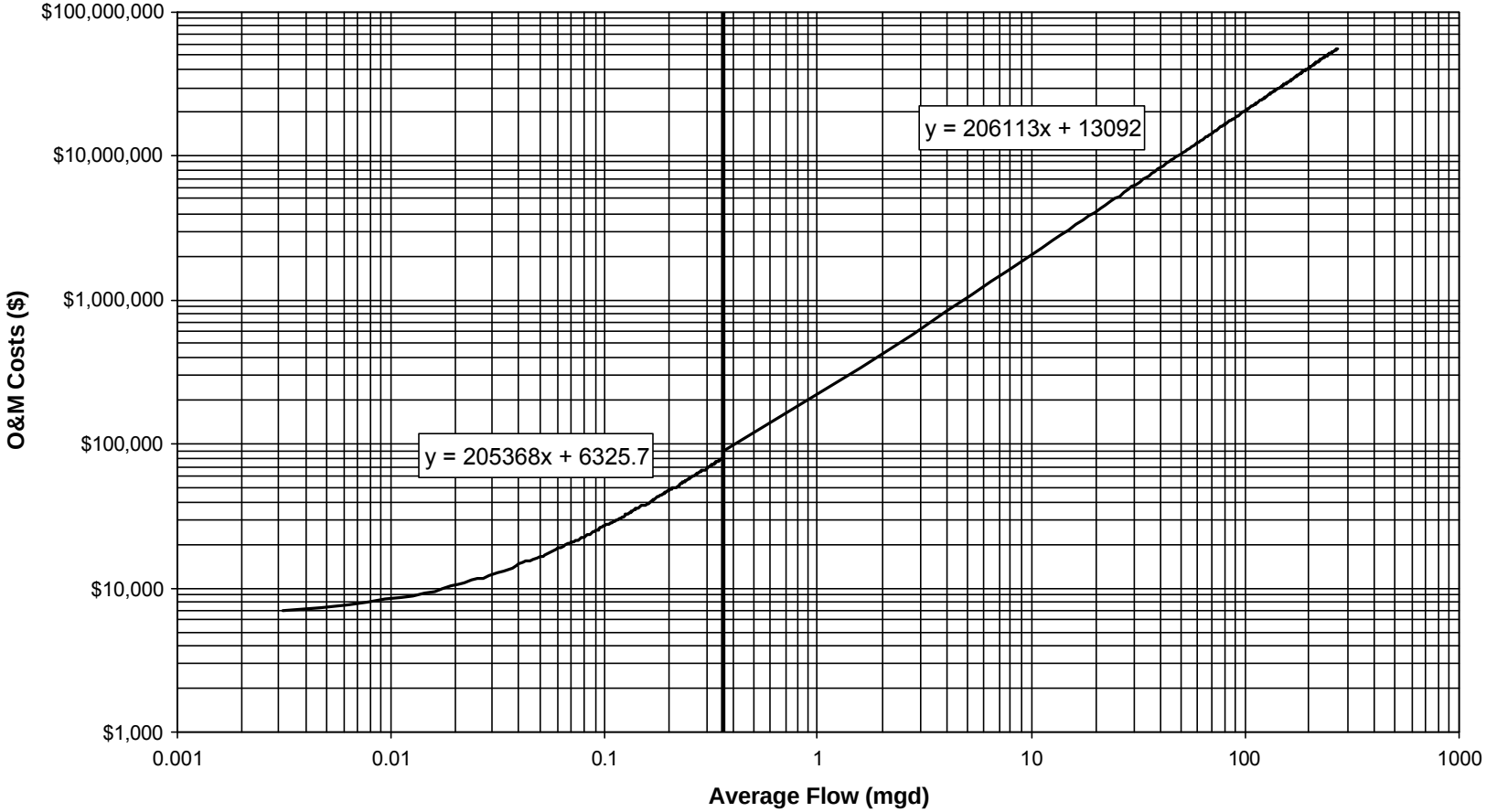


Figure 3-15
Bed Volumes to Arsenic Breakthrough as a Function of Sulfate Concentration (Clifford, 1995)

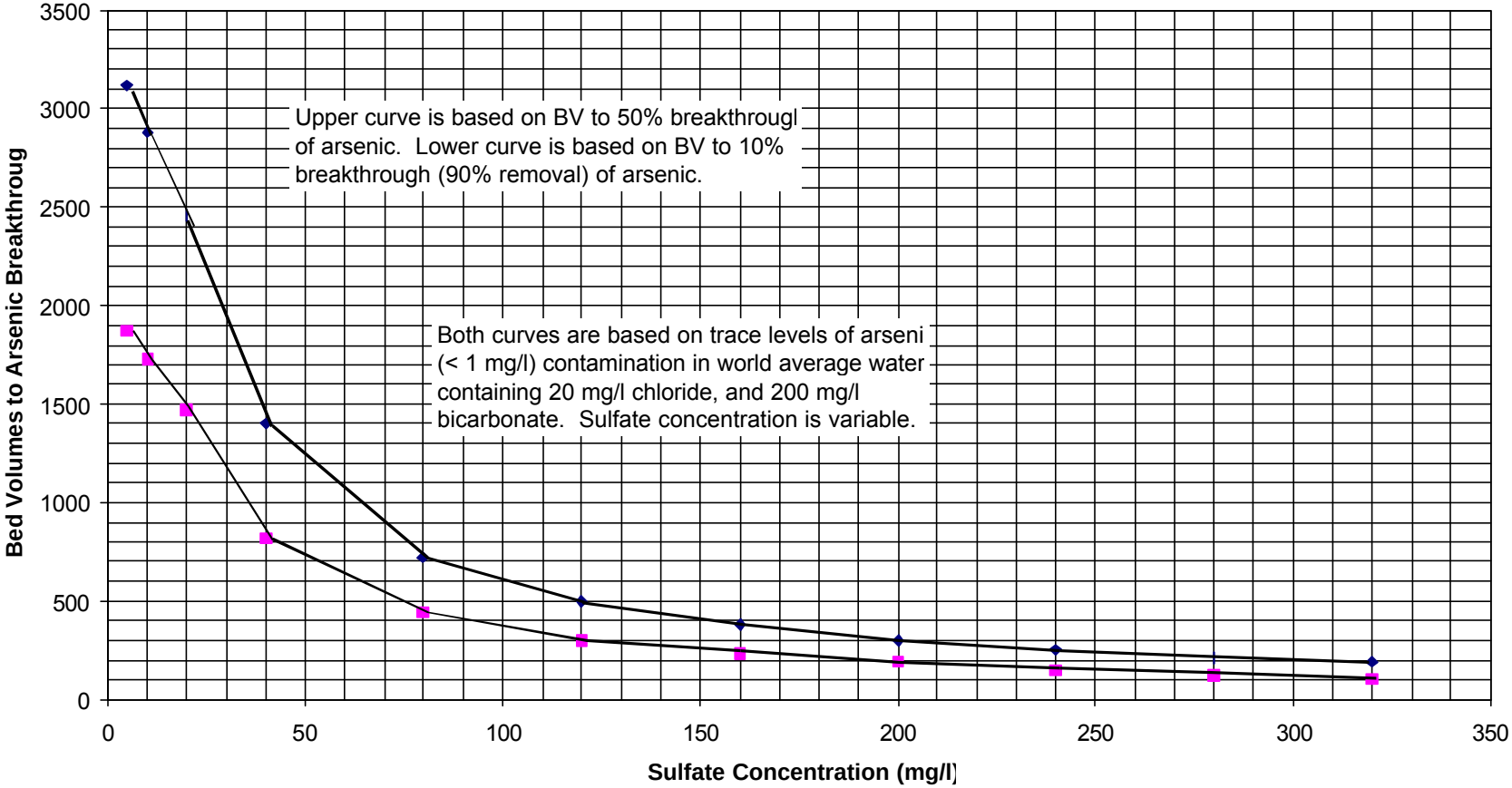


Figure 3-16
Anion Exchange (< 20 mg/L SO4)
Capital Costs

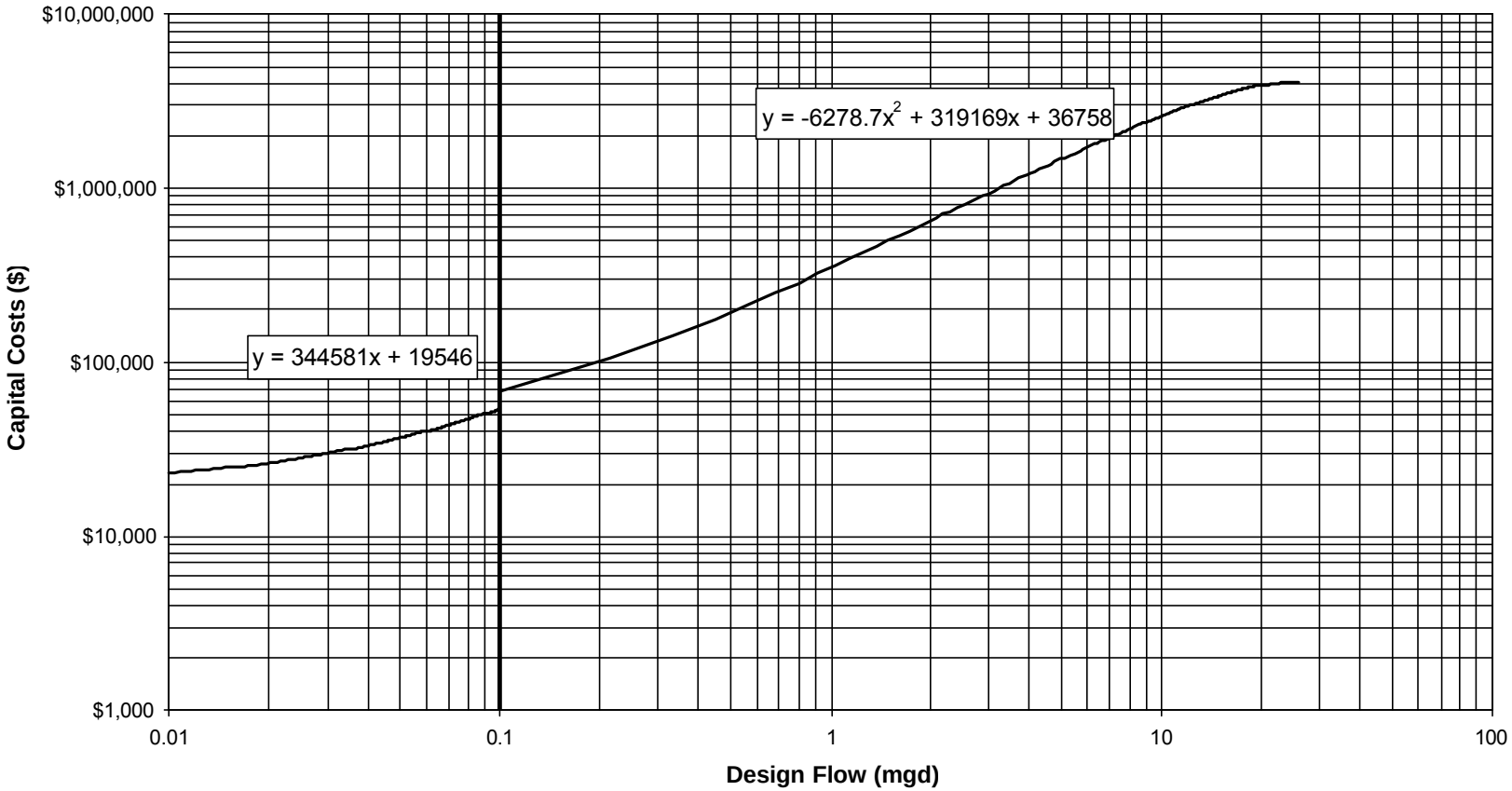


Figure 3-17
Anion Exchange (< 20 mg/L SO4)
O&M Costs

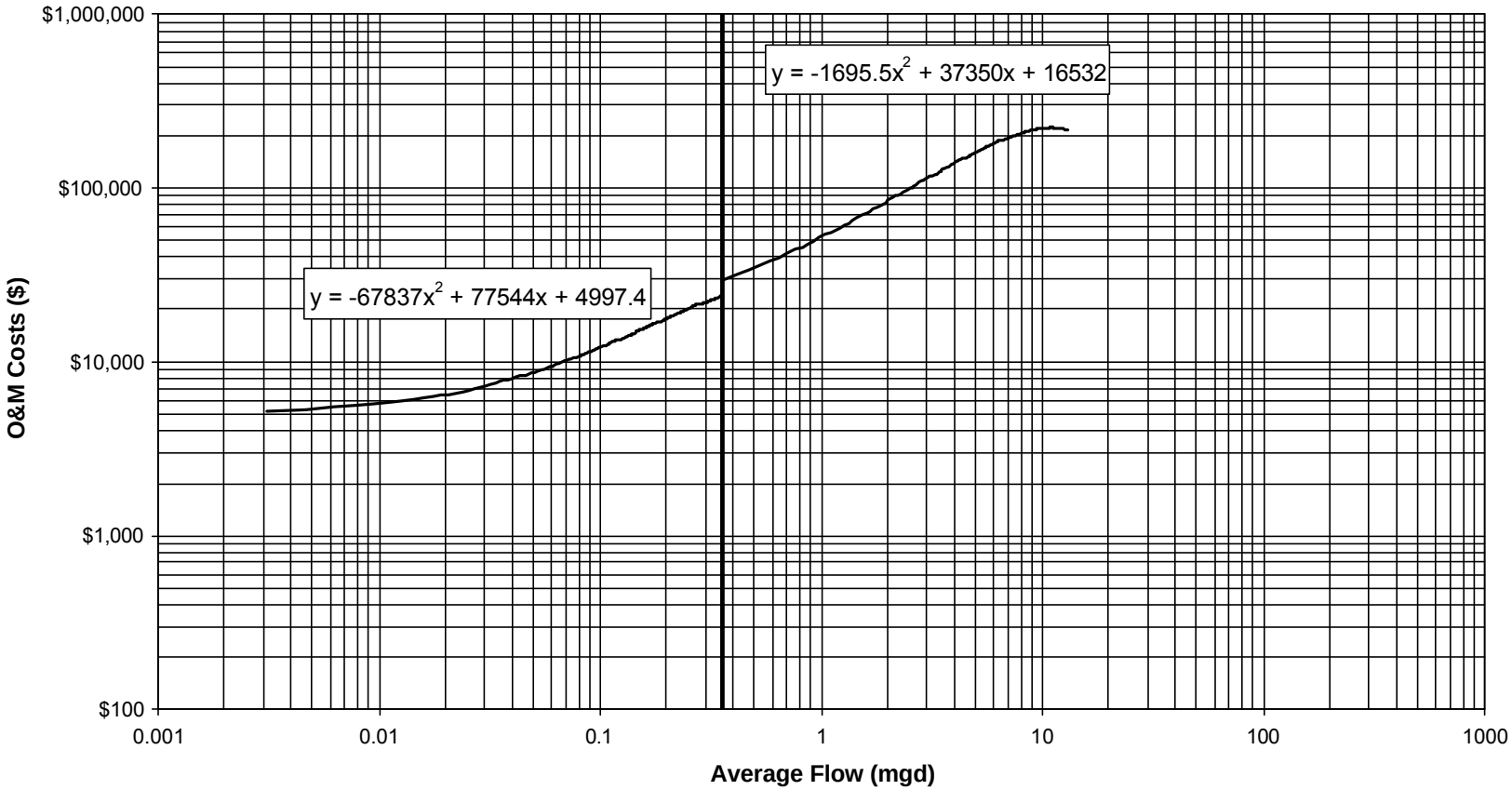


Figure 3-18
Anion Exchange (20-50 mg/L SO4)
Capital Costs

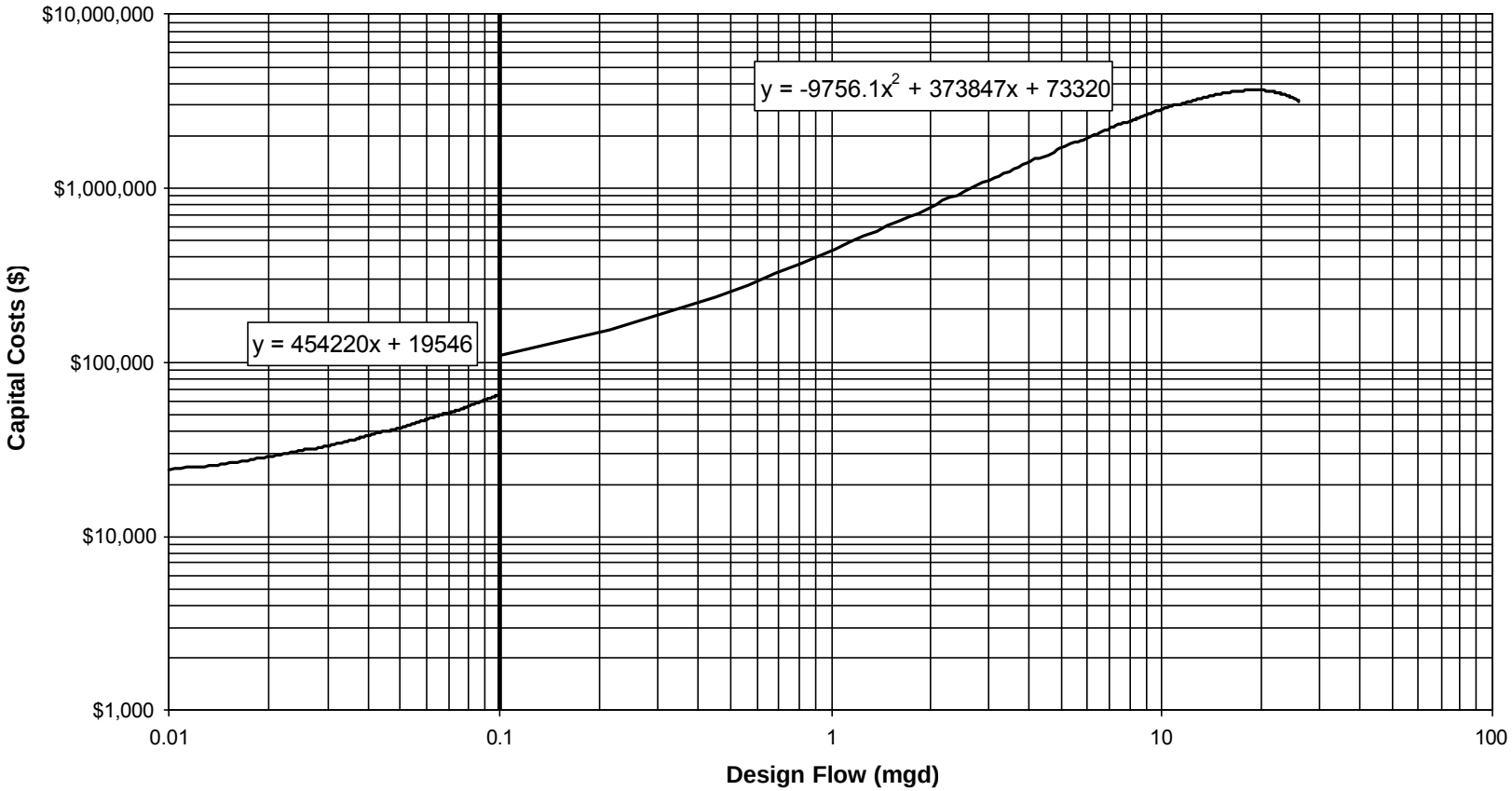


Figure 3-19
Anion Exchange (20-50 mg/L SO4)
O&M Costs

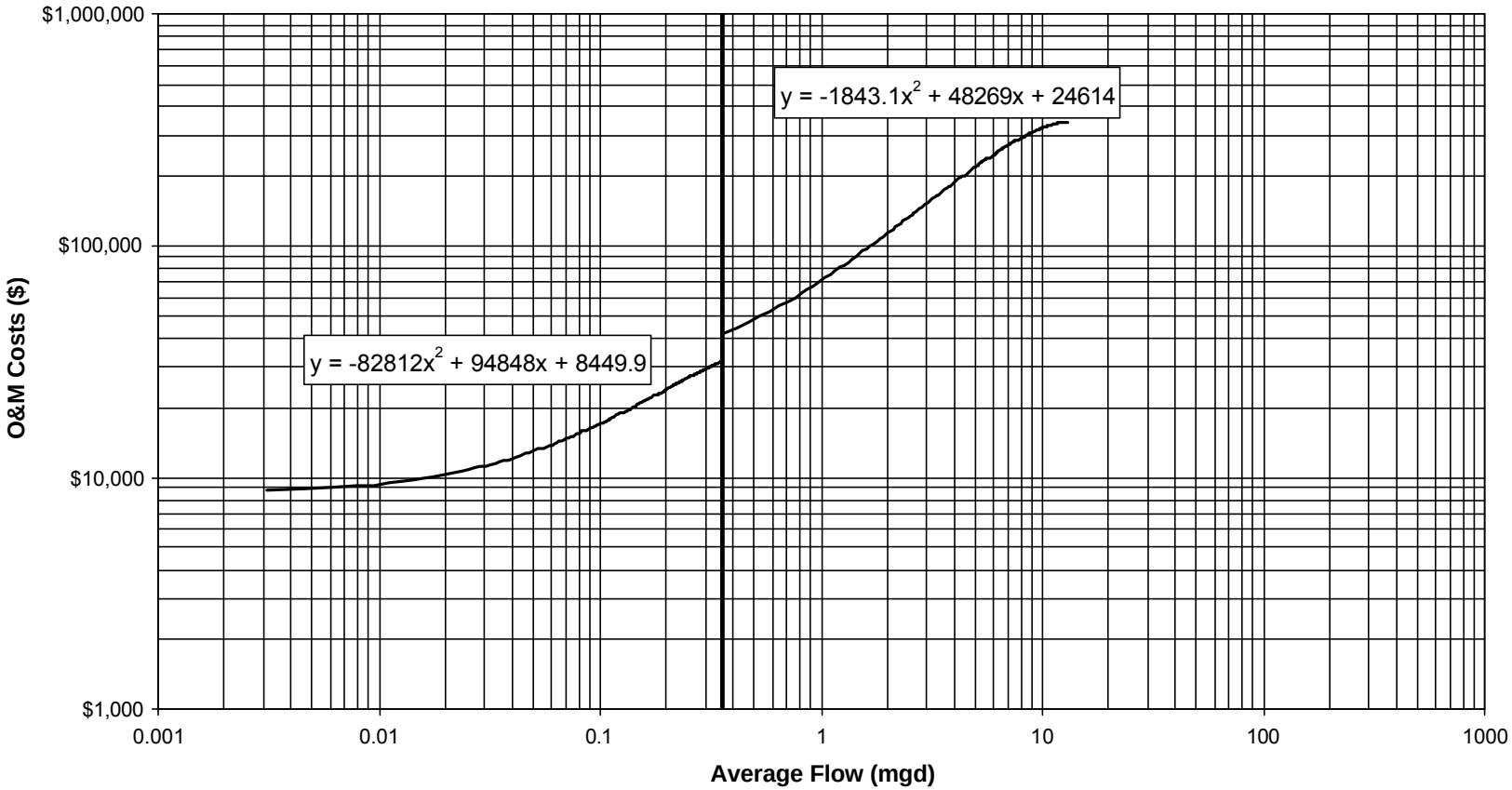


Figure 3-20
Greensand Filtration
Capital Costs

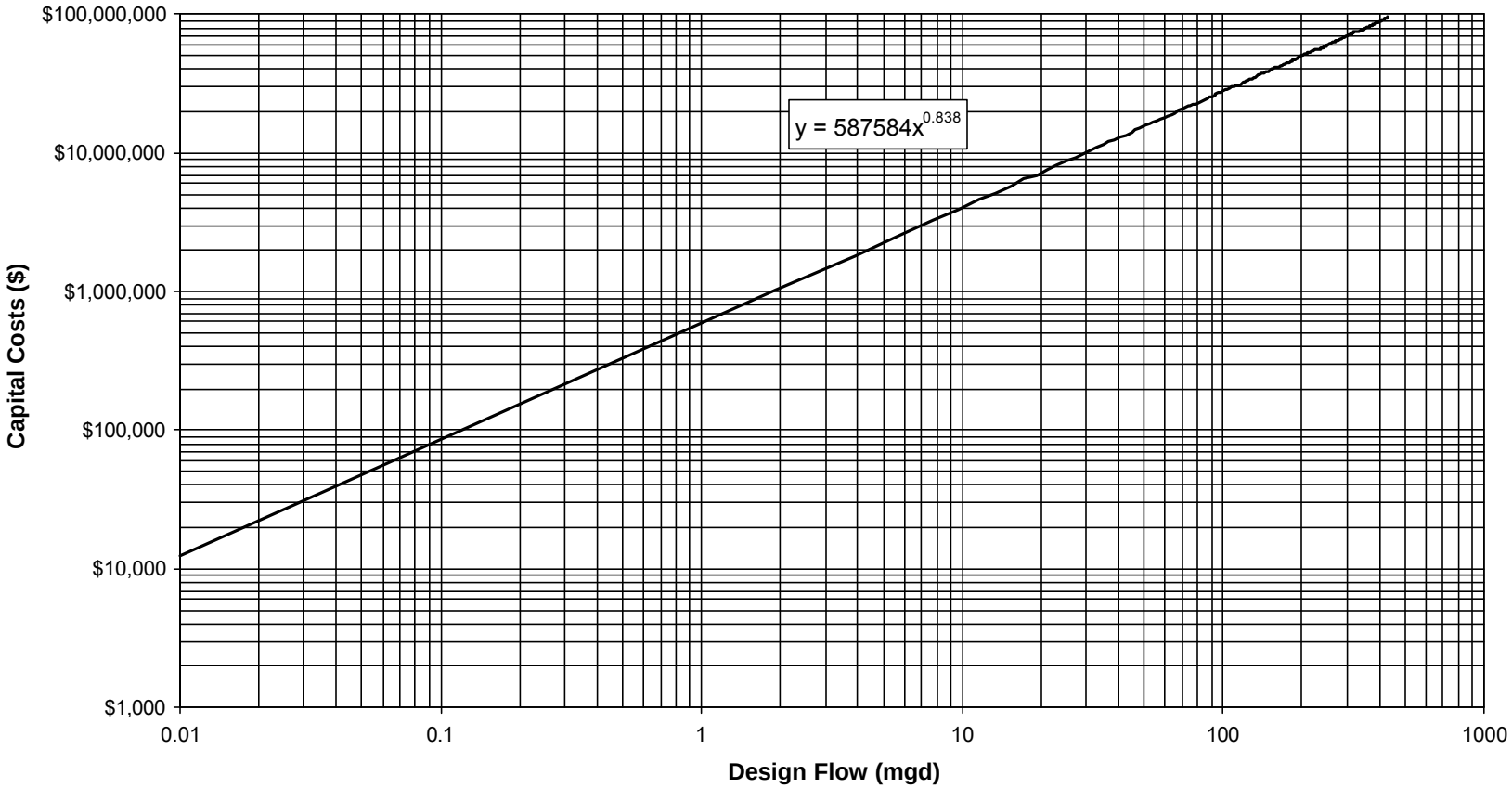


Figure 3-21
Greensand Filtration
O&M Costs

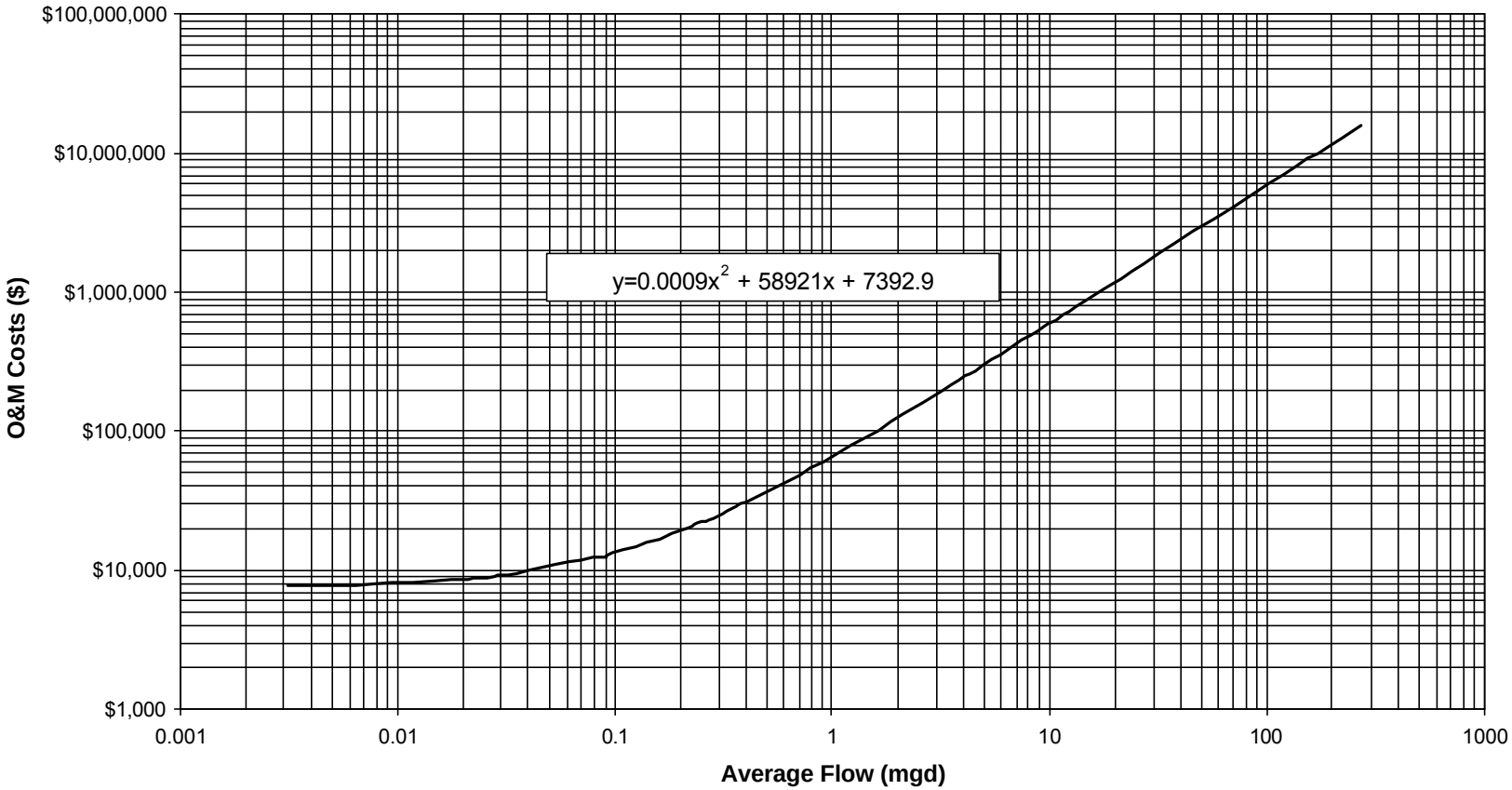


Figure 4-1
Anion Exchange (< 20 mg/L SO4)
Waste Disposal Capital Costs

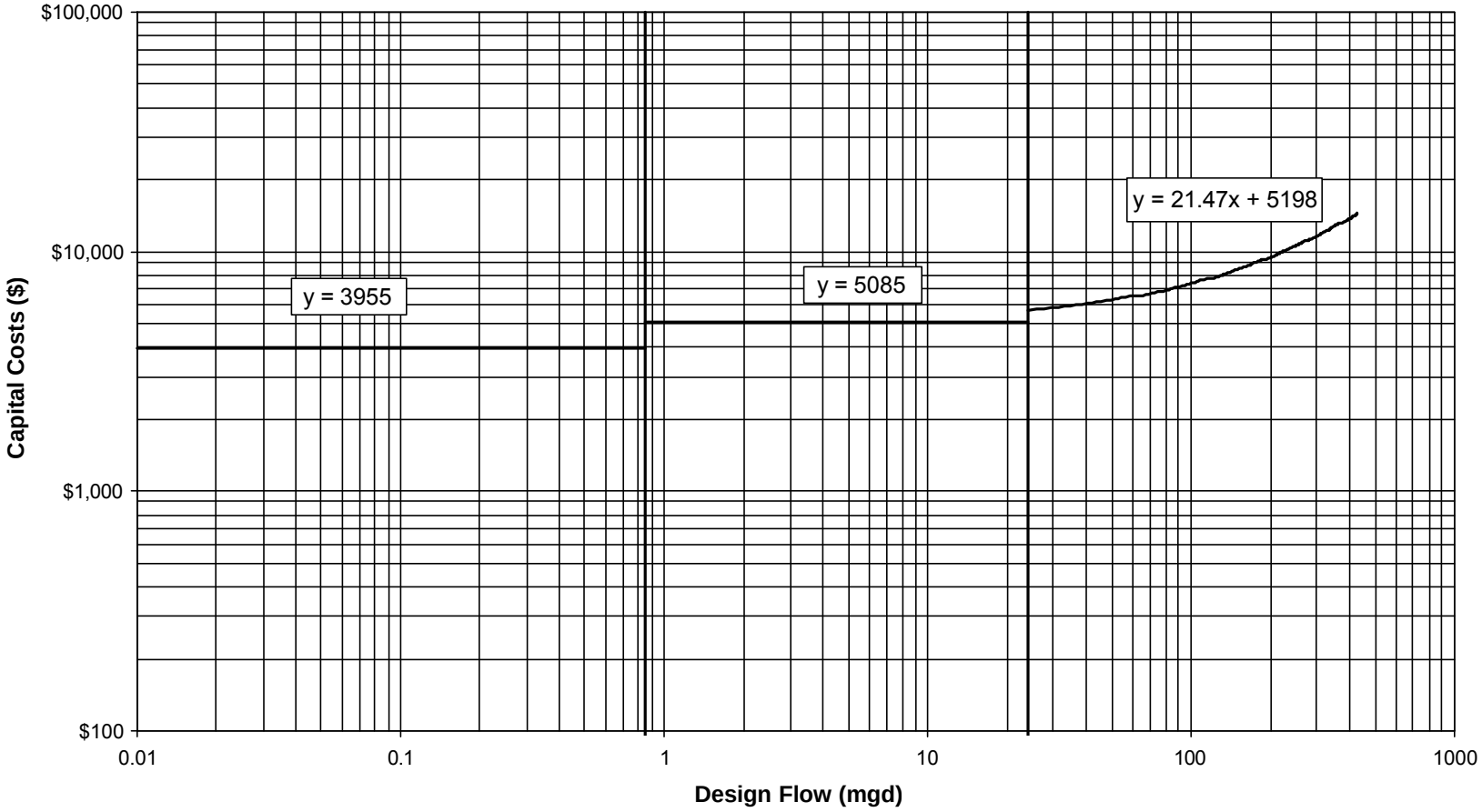


Figure 4-2
Anion Exchange (< 20 mg/L SO4)
Waste Disposal O&M Costs

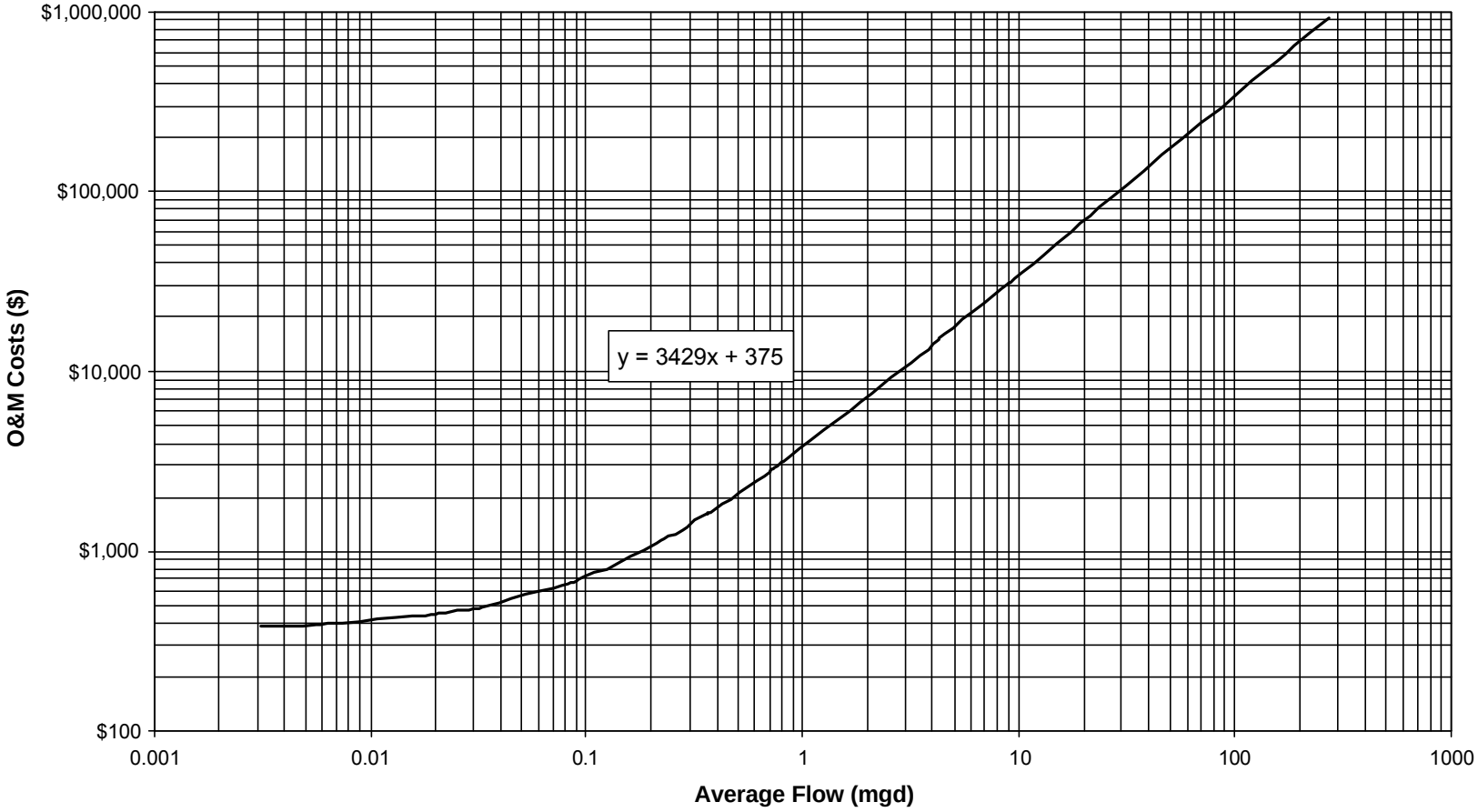


Figure 4-3
Anion Exchange (20-50 mg/L SO4)
Waste Disposal Capital Costs

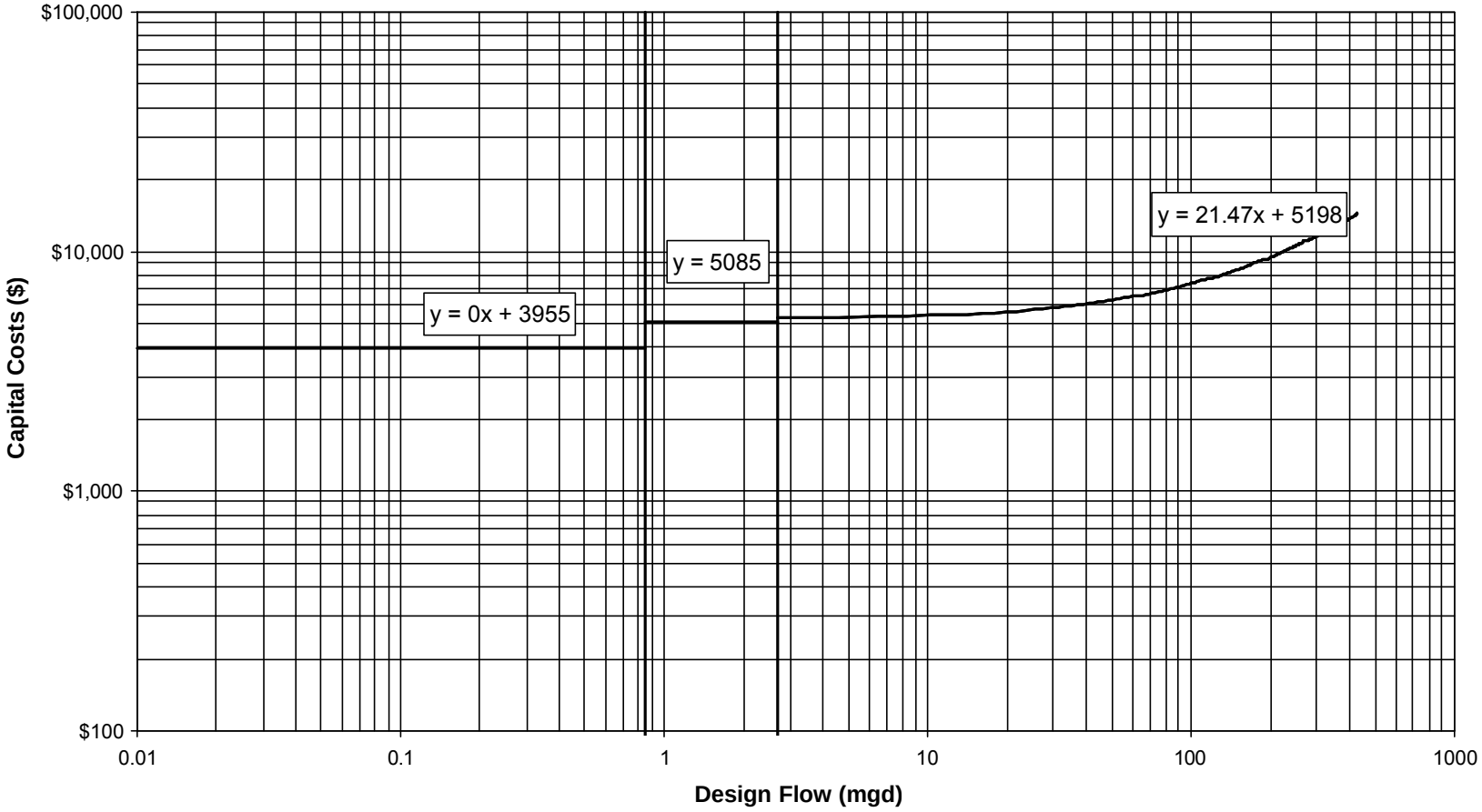


Figure 4-4
Anion Exchange (20-50 mg/L SO4)
Waste Disposal O&M Costs

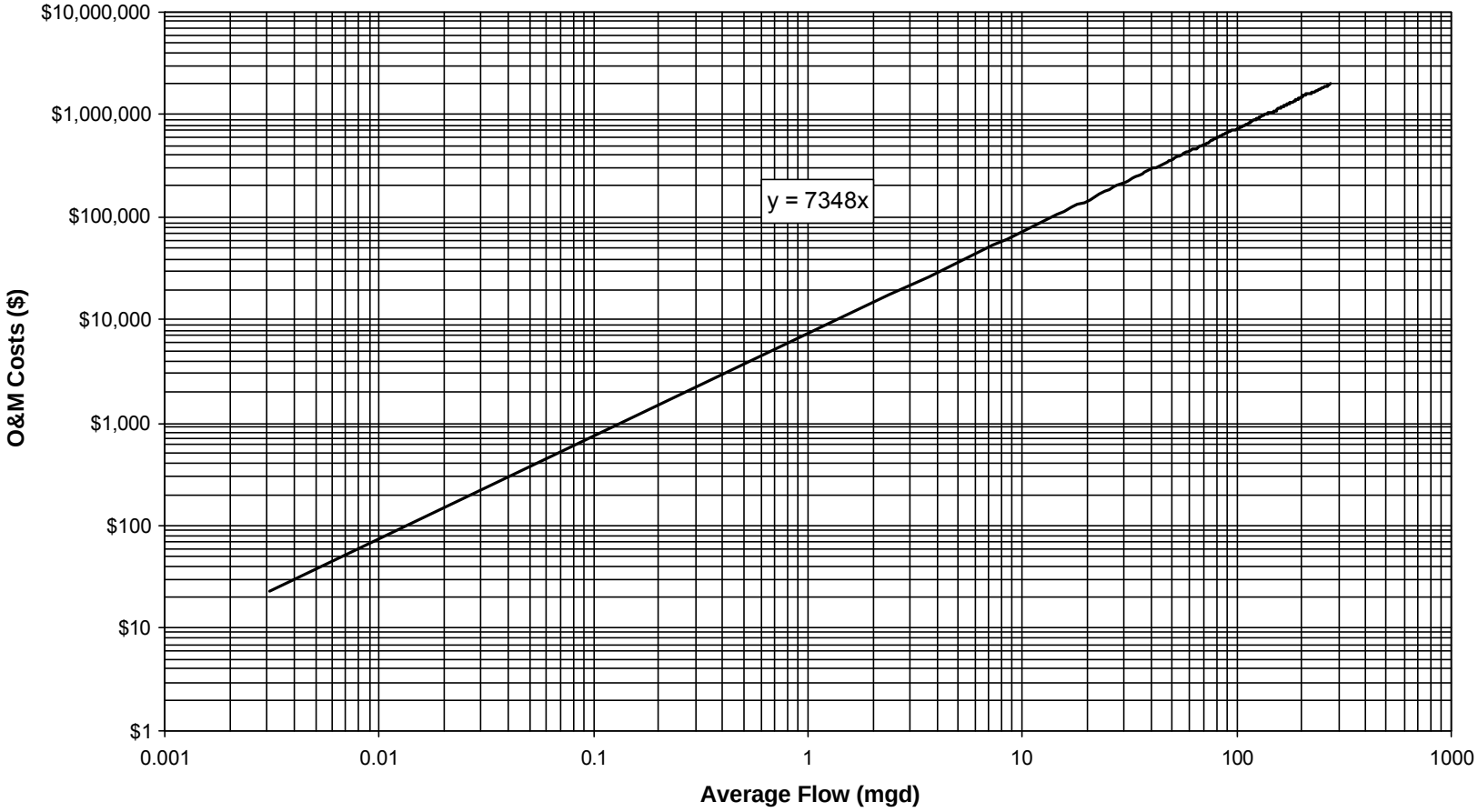


Figure 4-5
Coagulation Assisted Microfiltration (Mechanical)
Waste Disposal Capital Costs

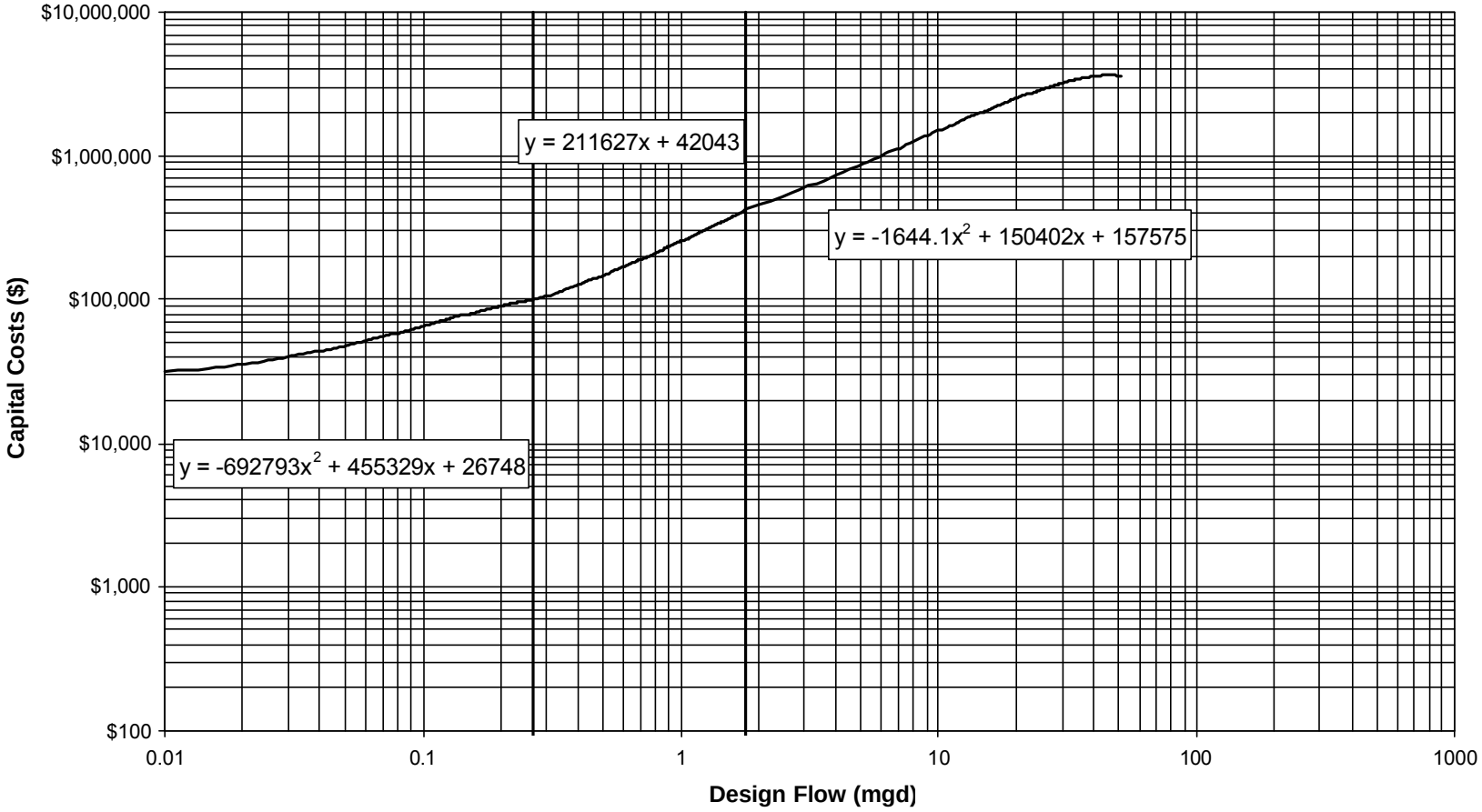


Figure 4-6
Coagulation Assisted Microfiltration (Mechanical)
Waste Disposal O&M Costs

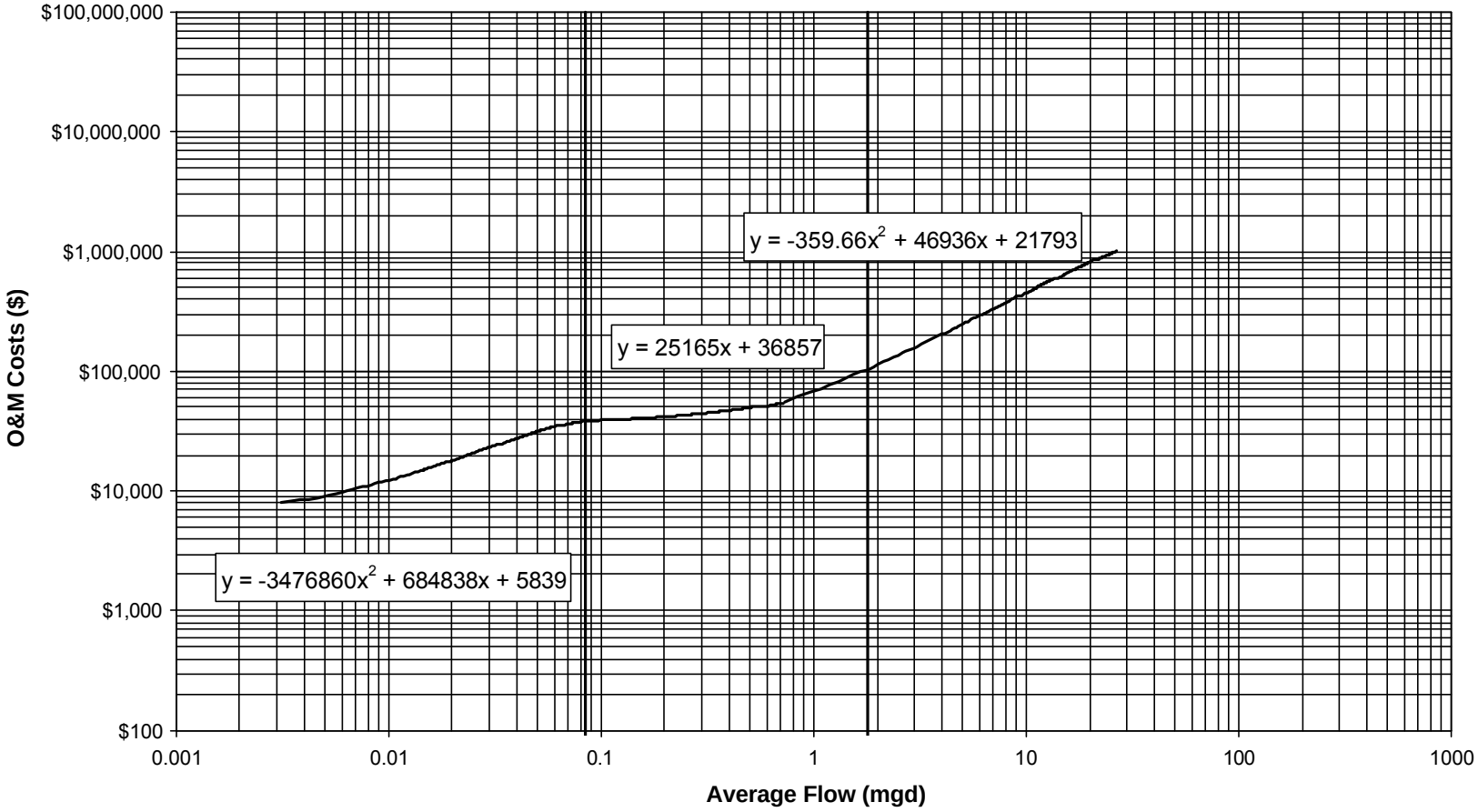


Figure 4-7
Coagulation Assisted Microfiltration (non-mechanical)
Waste Disposal Capital Costs

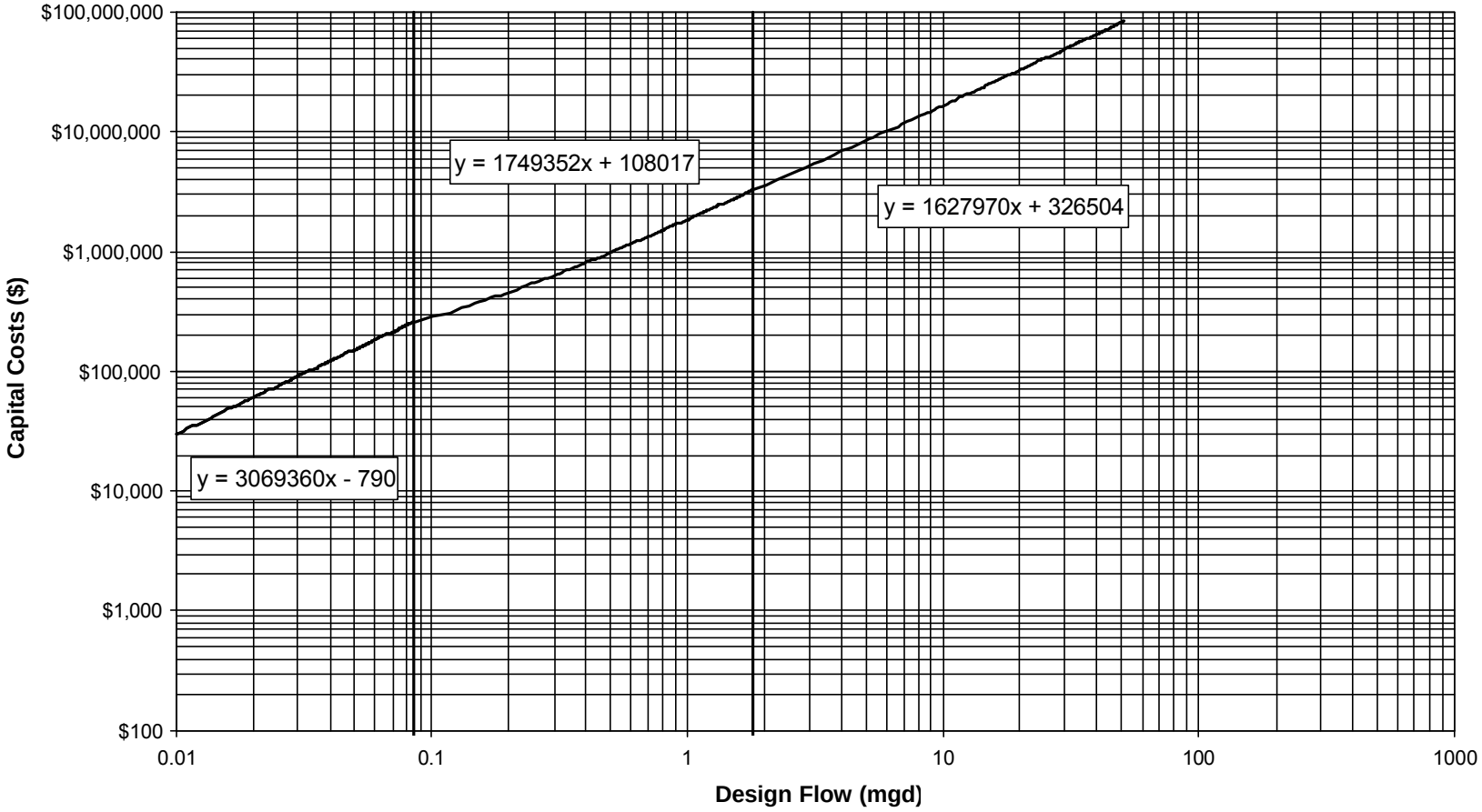


Figure 4-8
Coagulation Assisted Microfiltration (non-mechanical)
Waste Disposal O&M Costs

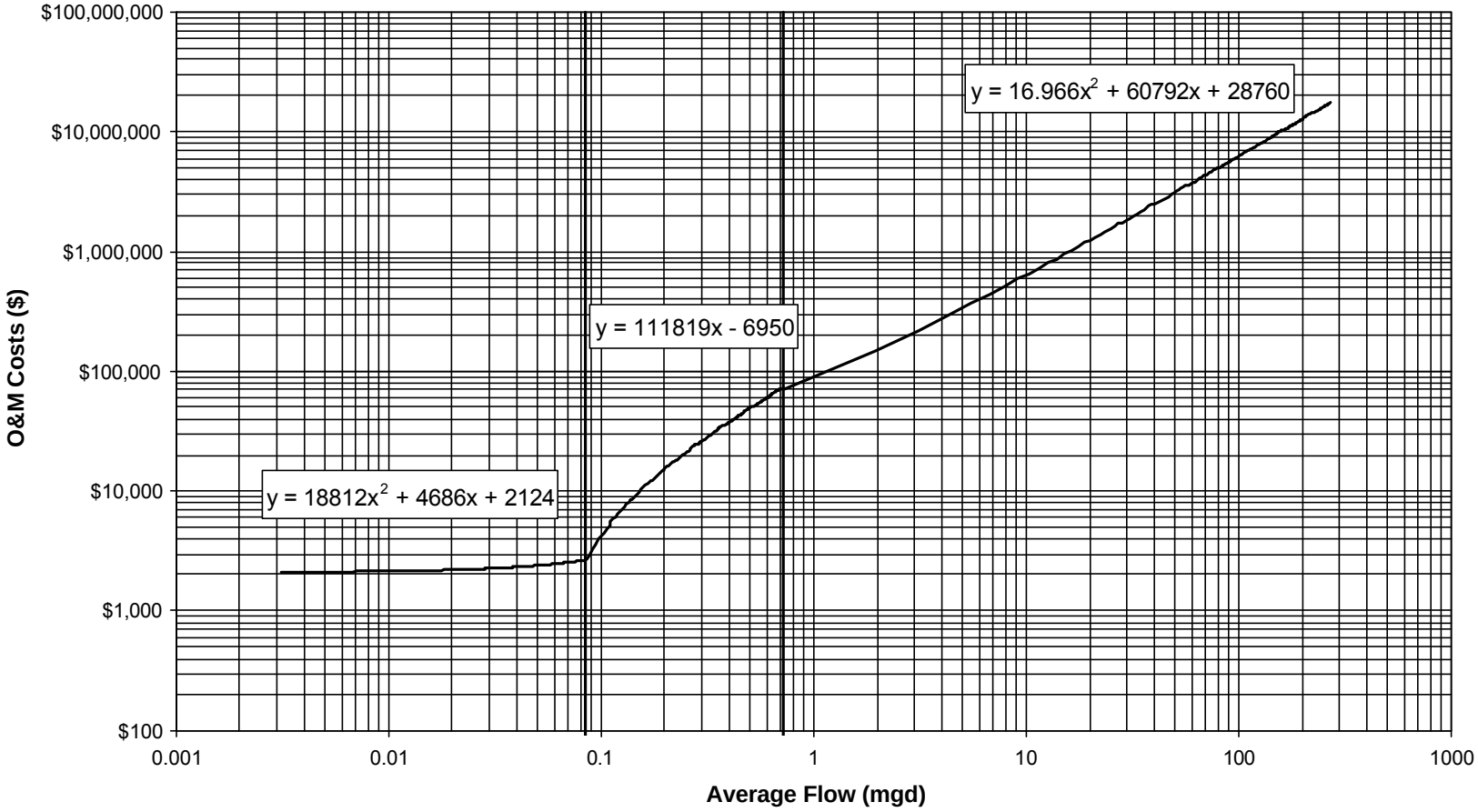


Figure 4-9
Activated Alumina (pH 7 - 8)
Waste Disposal O&M Costs

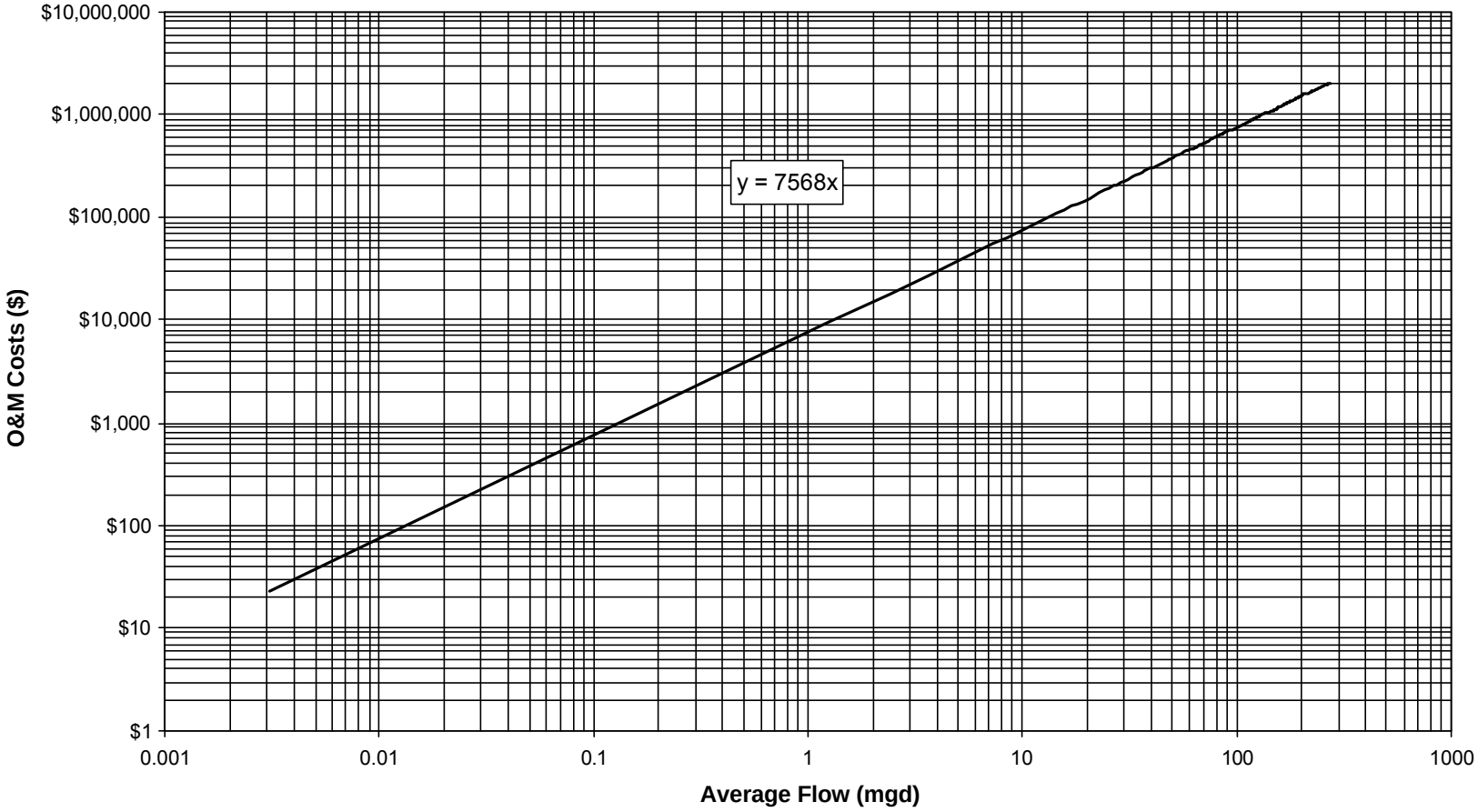


Figure 4-10
Activated Alumina (pH 8 - 8.3)
Waste Disposal O&M Costs

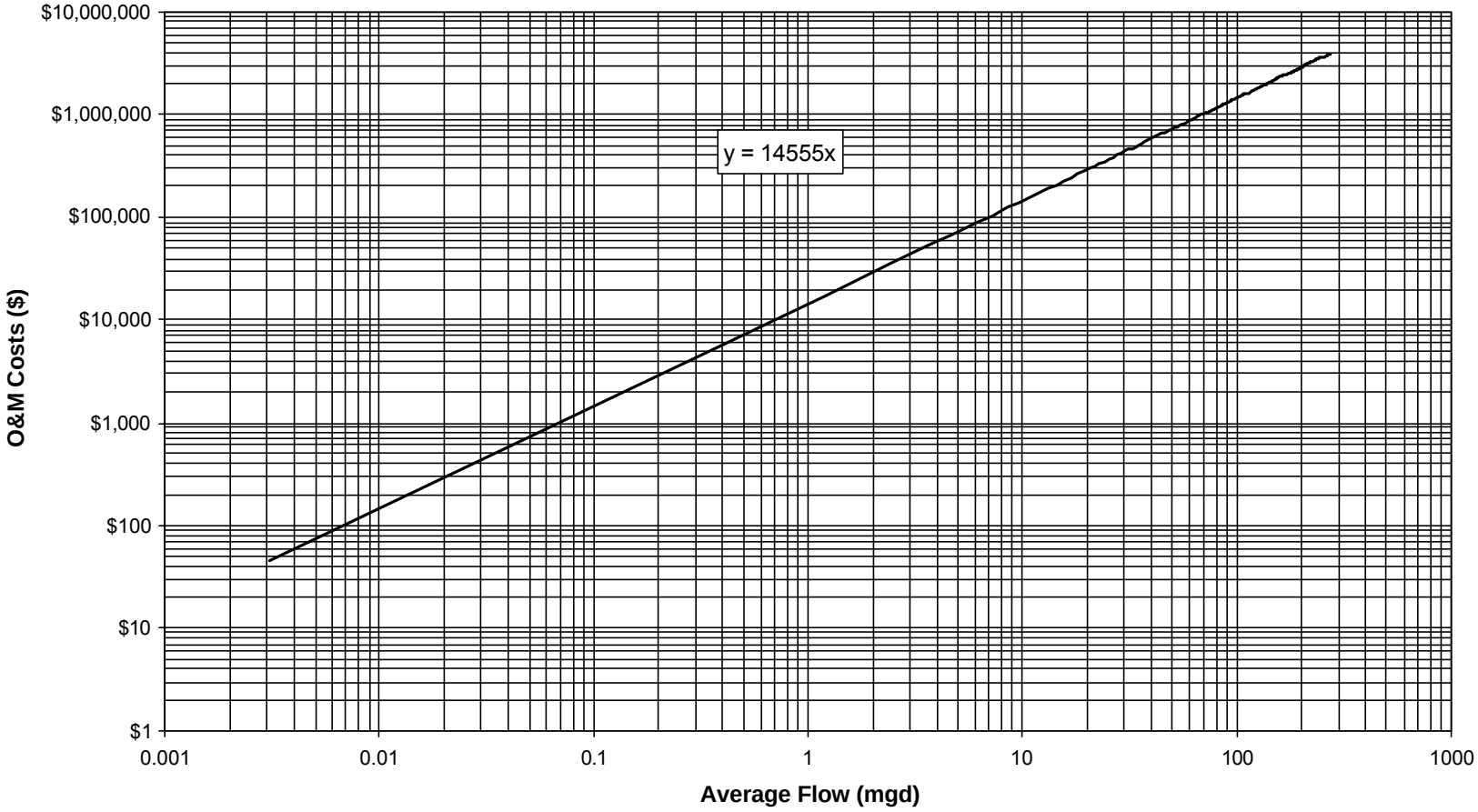


Figure 4-11
Activated Alumina (pH Adjusted to 6.0, 23,100 BV)
Waste Disposal O&M Costs

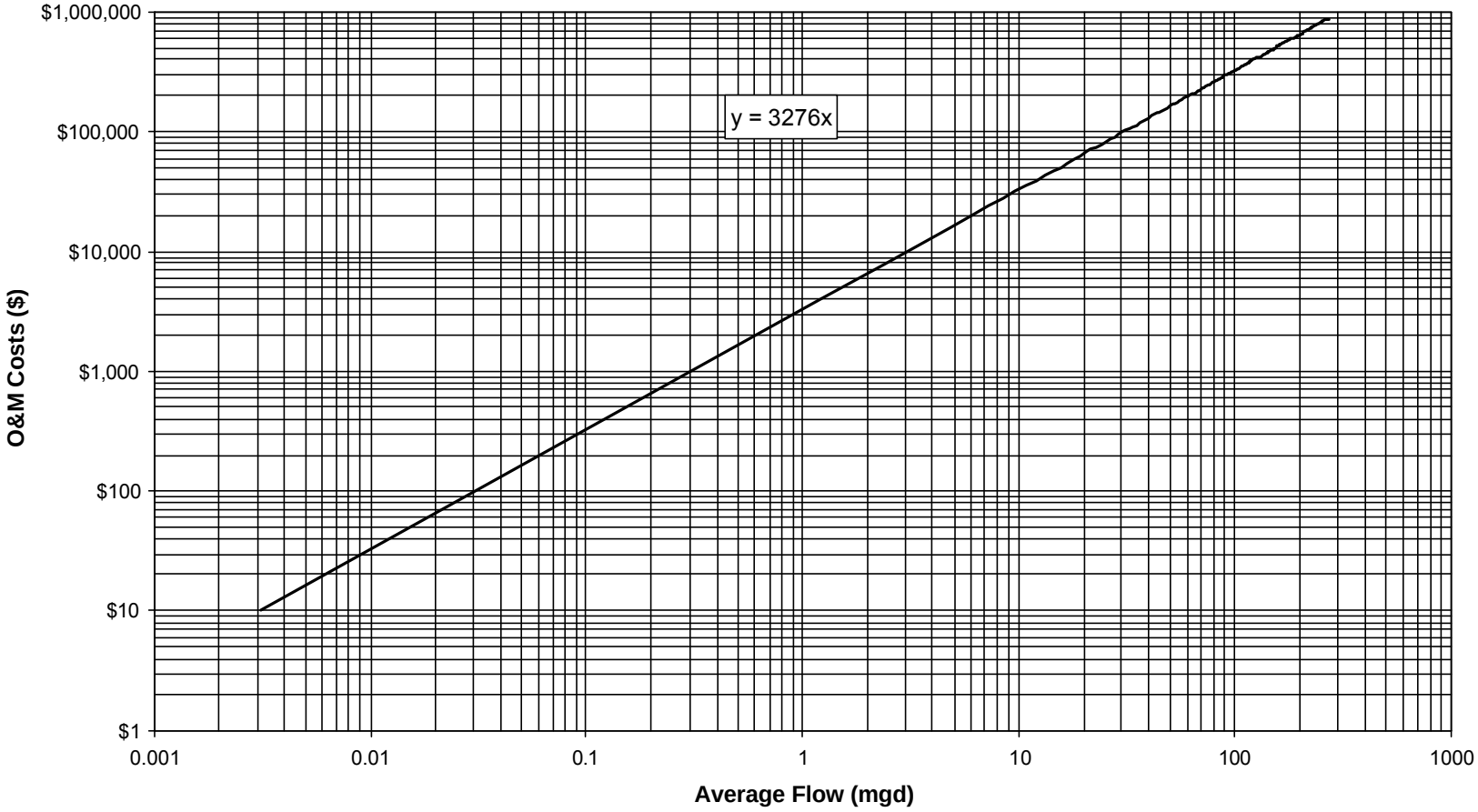


Figure 4-12
Activated Alumina (pH Adjusted to 6.0, 15,400 BV)
Waste Disposal O&M Costs

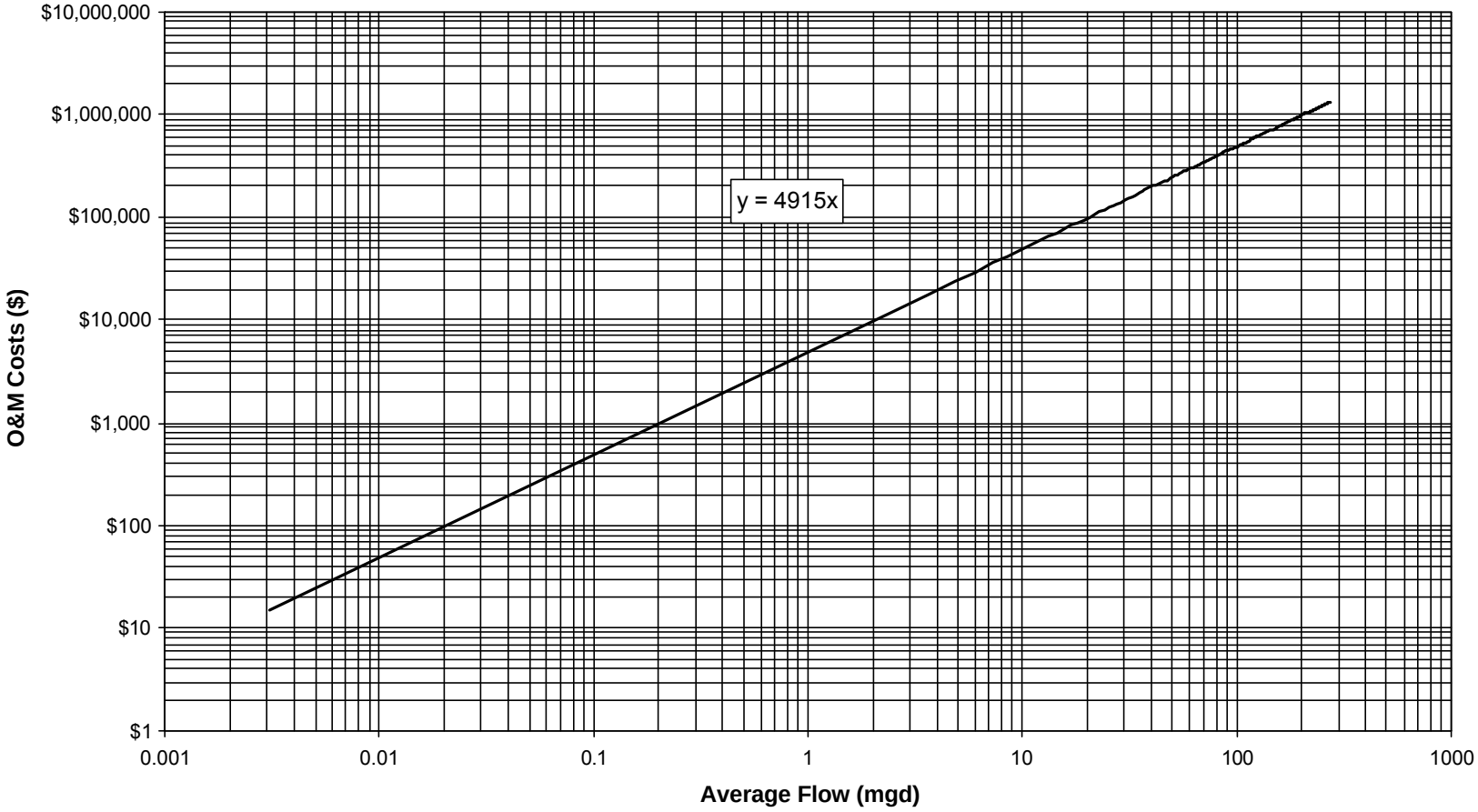


Figure 4-13
Greensand Filtration
Waste Disposal Capital Costs

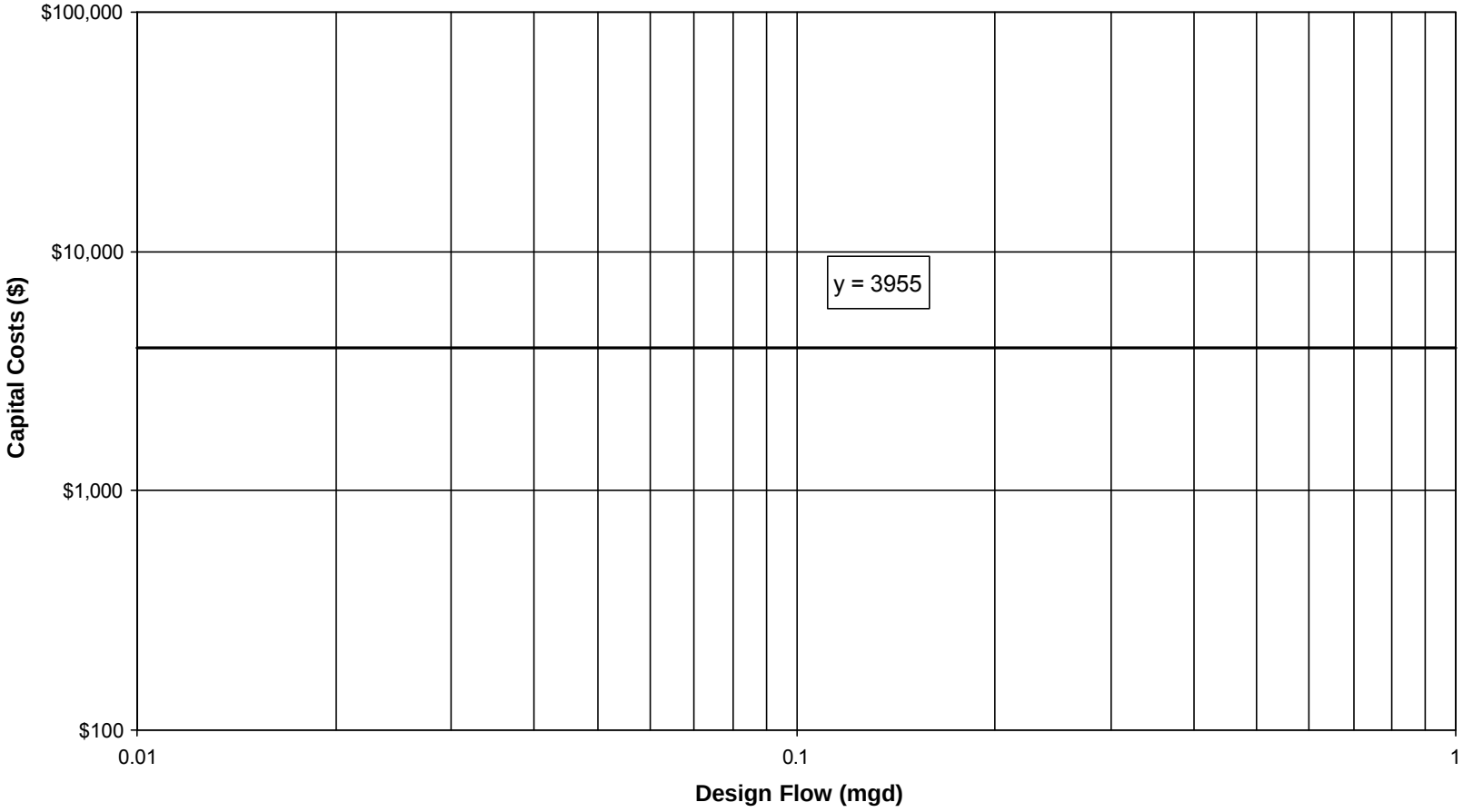


Figure 4-14
Greensand Filtration
Waste Disposal O&M Costs

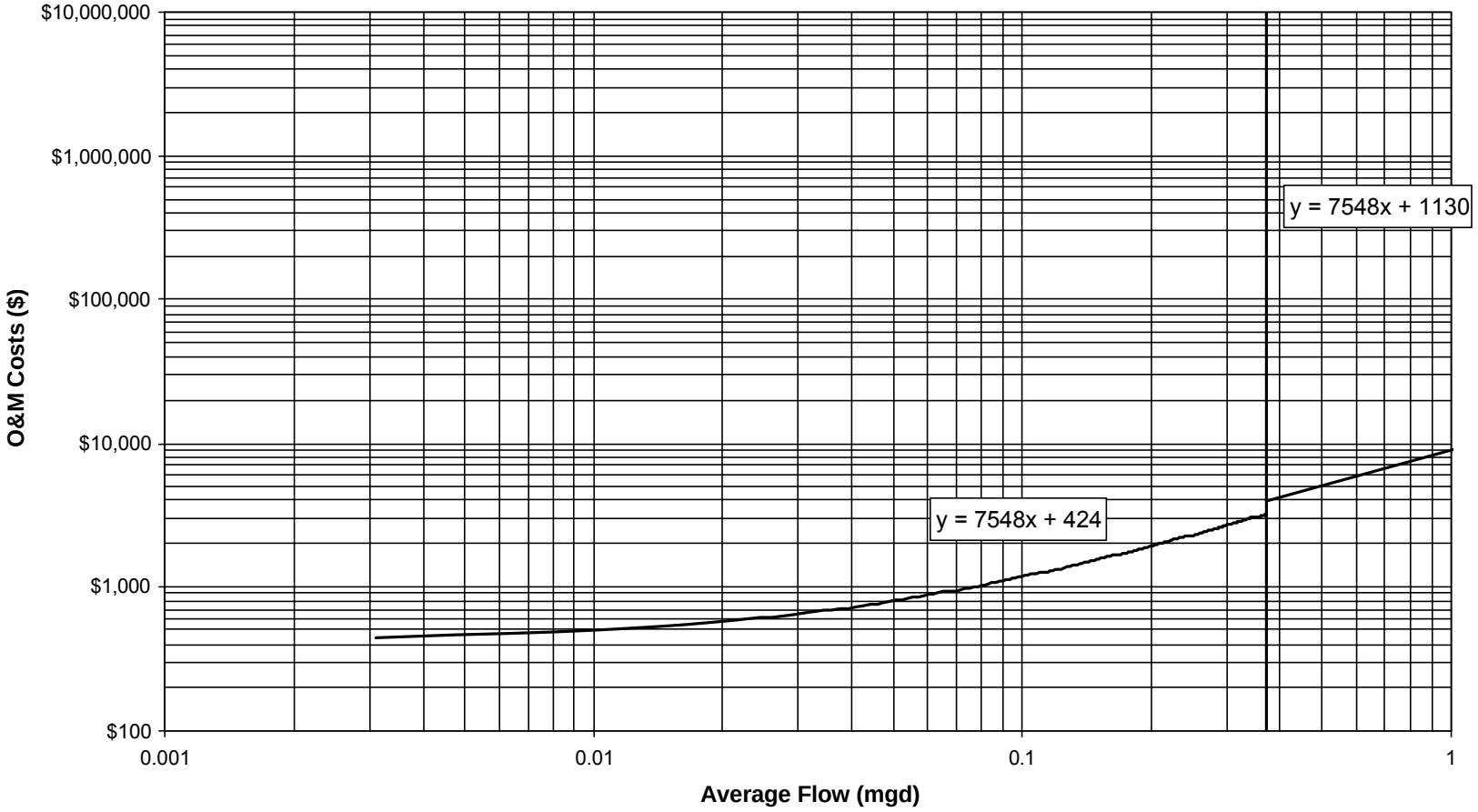


Figure 5-1
POU Reverse Osmosis
Total Capital Costs

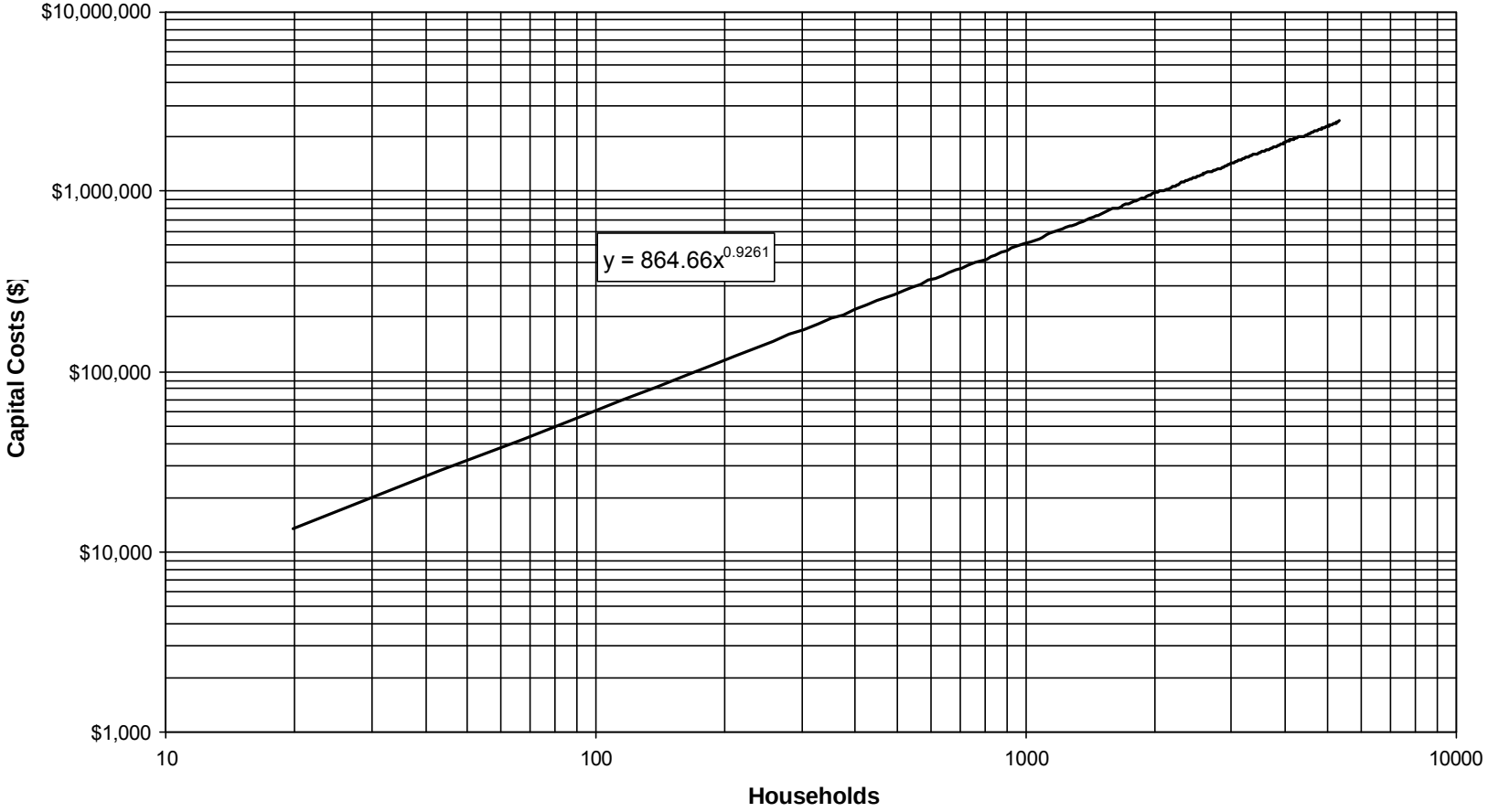


Figure 5-2
POU Reverse Osmosis
O&M Costs

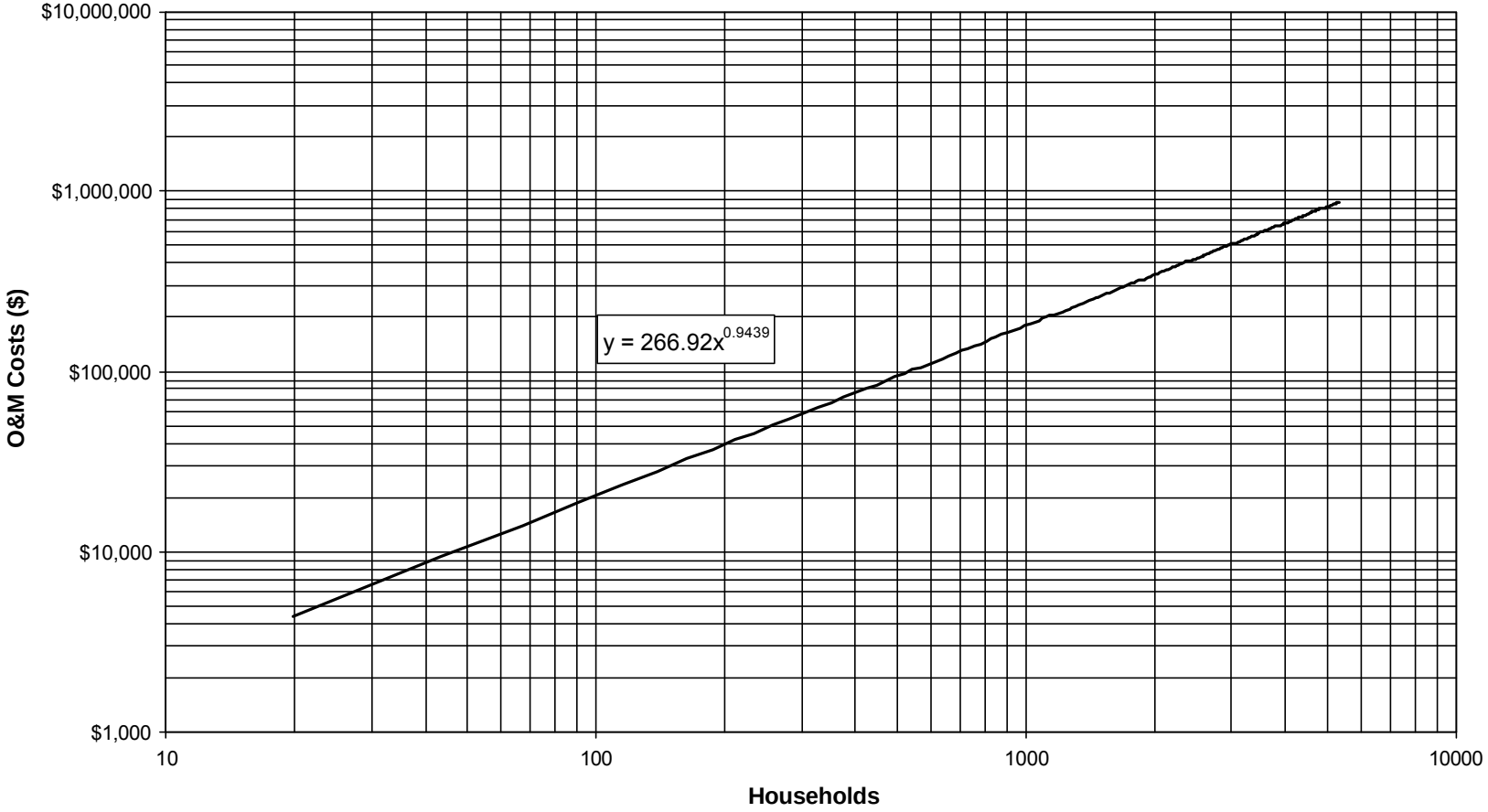


Figure 5-3
POU Activated Alumina
Total Capital Costs

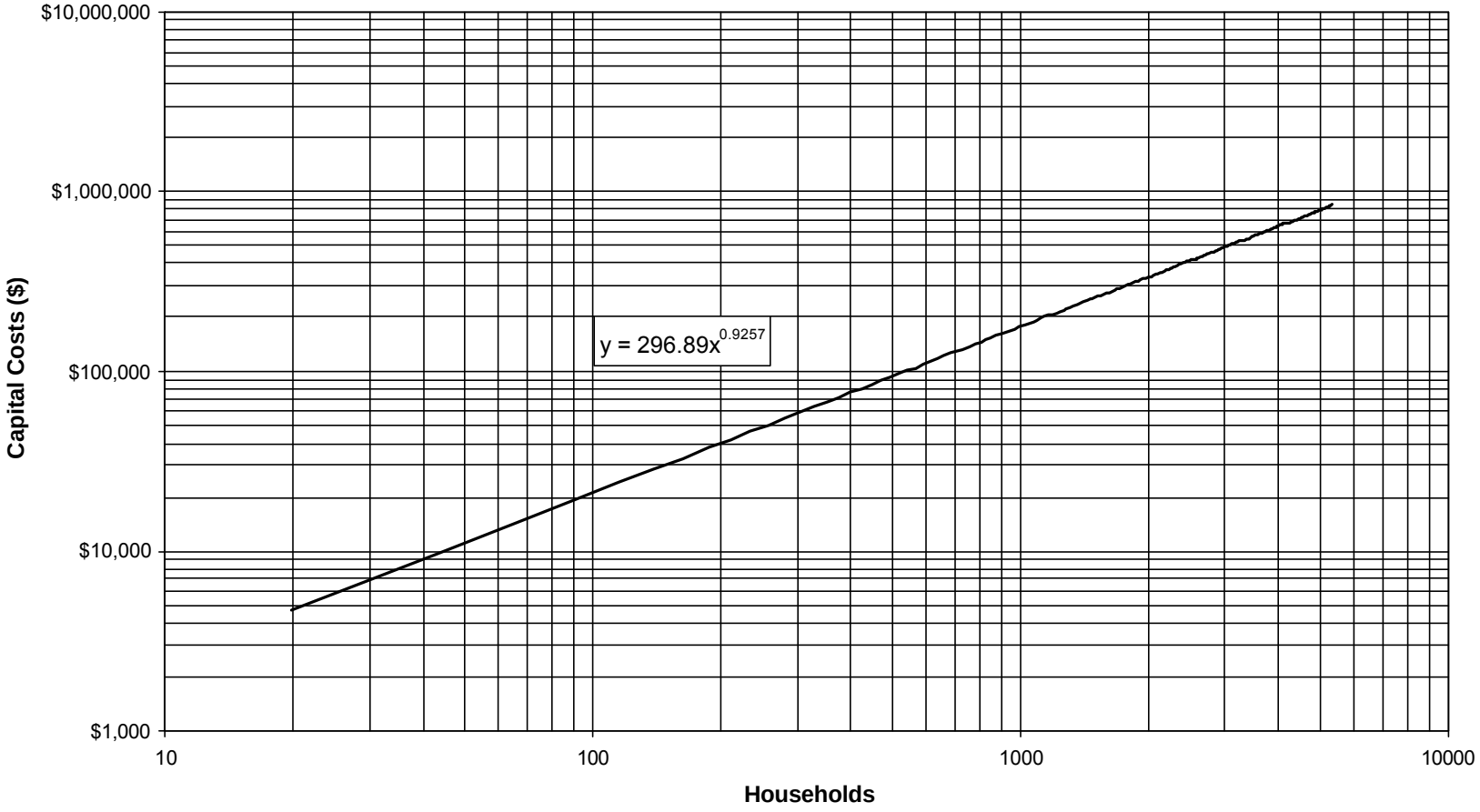
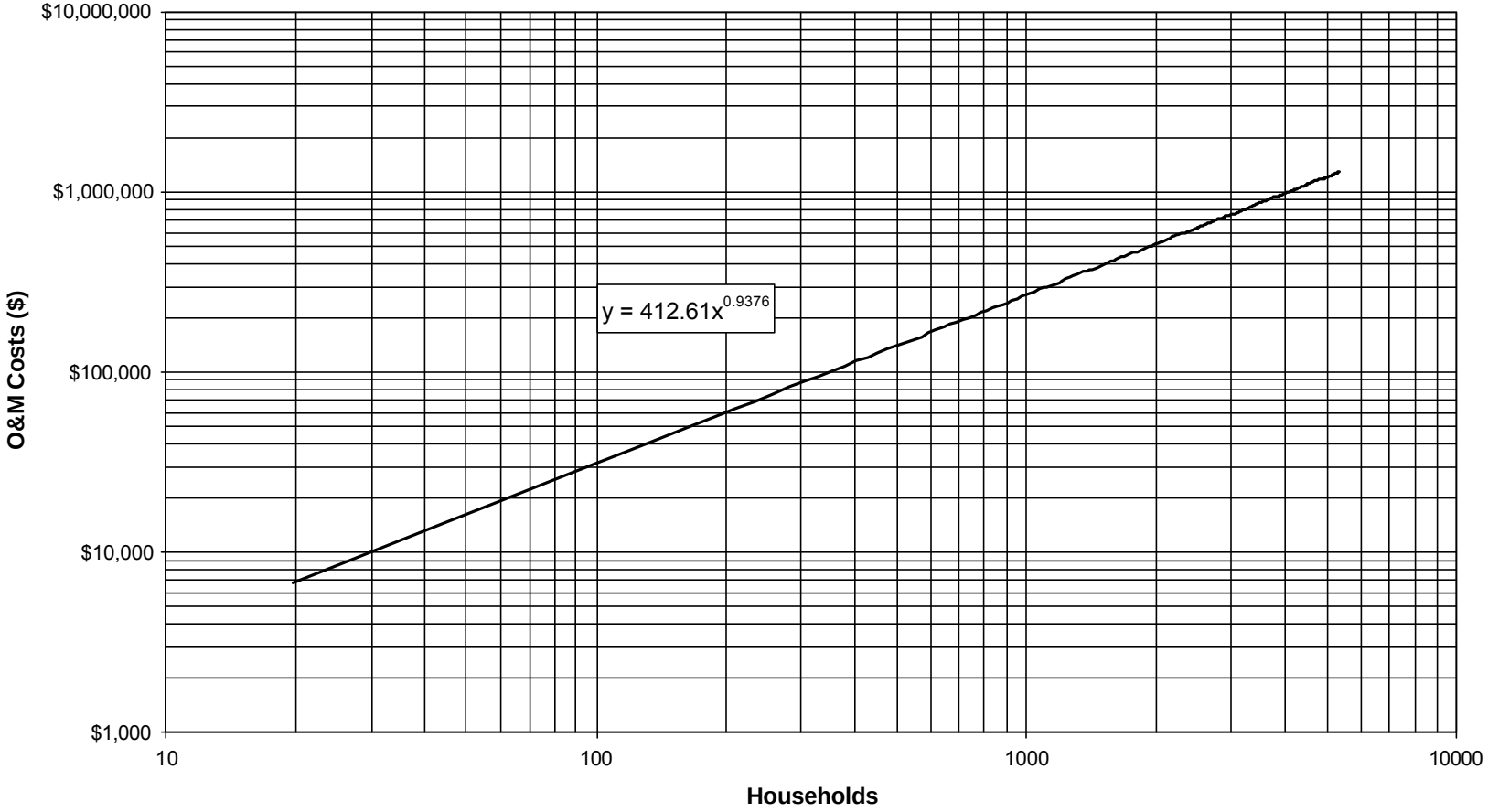


Figure 5-4
POU Activated Alumina
O&M Costs



SALT RIVER PIMA MARICOPA INDIAN COMMUNITY

ZONE 2 ARSENIC TREATMENT

FINAL

December 2006

SALT RIVER PIMA MARICOPA INDIAN COMMUNITY

ZONE 2 ARSENIC TREATMENT

TECHNICAL MEMORANDUM
NO. 1

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1.0 BACKGROUND

Salt River Pima Maricopa Indian Community (SRPMIC) is in the process of designing and constructing a central pump station and reservoir at the Zone 2 water production facilities. This facility will be supplied by several groundwater wells. Based on the initial well test data and projected water quality, it is anticipated that these wells will exceed the Environmental Protection Agency's arsenic maximum contaminant level (MCL) of 10 parts per billion (ppb), and will require treatment. The Community has retained Carollo/NCS team to provide an independent perspective on arsenic treatment issues, costs, and technologies for this project. This technical memorandum (TM) presents a discussion on the available treatment technologies for arsenic treatment, along with the key design, operating, environmental, and cost issues.

2.0 SYSTEM FLOWS AND ANTICIPATED WELL WATER QUALITY

The Community is planning for an initial well capacity of 5.3 million gallons per day (mgd) which will be expanded to ultimate capacity of 13 mgd under a phased approach. Multiple wells will feed this production facility. Initial samples from one of the representative wells indicated that the arsenic levels are in the range of 35 to 50 ppb. However, a more recent source approval sample showed an arsenic level of 20 ppb (sampled on 06/27/06 at Sampling Site ID SRPMIC-NS-62706). Based on a composite water quality projection made by the Community's hydrogeological consultant, arsenic levels in the range of 35-50 ppb are conservatively used for this evaluation. Other water quality parameters of concern for arsenic treatment are pH, silica, phosphorus, fluoride, vanadium, and nitrate. Based on the information available from the test bore and source water approval samples, pH, nitrate, fluoride, sulfate, and total alkalinity levels were 8.08, 0.95 mg-N/L, 1.2 mg/L, 26 mg/L, and 130 mg/L, respectively. No data is available on silica, phosphorus, and vanadium. Generally, in the East Valley area, the silica, phosphorus, and vanadium samples are in the range of 20-30 mg/L, 0.02-0.1 mg/L, and 20-30 ppb, respectively. These silica, phosphorus, and vanadium levels were assumed in this analysis. It is also noted that the arsenic levels observed at the Zone 2 wells are higher than generally observed in the East Valley. Other water quality parameters of concern are similar to East Valley water quality.

3.0 AVAILABLE ARSENIC TREATMENT TECHNOLOGIES

The primary arsenic removal technologies include adsorption, coagulation filtration (CF), coagulation microfiltration (CMF), and ion exchange (IX). Other innovative methods are also available, but they are generally some variation of the primary categories. Adsorption includes treatment using a special disposable or regenerable media that has effective

arsenic adsorption capabilities. CF treatment involves a pressurized granular media filtration process with iron addition beforehand. CF is a more complex process as compared to adsorption. CMF treatment utilizes a membrane filtration process with iron addition. Due to higher headloss through the membrane filter, re-pumping of the water is generally required. CMF is a more complex process as compared to CF. IX treatment includes arsenic adsorption on to resin-type media which requires regeneration using concentrated sodium chloride solution (brine). This is a very complex process as it involves pumps, storage of waste brine, and periodic discharge to onsite or offsite facilities.

Due to capital costs, complexity of the process, and waste handling considerations, CMF and IX are not deemed appropriate for this application. These technologies are more complex, use more chemicals, and are costlier than the CF and adsorption processes. Therefore, these technologies will not be considered further in this evaluation. This evaluation will focus on adsorption and CF treatment technologies and compare treatment costs, land requirements, operations, and waste handling aspects.

4.0 ADSORPTION TREATMENT PROCESS

The adsorption treatment process involves special adsorption media loaded in pressure vessels and the water is passed in the downward direction. Arsenic from the water is adsorbed on to the media and is removed. Adsorption media can remove arsenic to very low levels which may allow partial treatment of the entire flow. Partial flow treatment becomes feasible if the influent arsenic concentrations are less than 18 ppb. However, at concentrations more than 18 ppb, treatment of entire well flow is necessary, which will be applicable to the wells feeding this production facility. Adsorption media have a finite capacity for arsenic removal. When the arsenic removal capacity is exhausted, the spent media must be replaced with fresh or regenerated media. Media can be either used on a throw-away basis or can be regenerated at an off-site facility. Spent media is disposed as a non-hazardous waste at a landfill and meets Resource Conservation Recovery Act (RCRA) requirements for solid waste disposal. Media run length is primarily based on two factors. These factors are 1) well water quality; and 2) treatment flow. If the background concentrations of certain water quality parameters such as pH, silica, phosphorus, fluoride, and vanadium are high, the media run lengths are adversely impacted. A detailed description of the adsorption process is presented in Appendix A. A comparison of series vs. parallel adsorption system is also presented in Appendix A.

The most critical decision involved in an adsorption system is the media selection which impacts replacement frequency and O&M costs. There are various media commercially-available and most of the media have similar adsorption capacities for arsenic. The media could be either a throw-away media or regenerable. Obviously, more frequent media changeout would result in high O&M costs. The initial batch of the regenerable media is generally more expensive than throw-away media. However, costs of media regeneration are generally half the cost of throw-away media. Therefore, for an application where

frequent media changeout is a concern, regenerable media appears more economical, by approximately 30 percent. After the regenerable media has reached its capacity for arsenic removal, the media is removed from the vessel by the media vendor and transported to an off-site central regeneration facility. The regenerated media is installed in the vessel by the vendor for further application. As:X is one such commercially-available media which is an iron composite media made by Solmetex. Depending on the frequency of regeneration and media volume, an additional batch of media may be required to avoid interruption in operation during regeneration.

A typical 5.3 mgd adsorption system in parallel configuration would include five 12-foot diameter treatment vessels, a prefiltration system, one 30-ton carbon dioxide feed system, a caustic feed system, one 60,000 gallon backwash equalization tank, and a backwash pump station. If pH reduction is not used, the caustic soda & CO_2 systems would not be required. If a series system were to be provided, ten 12-foot diameter vessels would be required which would substantially increase the capital costs.

Based on our previous experience at similar facilities, it is anticipated that the media will last approximately 50,000 bed volumes at pH of 7.0. This corresponds to approximately seven (7) months of operation at a 50 percent well utilization rate. However, if pH adjustment is not provided, the media will last for approximately 20,000 bed volumes, which corresponds to approximately three months of operation at 50 percent utilization. The capital and annual O&M costs with pH adjustment would be $4.4M and $421,000, respectively. The capital and annual O&M costs without pH adjustment would be $3.7M and $687,000, respectively. The carbon dioxide and sodium hydroxide delivery frequencies will be approximately once every two weeks and would require some level of operator expertise to operate and maintain the feed systems. Figure 1 presents a typical schematic of such a facility. The land requirements for this facility would be 100 ft by 75 ft. The approximate capital costs of a series adsorption system with ten vessels and pH adjustment is estimated to be $6.2M.

For future expansion, the facility can be expanded in the modules of 5.3 mgd each. For example, for expansion up to 10 mgd, the facility will include ten 12-ft diameter vessels, two carbon dioxide feed system, two caustic feed systems, and another 60,000 gallon backwash tank. The facility would require approximately 200 ft. by 150 ft. of land for construction. For ultimate expansion to 13 mgd or more, the facility size will be tripled and the approximate land requirement for such a facility will be 300 ft by 225 ft.

5.0 COAGULATION FILTRATION

The Coagulation Filtration process involves addition of a coagulant such as alum or ferric chloride. For the Zone 2 application, ferric chloride is preferred due to pH and silica levels. The ferric chloride forms small solid particles in the water which attract the arsenic. These particles are then filtered using a granular filter media in a pressurized vessel. Unlike

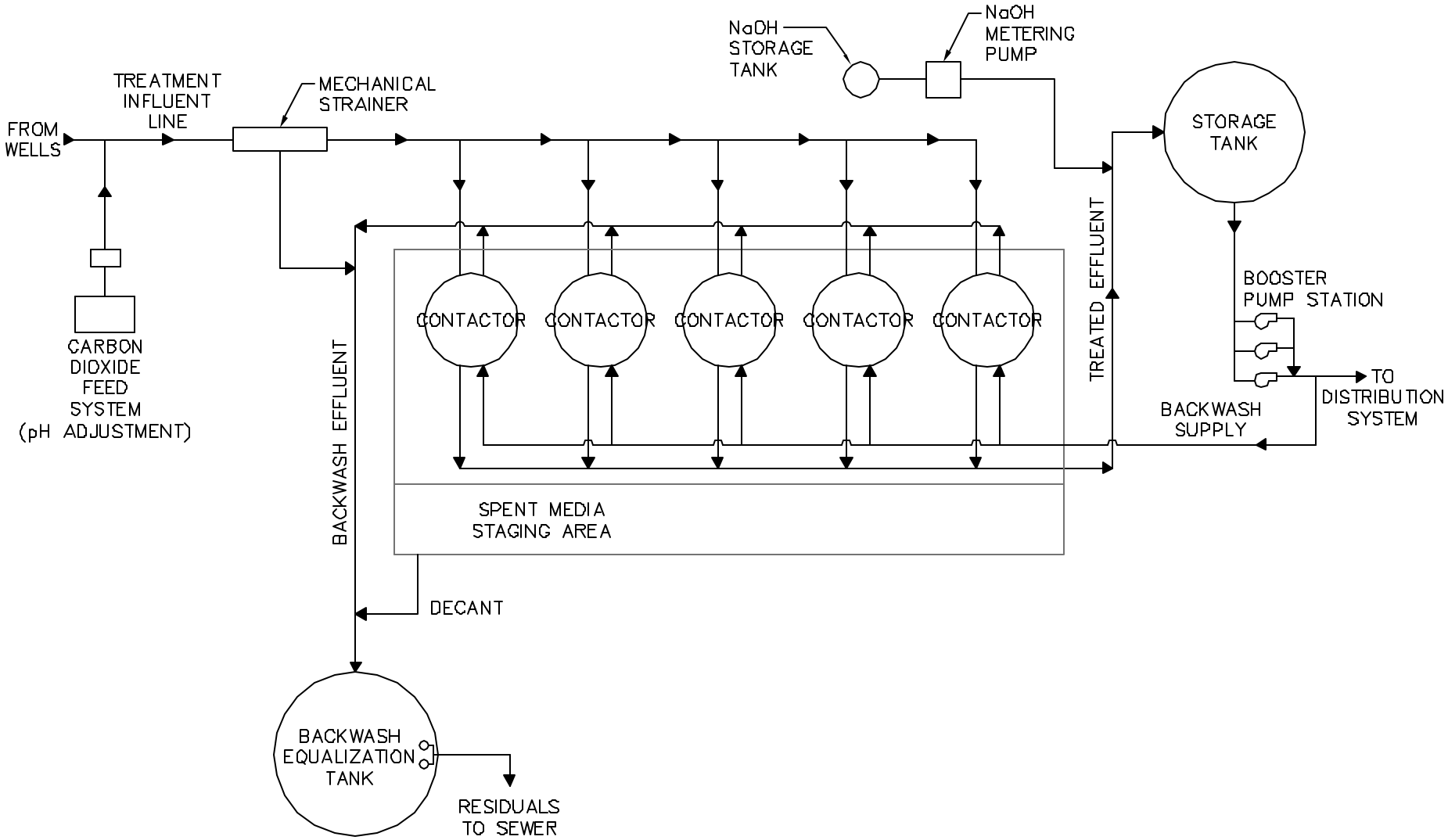

FIGURE 1
TYPICAL ADSORPTION SYSTEM SCHEMATIC

Narasimhan Consulting Services, Inc.

adsorption, the filter media does not have special characteristics to adsorb arsenic and the filter functions as a physical removal process much like a surface water treatment plant. As the particles are filtered, head loss builds up across the filter bed which requires backwashing. Based on the coagulant dosages and media bed depth, backwash may occur every 12 to 24 hours. Unlike adsorption, this process does not require frequent media change. A detailed description of the coagulation filtration process is presented in Appendix B.

A conventional coagulation filtration system for 5.3 mgd flow would include five 12-foot diameter filters, one 30-ton carbon dioxide feed system, one 60,000 gallon backwash storage tank, and a backwash water recovery system, if desired, or if sewer disposal of the backwash waste is not feasible. The backwash waste flow is approximately 5 percent of the main plant flow. The backwash water recovery system would include backwash clarification, sludge thickening, thickened sludge storage, and recycle pump station. Thickened sludge will be hauled to an off-site disposal facility. Assuming a 5 mg/L ferric chloride coagulant dose and 5.3 mgd flow, approximately 0.43 tons of dry solids will be generated per month operating 50 percent of the time (4,637 gallons as 2 percent sludge). This would require at least one load per week of off-site disposal of the sludge (or sludge disposal to sewer).

The capital and annual O&M costs for a facility with direct discharge to sewer are estimated to be $3.4M and $214,000, respectively. The capital and annual O&M costs for a facility with backwash recovery system are estimated to be $3.9M and $285,000, respectively. Figure 2 presents a typical schematic of such a facility. The land requirements for this facility without backwash water recovery system would be 125 ft. by 75 ft. If backwash recovery system is desired, additional 60 ft. by 40 ft. of land would be required.

For future expansion of the facility without backwash recovery, 5.3 mgd of treatment modules may be added. For example, for expansion up to 10 mgd, the facility will include ten 12-ft diameter filter, two carbon dioxide feed systems, two ferric chloride feed systems, two caustic feed systems, and another 60,000 gallon backwash tank. The facility would require approximately 250 ft. by 150 ft. of land for construction. For ultimate expansion to 13 mgd or more, the facility size will be tripled and the approximate land requirement for such a facility will be 375 ft. by 225 ft.

6.0 COMPARISON AND RANKING OF TREATMENT TECHNOLOGIES

Table 1 presents the comparison of the treatment technologies discussed above based on these criteria. The treatment technologies discussed above can be evaluated using standard evaluation criteria and rating system to determine the most appropriate treatment technology for the Community.

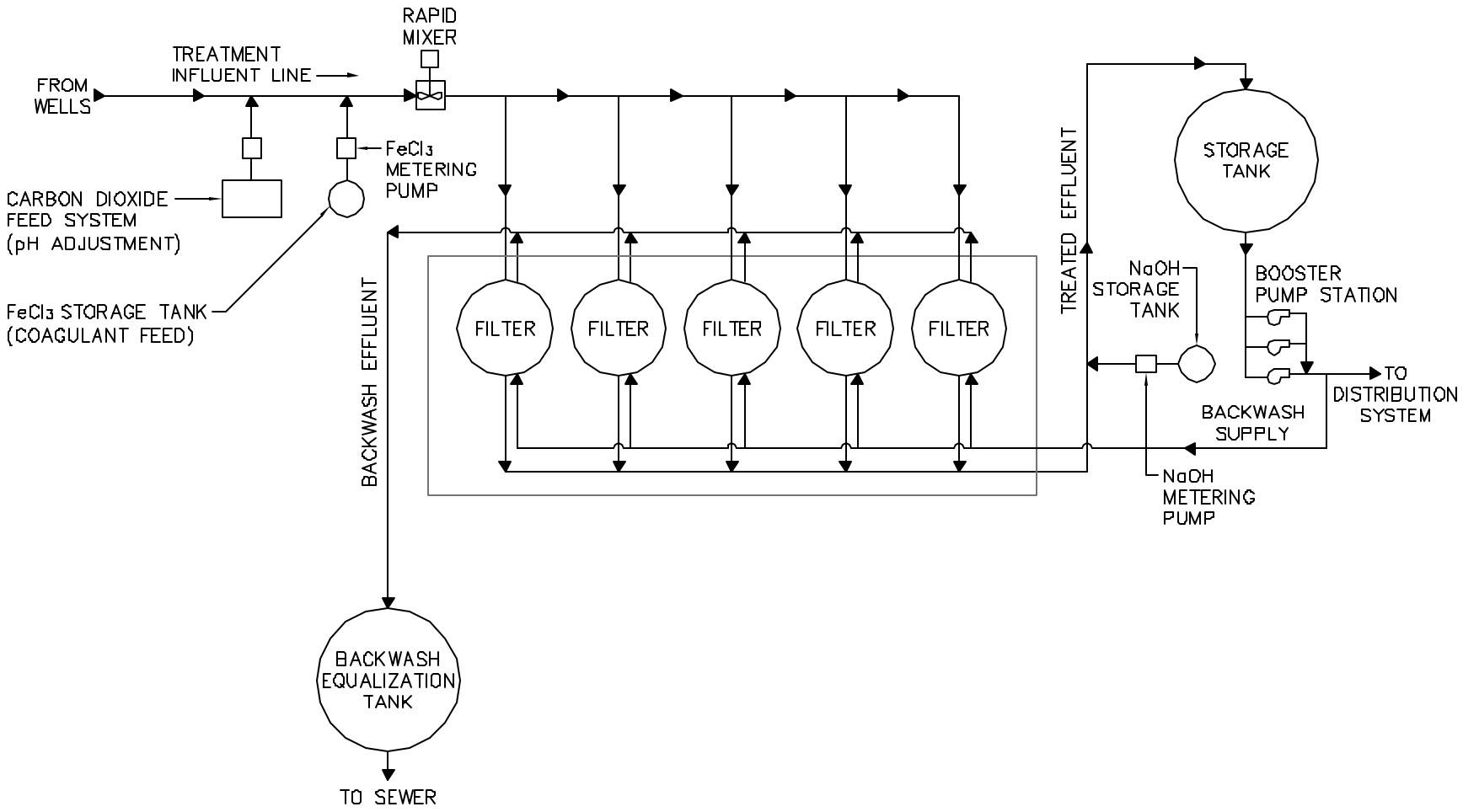

FIGURE 2
TYPICAL COAGULATION FILTRATION SYSTEM SCHEMATIC

Narasimhan Consulting Services, Inc.

The evaluation criteria includes treatment efficiency, bulk chemicals storage and handling, water recovery, hazardous waste considerations, water quality considerations, residuals handling, footprint size, labor required, mechanical reliability, and public acceptance.

Table 1 Comparison of Treatment Technologies
Zone 2 Arsenic Treatment
Salt River Pima Maricopa Indian Community

Criteria	Adsorption Treatment without pH Adjustment (regenerable media)	Adsorption Treatment with pH Adjustment (regenerable media)	CF without Backwash Recovery	CF with Backwash Recovery
Treatment Efficiency	>90%	>90%	85-90%	85-90%
Bulk Chemical Storage and Handling	No chemicals required	Requires carbon dioxide for pH reduction and sodium hydroxide for post treatment	Requires carbon dioxide, ferric chloride, may require sodium hydroxide for post-treatment pH adjustment	
Water Recovery	>99%	>99%	95-98%	>99%
Hazardous Waste	None	None	None	None
Water Quality Considerations	Parameters that impact treatment - pH, silica, phosphorus, vanadium, fluoride, iron and manganese		Parameters that impact treatment - pH, silica, phosphorus	
Residuals Handling Requirements	Minimal, spent media disposal can be contracted with a vendor and disposed offsite (six week interval)	Minimal, spent media disposal can be contracted with a vendor and disposed offsite (3 month interval)	Minimal, backwash water can be disposed to an on-site sewer after flow equalization	Significant, thickened solids can be stored onsite and require offsite hauling
Foot Print, Initial Ultimate	100 ft x 75 ft 300 ft x 225 ft	100 ft x 75 ft 300 ft x 225 ft	125 ft x 75 ft 375 ft x 225 ft	185 ft x 115 ft 555 ft x 345 ft
Labor Required	10 hours per week	15 hours per week	20 hours per week	25 hours per week
Mechanical Reliability	Minimal mechanical equipment; very reliable		Mechanical equipment includes coagulant metering pumps and backwash pumps	Mechanical equipment includes coagulant metering and backwash, pumps, backwash clarification thickeners
Vehicle Traffic	Media removal activities	Carbon dioxide, sodium hydroxide delivery, and media removal	Carbon dioxide, sodium hydroxide, and ferric chloride delivery	Carbon dioxide, sodium hydroxide, and ferric chloride delivery and sludge hauling

Table 1	Comparison of Treatment Technologies Zone 2 Arsenic Treatment Salt River Pima Maricopa Indian Community			
Criteria	**Adsorption Treatment without pH Adjustment (regenerable media)**	**Adsorption Treatment with pH Adjustment (regenerable media)**	**CF without Backwash Recovery**	**CF with Backwash Recovery**
Equipment maintenance and monitoring requirements	Very minimal, verify proper operation of valves	Verify proper operation of valves, pumps, carbon dioxide and sodium hydroxide feed system	Verify proper operation of valves, and controls associated with the backwash process	Verify proper operation of valves, pumps, and regular monitoring of process controls associated with the backwash process

The key routine operations for an adsorption type system would involve verifying proper valve positioning, system flows, carbon dioxide system and caustic soda feed system check, and ordering carbon dioxide as needed. Backwashing of the media may be desirable once every three months. At an average, this accounts for 10-15 hours per week of operator time. The key routine operational associated with CF process include verifying proper valve positioning, system flows, carbon dioxide system check, measurement of pH and iron residuals, coagulant feed system check, maintenance of metering pumps, and backwash process which automatically occurs at a preset interval (backwashing every 16 to 24 hours). At an average, this accounts for 20-25 hours of operator time. It is noted that since CF process involves frequent backwashing and has more mechanical equipment, the labor requirements are slightly higher as compared to adsorption systems. Both adsorption and coagulation filtration facilities typically require a Grade 2 operator.

Table 2	Costs Summary Zone 2 Arsenic Treatment Salt River Pima Maricopa Indian Community				
		Capital Costs	**O&M Costs**	**Annual Costs**	**20-Yr PW**
Treatment Process		**$M**	**$/1000 gallons**	**$**	**$M**
Adsorption	with pH	4.4	0.22	421,000	9.2
	w/o pH	3.7	0.36	687,000	11.6
Coagulation Filtration	with recovery	3.9	0.15	285,000	7.2
	w/o recovery	3.4	0.11	214,000	5.9

Table 2 presents the costs summary and comparison of all feasible treatment alternatives. A detailed breakdown of individual cost component is presented in Appendix C. The capital costs for adsorption system with and without any pH adjustment were $4.4 and $3.7 million, respectively. The annual O&M costs for these options are $421,000 and $687,000, respectively. The reason for a high difference in the annual O&M cost with and without pH adjustment system can be attributed to higher media consumption with no pH adjustment. For a coagulation filtration system, the capital costs for systems with and without backwash

recovery system was $3.9 and $3.4 million, respectively. The annual O&M costs for these options are $285,000 and $214,000, respectively. It is noted that the treatment alternative with no backwash water recovery will result in approximately 5 percent (of the total plant flow) water loss. It can be seen that coagulation filtration process without recovery (direct discharge to sewer after flow equalization) is the most economical process.

There is a trade-off between a coagulation filtration system and an adsorption system that involves cost and operational considerations. The adsorption system is easy to operate, but has high capital and O&M costs. However, coagulation filtration system is slightly complex to operate but has a low capital and O&M costs. Comparing adsorption system with pH adjustment and coagulation filtration system without backwash recovery, an annual savings of over $200,000 can be achieved if coagulation filtration system is implemented. Comparing 20-year present worth costs, an overall savings of $3.3M can be achieved if the coagulation filtration system is implemented.

7.0 RECOMMENDATION

Our recommendation for the Zone 2 Arsenic Treatment System is coagulation filtration, with sewer disposal. This recommendation is primarily based on the fact that CF is the most economical solution, for both capital and long term O&M costs. Additionally, there is not any significant difference between CF and adsorption systems in regards to treatment reliability and efficiency. The adsorption option without pH adjustment is the simplest system to operate, but the O&M costs are substantially higher as compared to CF, and the operation of either system typically requires a Grade 2 operator. A common concern regarding CF systems is that, at a loss of coagulant feed, the system does not effectively remove arsenic and there is a potential that the treated water will not meet the MCL requirements. This could be interpreted as CF treatment having a greater risk than an adsorption system, but it is our opinion that, with the proper design system interlocks, this risk is minimal. Because this treatment facility feeds into a storage reservoir, the system can be designed with redundant coagulant feed systems and interlocked to shutdown well water supply at the detection of lost chemical feed.

Appendix C

TREATMENT COSTS

APPENDIX C
TREATMENT COSTS

Adsorption Treatment Facility with pH adjustment

Capital Costs Summary	
Residuals Handling Facilities	$304,900
Pretreatment	$84,000
Adsorption System Facilities	$1,560,400
Chemicals Handling Facility	$472,400
Concrete Support for Treatment Vessels	$144,400
Piping, I&C, Electrical, Yard Piping Allowances	$545,800
Total Facility Cost, $	$3,112,100
Contingency, 30%	$933,600
Taxes & Bonding, 8.5%	$343,900
Total Estimated Facility Cost	$4,389,600
Annual O&M Costs Summary	
Annual Power Cost, $/yr	$3,500
CO2 Cost, $/yr	$20,200
NaOH Cost, $/yr	$41,100
Annual Media Replacement Costs, $/yr	$258,600
Waste Media Disposal Costs, $/yr	$6,000
Total Estimated Labor Costs, $/yr	$44,700
Equipment Maintenance Costs, $/yr	$47,100
Total Estimated Annual O&M Costs, $/yr	$421,200

Adsorption Treatment Facility without pH adjustment

Capital Costs Summary	
Residuals Handling Facilities	$304,900
Pretreatment	$84,000
Adsorption System Facilities	$1,560,400
Concrete Support for Treatment Vessels	$144,400
Piping, I&C, Electrical, Yard Piping Allowances	$545,800
Total Facility Cost, $	$2,639,700
Contingency, 30%	$791,900
Taxes & Bonding, 8.5%	$291,700
Total Estimated Facility Cost	$3,723,200
Annual O&M Costs Summary	
Annual Power Cost, $/yr	$1,000
Annual Media Replacement Costs, $/yr	$581,900
Waste Media Disposal Costs, $/yr	$12,000
Total Estimated Labor Costs, $/yr	$36,400
Equipment Maintenance Costs, $/yr	$37,200
Total Estimated Annual O&M Costs, $/yr	$686,600

Coagulation Filtration Treatment Facility
without Backwash Recovery System

Capital Cost Summary	
Rapid Mixing	$33,600
Granular Media Filters	$780,000
Chemical Feed Systems	$603,500
Solids Handling	$333,600
Treatment Support Structure	$62,200
Piping, I&C, Electrical, Yard Piping Allowances	$612,700
Total Facility Cost, $	$2,425,600
Contingency and Materials Increase, 30%	$727,700
Taxing & Bonding, 8.5%	$268,000
Total Estimated CF Facility Cost	$3,421,300
Annual O&M Costs Summary	
Annual Power Cost, $/yr	$5,700
FeCl3 Cost, $/yr	$7,700
CO2 Cost, $/yr	$24,200
NaOH Cost, $/yr	$54,900
Residuals Disposal Costs, $/yr	$0
Total Estimated Labor Costs, $/yr	$51,000
Equipment Maintenance Costs, $/yr	$70,900
Total Estimated Annual O&M Costs, $/yr	$214,400

Coagulation Filtration Treatment Facility
with Backwash Recovery System

Capital Cost Summary	
Rapid Mixing	$33,600
Granular Media Filters	$780,000
Chemical Feed Systems	$603,500
Solids Handling	$578,900
Treatment Support Structure	$62,200
Building	
Piping, I&C, Electrical, Yard Piping Allowances	$698,600
Total Facility Cost, $	$2,756,800
Site Aesthetics, 25%	
Contingency and Materials Increase, 30%	$827,000
Taxing & Bonding, 8.5%	$304,600
Total Estimated CF Facility Cost	$3,888,400
Annual O&M Costs Summary	
Annual Power Cost, $/yr	$8,500
FeCl3 Cost, $/yr	$7,700
CO2 Cost, $/yr	$24,200
NaOH Cost, $/yr	$54,900
Residuals Disposal Costs, $/yr	$35,100
Total Estimated Labor Costs, $/yr	$73,800
Equipment Maintenance Costs, $/yr	$80,600
Total Estimated Annual O&M Costs, $/yr	$284,800

ARIZONA WATER COMPANY

Valley Vista Well Head Arsenic Treatment Facility

PRELIMINARY DESIGN REPORT

Draft

July 2008

carollo

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3.3 COMPARISON OF ADSORPTIVE MEDIUMS

Four adsorptive media/system suppliers, representing different types of media currently proven and available in the market, were selected for consideration in this project. A comparative media performance and cost were evaluated to determine the most suitable media/system for this application.

3.3.1 Performance Comparison

The media performance on arsenic removal is in general site specific, primarily depending on water quality characteristics. Although bench or pilot testing was not conducted for evaluating the arsenic removal performance, all these medias have been installed in full-scale plants and have performed reliably for arsenic removal at groundwater treatment sites. Information for media performance predictions was provided by the media suppliers based on Valley Vista Well 13 water quality. A comparative arsenic removal performance is summarized in Table 3.1.

Table 3.1 Comparison of Anticipated Media Performance & Replacement Cost Valley Vista Well Head Arsenic Treatment Facility Project Arizona Water Company

Type of Media and Supplier	Performance in $/ac-ft (Predicted Bed Volumes)(1)	Media Replacement Cost(2) ($/ft^3)
Bayoxide E-33/ Severn Trent	94 (104,000)	225
GFH/ Siemens	217, (50,000)	111
Metsorb/ Graver	453 (78,000)	400
ArsenX/ Layne Christensen	421 (NA)	408

Notes:

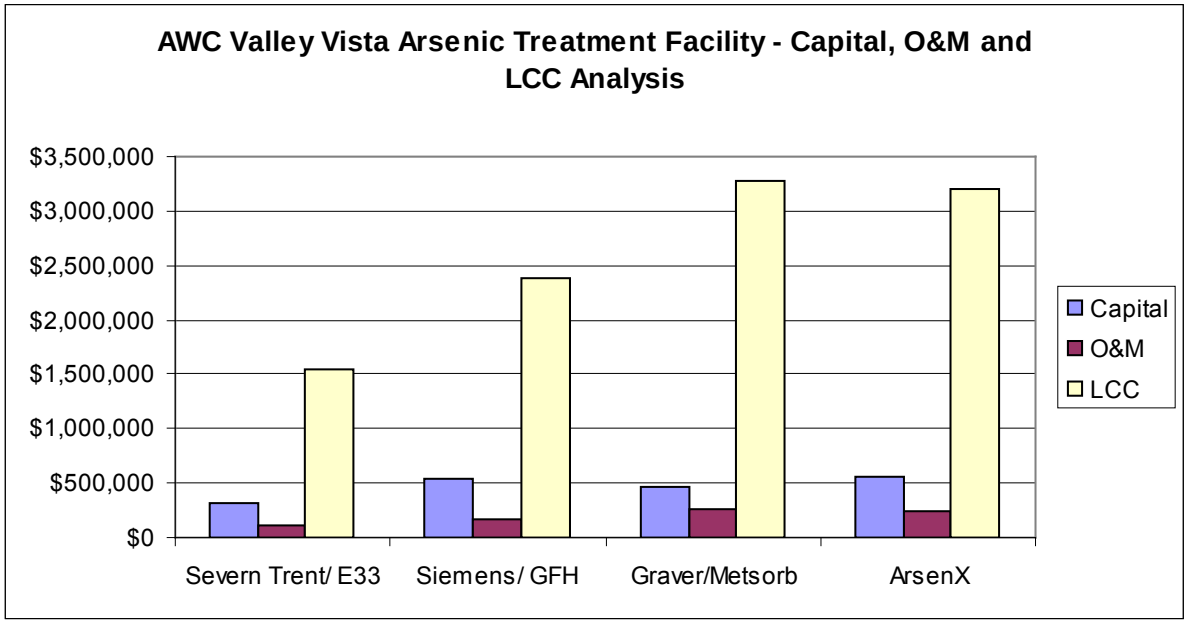
1) The information of projected media performance is provided by the manufacturers based on assumed water quality data.
2) The media replacement unit costs are either provided by the manufacturer or estimated based on a normalized condition assuming treating same quantity of water.

3.3.2 Cost Comparison

An economic evaluation was performed to compare the relative costs between the various arsenic removal system alternatives under consideration. Sources of cost data used for this study include AWC's labor, chemical and electrical rates, as well as budgetary equipment and materials costs from system vendors. Table 3.1 summarizes medias' water production and replacement costs for the four medias.

Capital, operations and maintenance, and present worth life cycle cost estimates of the selected media/system alternatives are shown in Figure 3.1. This cost comparison only represents relative cost differences among the suppliers. Capital costs listed in the table only include the arsenic equipment vendor quotes. Detailed cost estimates, economic assumptions, and unit prices used to develop the costs are located in the Appendix B. A cost quote was requested and received from Basin Water, and is included in Appendix B. However, the quote was received after this preliminary design report was basically published. The quoted capital cost of $698,227 is higher than the other capital cost quotes received by Carollo. An evaluation will be made on the Basin Water media replacement costs and included in the final Preliminary Design Report.

Figure 3.1 Comparative Capital, O&M, and Life Cycle Costs for the Selected Media/System Suppliers



The results of the economic analysis show that Bayoxide E-33 media provided by the Severn Trent had the lowest total life cycle costs. However, AWC was not able to come to terms with Severn Trent on a previous groundwater treatment project. AWC has expressed concerns that they still may not be able to work with Severn Trent due to contract issues. AWC indicated the final decision would be based on a media/system supplier that can provide both a cost competitive media and a satisfactory contract agreement to AWC.

ESTIMATED COSTS

The cost estimate developed for this study was based on the conceptual design developed for the selected project configuration.

Table 7.1 summarizes the baseline contingency and cost parameters used for the cost calculations for the arsenic treatment facility. The cost opinion includes a 15 percent contingency allowance for general conditions, 12 percent for the general contractor adjustments including overhead, profit and risk. The treatment plant cost estimates do not include costs associated with permitting. The anticipated construction cost is in July 2008 dollars (ENR = 8293).

Table 7.1 Baseline Cost Parameters
Valley Vista Arsenic Wellhead Treatment Facility Project
Arizona Water Company

Construction Costs	
Contingency	15%
General Contractor, Overhead, Profit & Risk	12%
Escalation to Mid-point	3%
Sale Tax (Based on 50% of cost is materials)	4%
O&M Costs	
Electricity	$0.12/kWh
Sodium Hypochlorite	$0.086/lb
Labor (1)	$40/hour
Life Cycle Time Period	20 years
Other	
Cost Estimate Accuracy	Per AACEI Class 4/5; +50 to -30% for Planning/Study Level Costs
Total Life Cycle Cost	Capital + Annual O&M Present Worth = 20 yr Life Cycle Costs
Past to Present Cost Escalation	ENR 20 Cities Index to July 2008=8293
Interest Rate	6.95% per year (1)
Year of Present Worth Costs	2008

Notes:
(1) Provided by AWC.

7.1 CAPITAL, O&M AND LIFE CYCLE COSTS

A conceptual capital cost estimate was prepared using Carollo's Cost Estimating System that collects unit costs from sources such as Means, supplier quotations, and other industry-standard sources. This estimate is generally based on the conclusions and recommendations presented in this report, and are also based on the following assumptions:

1. An adsorptive media, two-vessel, lead/lag arsenic removal system similar to that supplied by Siemens or Severn Trent will be provided. The arsenic removal system will be competitively bid and will include a control panel, backwash tank and backwash pumps. Piping and valves will be provided separately by the general contractor.
2. The arsenic removal system will be housed in a prefabricated metal building except for the backwash tank. The building will not have separate rooms but will be insulated and heated.
3. No chemical storage and feed systems will be initially provided in the building.
4. Minimal site preparation will be required, but new pea gravel will be provided to improve access to the building.

Using the construction cost parameters indicated in Table 7.1, a value of approximately $1.3M for the opinion of probable cost is calculated. Printouts from the spreadsheet used to calculate the construction cost are included in Appendix D.

This budgetary cost estimate is higher than the $1M that Arizona Water Company has budgeted for this project. Some of the factors that may reduce the capital cost include lowering the contingency as the final design near completion without adding elements to the project, and receiving lower costs for the arsenic removal system through the competitive bidding process.

The O&M cost estimates include 1) media replacement and disposal, 2) chemical supply (i.e., sodium hypochlorite only), 3) power consumption, and 4) labor required for operations and maintenance. Sources of cost data used for this study include AWC's labor, chemical and electrical rates as well as budgetary equipment and materials costs from system vendors and manufacturers. Table 7.2 shows the O&M cost ranges between $116,000 and $266,000, representing the lowest and highest costs among the selected four media/system suppliers.

Present worth values were calculated based upon a 6.95 percent interest factor and a 20-year annualized life cycle.

Table 7.2	**Conceptual Cost EstimateCapital, O&M, and Present Worth Valley Vista Arsenic Wellhead Treatment Facility Project Arizona Water Company**
CAPITAL COST	
TOTAL CAPITAL COST	**$1,320,000**
O&M COST	
DESCRIPTION	
Electrical	$55,000$57,000
ChemicalSodium Hypochlorite	$1,000
Media Replacement and Disposal	$44,000$190,000
Labor and Maintenance	$16,000$18,000
TOTAL ANNUAL O&M COST	**$116,000$266,000**
PRESENT WORTH COST	
Present worth (20 years, I=6.95%, PW Factor =10.64)	**$2,530,0004,120,000**

Notes:
(1) ENR 20-Cities CCI = 8293 (July, 2008)
(2) The cost estimate herein is based on our perception of current conditions at the project location. This estimate reflects our professional opinion of accurate costs at this time and is subject to change as the project design matures.
(3) O&M cost estimates are based on the selected medias/system suppliers for consideration.
(4) Carollo Engineers has no control over variances in the cost of labor, materials, equipment, services provided by others, contractor's methods of determining prices, competitive bidding or market conditions, practices or bidding strategies. Carollo Engineers cannot and does not warrant or guarantee that proposals, bids or actual construction costs will not vary from the costs presented herein.

IMPLEMENTATION PACKAGE FOR COAGULATION, FLOCCULATION, AND FILTRATION

COAGULATION/FILTRATION TREATMENT TECHNOLOGY

A coagulation/filtration treatment facility generally consists of coagulant addition, optional pH adjustment chemicals, mixing through an inline static mixer or rapid mix/flocculation process, granular media filters, disinfection chemicals, finished water storage, finished water pumping and optional residual handling. The coagulation/filtration treatment technology basis of design is included in Table WT.E-1. The coagulation/filtration process flow diagram is included in Figure WT.E-1.

Table WT.E-1 Coagulation Filtration Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	80	When iron:arsenic >20:1, verify with media supplier with specific water quality
Treatment Water Loss(3)	%	5	3 ~ 7
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	636	Example
Flow Bypassed for Blending (4)	gpm	26	Example
Flow Rate to the Final Blended Stream(3)	gpm	662	Example
Treated Flow Percentage (4)	%	96	Example
Coagulation			
Chemical for Coagulation		Ferric Chloride	
Coagulant Dose	mg/L	10	5 - 15 ppm
Rapid Mixing Velocity Gradient	1/s	500	500-1000
Flocculation			
Type of Flocculator		Three Stage	Two or three stage
Retention Time	min	20	0 – 30
1st Stage Velocity Gradient	1/s	90 - 30	
2nd Stage Velocity Gradient	1/s	60 - 20	
3rd Stage Velocity Gradient	1/s	30 - 10	
Granular Media Filters			
Filter Media	-	Dual Media (anthracite and sand)	Mono or dual media
Surface Loading Rate	gpm/sf	6	5 ~ 8
Required Surface Area	sf	106	
Filter Diameter	feet	8	4 ~ 12
Surface Area of each Filter	sf	50	
Number of Duty Filters	-	3	
Total Surface Area in Operation	sf	151	Change filter size to optimize the total
Number of Standby Filters	-	1	1 minimum
Total Number of Filters	-	4	

Table WT.E-1 Coagulation Filtration Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Media Bed Depth	feet	3	2 ~ 4 feet, 18-24 inches of anthracite and 6-12 inches of sand, proprietary medias are also available
Total Media Volume	cf	452	
Anthracite Effective Size	mm	1	
Sand Effective Size	mm	0.5	
Uniform Coefficient		1.4 or less	
Depth of Bed to Effective Size of Media Ratio L/D		>1000	
Filter Backwash			
Backwash Frequency	-	Once every 24 hours	Once every 24 to 48 hours
Type of Backwash		Water and Air Scouring	
Backwash Rate	gpm/sf	18	10 ~ 30(5)
Backwash Flow Rate	gpm	900	Backwash 1 filter at a time
Backwash Duration	minutes	15	10 ~ 20
Backwash Waste Volume	gallons	15,000	
Recommended Residuals Handling		Sewer Discharge, if permitted. See Note (6) if sewer discharge is not permitted.	
Optional Backwash Equalization Tank			
Backwash EQ Tank Volume	gallons	40.500	Sized for three backwashes
Backwash EQ Tank Diameter	feet	20	
Backwash EQ Tank Height	feet	22	Include 2 feet freeboard
Number of Backwash EQ	ea	1	
Optional Thickener			
Type of Thickener		Gravity thickener with or without plate / tube settler	
Design Surface Loading Rate	gpm/sf	0.4	
Design Solids Loading Rate	lb/day/sf	10	
Estimated Sizes	sf	40	
Estimated Diameter	feet	10	
Side Water Depth	feet	12	

Table WT.E-1 Coagulation Filtration Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Number of Thickener	ea	1	
Thickened Sludge Concentration	%	5	3 - 5%
Optional Mechanical Dewatering			
Type of Dewatering		Centrifuge Dewatering	
Number of Centrifuges	ea	1 duty plus 1 standby	Or use sewer discharge as backup
Centrifuge Capacity	gpm	100	Run time < 8 hrs a day
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Type of System	-	Sewer Discharge, if permitted. See Note (6) if sewer discharge is not permitted.	

Note:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

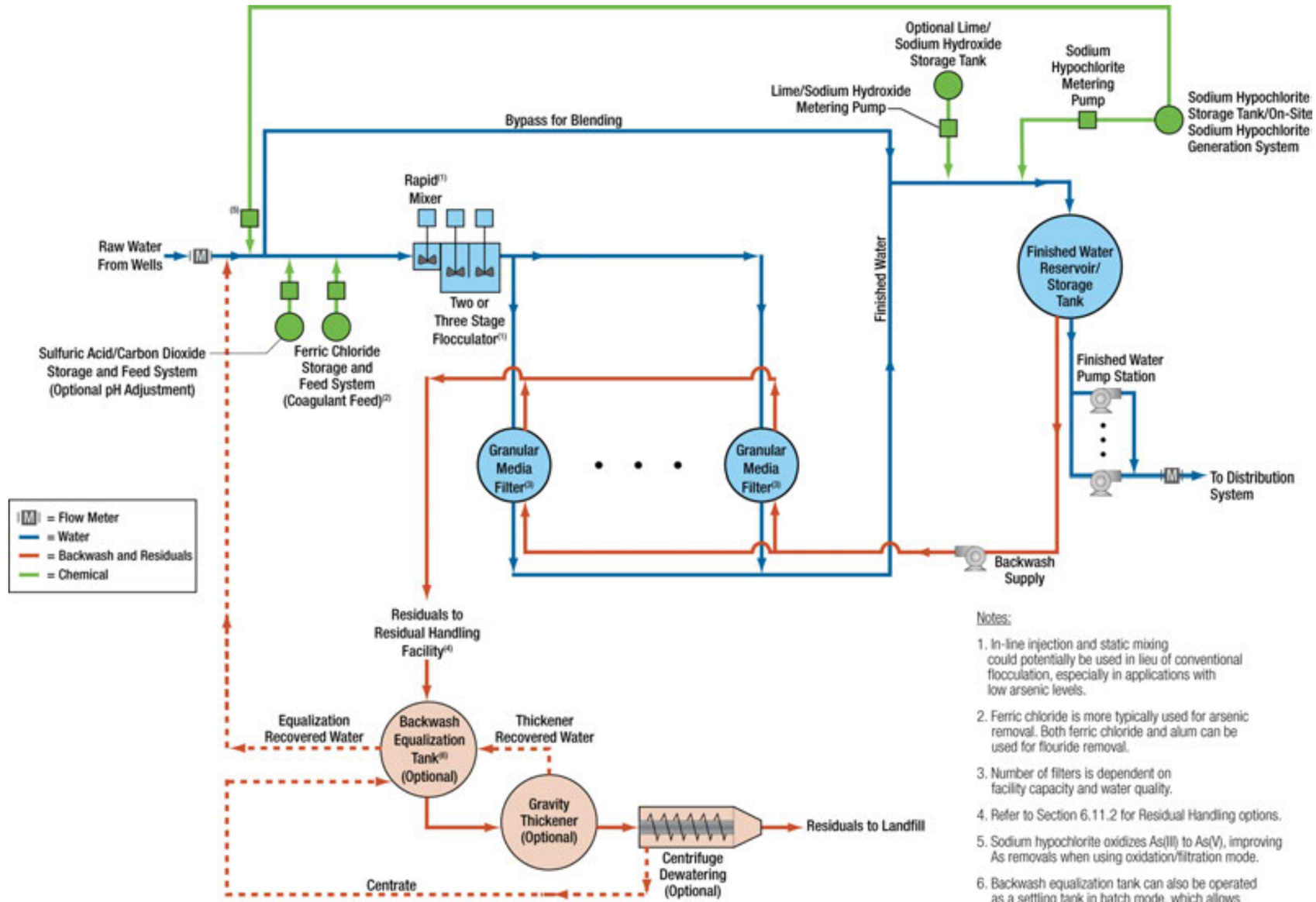
(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality and site-specific considerations.

(3) Flow rates assume backwash water is not recycled.

(4) The allowable blending ratio depends on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(5) Backwash flow rate depends on media type.

(6) If sewer discharge is not permitted, the following residuals handling alternatives are recommended. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. In-line injection and static mixing could potentially be used in lieu of conventional flocculation, especially in applications with low arsenic levels.
2. Ferric chloride is more typically used for arsenic removal. Both ferric chloride and alum can be used for flouride removal.
3. Number of filters is dependent on facility capacity and water quality.
4. Refer to Section 6.11.2 for Residual Handling options.
5. Sodium hypochlorite oxidizes As(III) to As(V), improving As removals when using oxidation/filtration mode.
6. Backwash equalization tank can also be operated as a settling tank in batch mode, which allows deletion of the gravity thickener.

COAGULATION FILTRATION PROCESS FLOW DIAGRAM

FIGURE WT.E-1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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COAGULATION/FILTRATION DESIGN CONSIDERATIONS

The following list includes design considerations associated with coagulation/filtration technology. This list should be reviewed when initially considering coagulation/filtration technologies as well as during the preliminary and final design of any coagulation/filtration treatment facilities.

- Parameters that can impact the coagulation/filtration process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, fluoride, sulfate, iron, manganese, TOC, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- The coagulation/flocculation process involves the addition of large volumes of chemicals (aluminum salts, iron salts, polymer, PACL, etc.) and produces a large volume of residuals (5% of the treated flow).
- Typically, the coagulation/flocculation process utilizes rapid and gentle mixing to initiate the formation of floc.
- The coagulation/flocculation process should be designed to provide proper mixing energies. The mixers should be variable speed type to allow process optimization. Insufficient mixing may not produce flocs large enough to be captured by the downstream filtration process. Excessive mixing may break the flocs and impact the removal efficiency.
- Static in-line mixing may be used in lieu of rapid mix and flocculation processes when sufficient mixing can be achieved. Static mixing must be properly designed and proven to be effective for the application to be considered an acceptable alternative. An in-line static mixer requires less maintenance than mechanical mixing, but will have limited turn-down.
- Particles are removed through either direct filtration or sedimentation and filtration (granular media or membrane filtration). For groundwater applications (low turbidity and low TOC water), coagulation / flocculation followed by granular media filtration provides sufficient and reliable treatment economically.
- Both ferric and alum are effective coagulants for arsenic removal. Below a pH of approximately 7, arsenic removal with alum or ferric sulfate/chloride is similar. Above a pH of 7, removals with alum decrease dramatically (at a pH of 7.8, alum removal efficiency is approximately 40%).
- Additional process optimization can be achieved, if necessary, through enhanced coagulation by means of increasing coagulant doses, adjusting the pH, and optimization of coagulant type. For example, systems may need to lower pH or add more coagulant to achieve higher removals.

- Coagulation can be used to remove multiple contaminants, including iron, manganese, arsenic, and fluoride. Coagulation can reduce fluoride at high concentrations (from 15 ppm down to 5 ppm). However, it may not reduce fluoride to levels less than 2 ppm. It can be used as an economic pretreatment to reduce adsorption, ion exchange, and RO costs.
- Coagulation/filtration and oxidation/filtration are best available technologies (BAT) for arsenic treatment as identified in the Safe Drinking Water Act. To obtain high arsenic removals, the iron to arsenic ratio must be at least 20:1.
- Coagulation/filtration using alum as a coagulant is a best available technology (BAT) for fluoride treatment as identified in the Safe Drinking Water Act.
- Coagulation is a cost effective way to reduce high concentrations of arsenic and fluoride. However, the product levels of arsenic and fluoride may not be as low as IX and AA product water. For such applications, consider using coagulation as a pretreatment followed by a polishing (smaller) adsorption or IX.
- Compared to adsorption and ion exchange, coagulation and granular media filtration is typically more economical - especially for large facilities.
- Coagulation and filtration facilities can utilize concrete tanks or metal pressure vessels. Utilizing pressure vessels may promote more efficient hydraulics and help to reduce energy consumption.
- Coagulant type and dosage can be easily determined and optimized using jar testing equipment. Consider performing such routine testing during preliminary design and throughout the operational phase.
- The residuals from coagulation / flocculation are relatively easy to treat. For a small facility, it may be more economical to discharge the waste to sewer if sewer discharge is an option at the proposed site. To avoid overloading the sewer system during the discharge, the backwash waste can be stored and equalized in a backwash waste equalization tank.
- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the economics of alternative treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.
- For a large facility, or when discharging un-thickened residuals is not an option, backwash residuals from the equalization tank can be thickened in a backwash settling tank or in gravity thickeners with or without lamella plate / tube settlers (non-mechanical residuals handling). Water recovered from the thickeners can be returned to the process. The thickened sludge can be discharged to the sewer or further treated using drying beds or mechanical dewatering equipment such as centrifuges or plate and frame press. The dewatered solids can be disposed of in a landfill.

- When actual source water quality and site-specific conditions are available, evaluate the feasibility and economics of different residuals treatment (sewer discharge, non-mechanical residuals handling and mechanical residuals handling) and water recovery options.

IMPLEMENTATION PACKAGE FOR ADSORPTION

ADSORPTION TREATMENT TECHNOLOGY

An adsorption treatment facility generally consists of prefilters, optional pH adjustment chemicals, adsorption contactors, disinfection chemicals, finished water storage and finished water pumping. The adsorption treatment technology basis of design is included in Table WT.F-1. The adsorption process flow diagram is included in Figure WT.F-1.

Table WT.F-1 Adsorption Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	95	Verify with media supplier based on specific water quality
Treatment Water Loss(3)	%	2	1 ~ 2
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	536	Example
Flow Bypassed Treatment(4)	gpm	148	Example
Flow Rate to the Final Blended Stream(3)	gpm	683	Example
Treated Flow Percentage(4)	%	78	Example
Prefiltration			
Type of Filters	-	Bag Filters / Cartridge Filters 20 micrometers nominal pore size	
Number of Filters	-	1 per train	
Size of Filters	gpm	694	
Adsorption Vessels			
Recommended Media	-	Activated alumina (Arsenic and Fluoride); Iron Based Oxide / Hydroxide (Arsenic only)	
Surface Loading Rate	gpm/sf	7	6 ~ 8
Required Surface Area	sf	77	
Vessel Diameter	feet	10	4 ~ 12
Surface Area of each Vessel	sf	79	
Vessel Train Configuration	-	Single or Lead - Lag	
Number of Vessels per Train	-	2	1 for single, 2 for Lead / Lag
Number of Duty Trains	-	1	
Total Surface Area in Operation (Single or lead vessel)	sf	79	Change vessel size to optimize the total
Number of Standby Train(s)	-	1	1 minimum
Total Number of Trains	-	2	
Media Bed Depth(5)	feet	3	2 ~ 4
Total Media Volume (single or lead vessel)	cf	236	
Required Empty Bed Contact Time	minutes	3	2.5 ~ 5

Table WT.F-1 Adsorption Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Actual Empty Bed Contact Time (Single or lead vessel)	minutes	3.3	
Typical Media Regeneration / Disposal Cycle[(4)]	-	50,000 bed volumes at pH 7; 20,000 bed volumes without pH adjustment	Check with Media Supplier
Backwash			
Backwash Frequency	-	Once every 1 to 3 weeks	
Backwash Rate	gpm/sf	12	10 ~ 12
Backwash Flow Rate	gpm	950	Backwash 1 vessel at a time
Backwash Duration	minutes	15	10 ~ 20
Backwash Volume	gallons	15,000	
Equalization Tank Volume	gallons	30,000	Sized for two backwashes
Backwash Tank Diameter	feet	20	
Backwash Tank Height	feet	15	Include 2 feet of freeboard
Number of Backwash EQ	ea	1	
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Backwash Wastes	-	Sewer Discharge with Equalization, if permitted See Note (6) if sewer discharge not permitted.	
Exhausted Adsorption Media	-	Disposal at Landfill	
Optional Backwash Equalization Tank			
Backwash EQ Tank Volume	gallons	45,000	Sized for three backwashes
Backwash EQ Tank Diameter	feet	20	
Backwash EQ Tank Height	feet	22	Include 2 feet freeboard
Number of Backwash EQ	ea	1	

Table WT.F-1 Adsorption Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Optional Thickener			
Type of Thickener		Gravity thickener with or without plate / tube settler	
Design Surface Loading Rate	gpm/sf	0.4	
Design Solids Loading Rate	lb/day/sf	10	
Estimated Sizes	sf	40	
Estimated Diameter	feet	10	
Side Water Depth	feet	12	
Number of Thickener	ea	1	
Thickened Sludge Concentration	%	5	3 - 5%
Optional Mechanical Dewatering			
Type of Dewatering		Centrifuge Dewatering	
Number of Centrifuges	ea	1 duty plus 1 standby	Or use sewer discharge as backup
Centrifuge Capacity	gpm	100	Run time < 8 hrs a day

Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

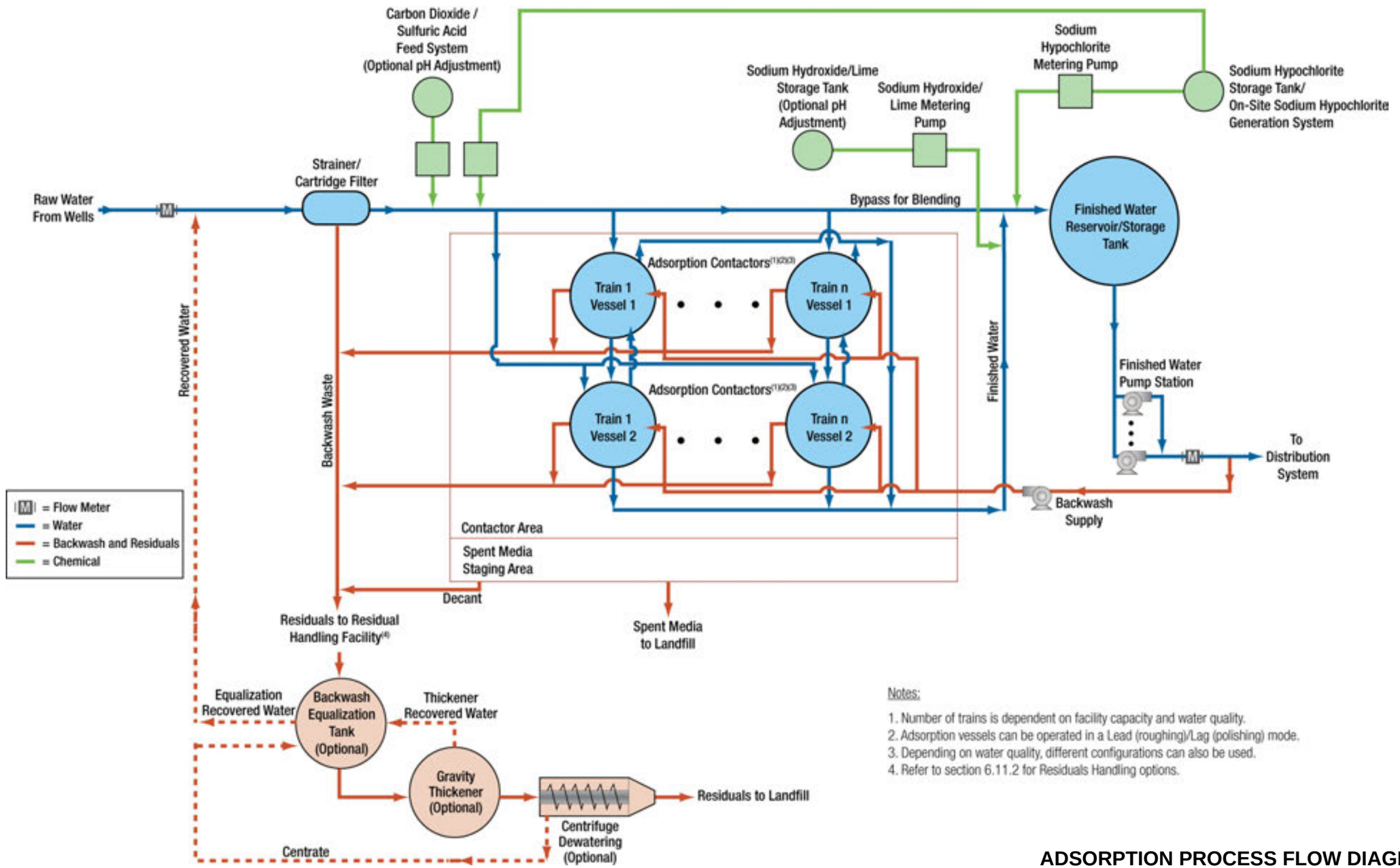
(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection and site-specific considerations.

(3) Flow rates assume backwash water is not recycled.

(4) The media disposal frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(5) Media depth will depend on the media specific contact time.

(6) If sewer discharge is not permitted, the following residuals handling alternatives are recommended for the backwash wastes. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. Number of trains is dependent on facility capacity and water quality.
2. Adsorption vessels can be operated in a Lead (roughing)/Lag (polishing) mode.
3. Depending on water quality, different configurations can also be used.
4. Refer to section 6.11.2 for Residuals Handling options.

ADSORPTION PROCESS FLOW DIAGRAM

FIGURE WT.F-1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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DESIGN CONSIDERATIONS FOR ADSORPTION

The following list includes design considerations associated with adsorption technology. This list should be reviewed when initially considering adsorption technologies as well as during the preliminary and final design of any adsorption treatment facilities.

- Parameters that can impact the adsorption process may include, but are not limited to pH, alkalinity, arsenic, phosphorous, silica, nitrate, calcium, magnesium, vanadium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and current market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- When specific water quality data is available, the design Engineer should consult the adsorption media supplier to select the optimal adsorption media. Bench and pilot testing may be required to obtain media performance guarantees.
- Investigate the impact of feed water pH on media life and the cost:benefit ratio of pH adjustment.
- Consider the feasibility and economics of different vessel design configurations (e.g., single vessels versus lead-lag versus parallel).
- Adsorption using activated alumina is a best available technology (BAT) for arsenic and fluoride treatment as identified in the Safe Drinking Water Act.
- Consider oxidation. Virtually all adsorption media remove Arsenic (V) more efficiently than Arsenic (III). Although most groundwater sources in the Surprise area contain Arsenic (V), providing the flexibility to feed the primary disinfectant chemical (e.g., sodium hypochlorite) for pre-oxidation is recommended. This improves the system reliability and product water quality at minimal additional cost.
- If the groundwater contains only arsenic (no fluoride), granular ferric hydroxide (GFH) or iron-modified media is more economical compared to Activated Alumina (AA) media. AA is effective but more pH sensitive than GFH. Although AA is highly efficient at removing arsenic over a broad range of pH, high pH shortens the run length.
- If the groundwater contains both arsenic and fluoride, an adsorption system using AA is simpler and potentially more economical because AA removes both fluoride and arsenic. However, depending on the actual concentrations of arsenic and fluoride, a system with an AA lead vessel and a GFH lag vessel may be more economical. The design Engineer should consult the media suppliers when actual water data are available.

- Compare the economics of disposal versus regeneration based on water quality. For example, when the source contains both arsenic and fluoride, depending on the concentration of each contaminant, disposal mode may be more economical for Arsenic removal, but regeneration may be more appropriate for fluoride removal.
- AA media can be regenerated with strong bases and acid. Regeneration recovers 50 – 70% capacity. Because the disposal of the regeneration waste is difficult, the disposal option (land filling the exhausted adsorption media) is generally less costly than regeneration. Typically, spent media can be disposed of in a non-hazardous landfill.
- In general, the backwash waste from the adsorption process represents 0.5 to 2% of the treated flow volume. It is economical to discharge the waste to sewer if sewer discharge is an option at the proposed site. To avoid overloading the sewer system during discharge, the backwash waste can be stored and equalized in a backwash waste equalization tank.
- Discharge of residuals to the sanitary sewer is not acceptable unless specifically approved by the City. The economics and adverse impacts of sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.
- When discharging un-thickened residuals is not an option, backwash residuals from the equalization tank can be thickened in gravity thickeners with or without lamella plate / tube settlers. Water recovered from the thickeners can be returned to the process. The thickened sludge can be discharged to the sewer or further treated using drying beds or mechanical dewatering equipment such as centrifuges or belt presses. The dewatered solids can be disposed of at a landfill.

IMPLEMENTATION PACKAGE FOR ION EXCHANGE

ION EXCHANGE TREATMENT TECHNOLOGY

An ion exchange treatment facility generally consists of prefilters, optional pH adjustment chemicals, ion exchange vessels, disinfection chemicals, finished water storage, finished water pumping, and a regeneration system. The ion exchange treatment technology basis of design is included in Table WT.G-1. The ion exchange process flow diagram is included in Figure WT.G-1.

Table WT.G-1 Ion Exchange Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	95	When sulfate < 50 mg/L, verify with media supplier based on specific water quality
Treatment Water Loss	%	2	2 -3
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	gpm	535.7	Example
Flow Bypassed Treatment	gpm	147.6	Example
Flow Rate to the Final Blended Stream	gpm	683.3	Example
Treated Flow Percentage	%	78.4	Example
Prefiltration			
Type of Filters	-	Bag Filters / Cartridge Filters 20 micrometers nominal pore size	
Number of Filters	-	1 per train	
Size of Filters	gpm	350	
Ion Exchange Vessels			
Synthetic Resin Type		Strong Base / Weak Base Anion Exchange Resin	Strong base preferred for As treatment
Recommended Regenerant Solution		Sodium Chloride Solution	OH- or Cl- Solution; other solution may be required depending on resin selection and water quality
Required Empty Bed Contact Time (EBCT)	minutes	5	2 ~ 10; Depends on water quality and resin selection
Total Media Volume Required	cf	358	
Media Bed Depth	feet	4	3 ~ 6
Required Surface Area	sf	90	
Surface Loading Rate	gpm/sf	6	3 - 10
Number of Duty Trains	ea	2	

Table WT.G-1 Ion Exchange Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Number of Standby Train(s)	ea	1	
Total Number of Trains	ea	3	
Surface Area per train	sf	45	
Vessel Diameter	feet	8	2 ~ 12
Actual Total Surface Area in Service	sf	101	
Actual Total Volume in Service	cf	402	
Regeneration			
Regeneration Frequency	-	300 ~ 60,000 Bed Volume	Check with Media Supplier. Dependent on resin type and water quality
Volume of Regenerant Solution per Regeneration		3	3 ~5 Bed Volume
Regeneration Volume	gallons	3,348	
Regeneration Waste Tank Volume	gallons	13,393	Sized for four regenerations - dependent on water quality.
Regeneration Waste Tank Diameter	feet	8	
Regeneration Waste Tank Height	feet	36	
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Chemical Post Treatment			
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Backwash and Rinse Water	-	Sewer Discharge with Equalization, if permitted. If not, see Note (4)	

Table WT.G-1 Ion Exchange Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Regeneration Wastes	-	May be a hazardous waste. Requires expensive volume reduction and concentration treatment. The concentrated brine may be disposed of only in permitted landfills.	
Replaced Resins	-	May be a hazardous waste and must be disposed of in permitted landfill.	

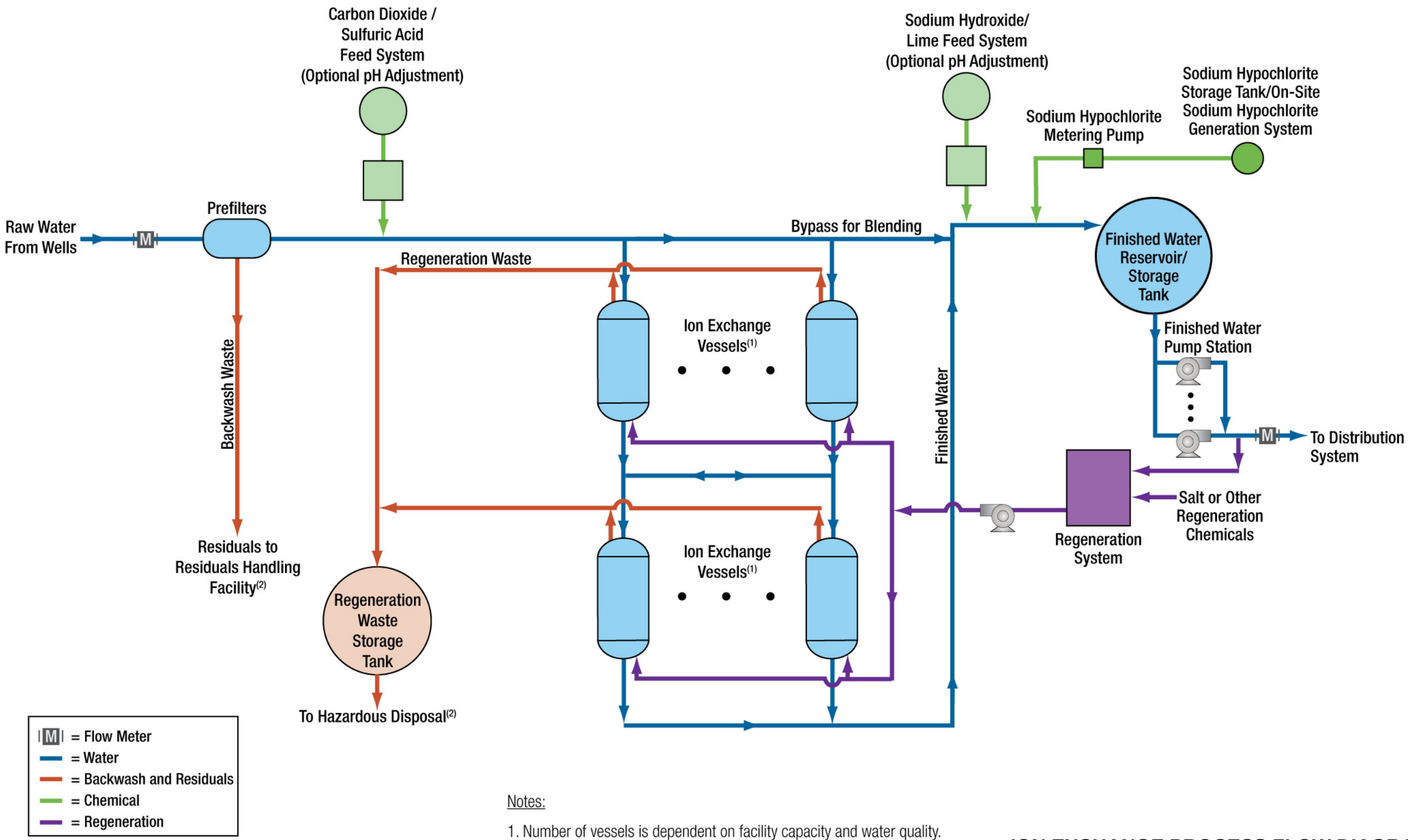
Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection, and site-specific considerations.

(3) The media disposal frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(4) If sewer discharge is not permitted, the following residuals handling alternatives are recommended for the backwash and rinse water. The recommended thickening processes include backwash equalization / clarification (with or without sludge removal) followed by gravity thickening, The recommended dewatering processes include, drying beds, if land is available and aesthetic concerns are not an issue, or mechanical dewatering using centrifuge dewatering. Other residuals handling alternatives must be approved by the City.



Notes:

1. Number of vessels is dependent on facility capacity and water quality.
2. Refer to Section 6.11.2 for Residual Handling options.

ION EXCHANGE PROCESS FLOW DIAGRAM

FIGURE WT.G-1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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ION EXCHANGE DESIGN CONSIDERATIONS

The following list includes design considerations associated with ion exchange technology. This list should be reviewed when initially considering ion exchange technology as well as during the preliminary and final design of any ion exchange treatment facilities.

- Parameters that can impact the ion exchange process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, silica, nitrate, calcium, magnesium, vandium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- When specific water quality data is available, the design Engineer should consult with the resin supplier to select the optimal ion exchange resins. Bench and pilot testing may be required for complicated applications.
- Anion exchange resins include two classes: Weak-base anion (WBA) and Strong-base anion (SBA). SBA resins are typically used for arsenic removal because they tend to be more effective over a larger pH range than WBA resins.
- Investigate the impact of feed water pH on media life and the cost:benefit ratio of pH adjustment. Most SBA resins do not remove uncharged As (III) when pH is under 9.0.
- SBA anion exchange resins remove contaminants based on their selectivity sequence. The process is very selective and should be closely evaluated based on actual source water quality.
- High sulfate (>150 mg/L) and TDS levels (>500 mg/L) can significantly reduce arsenic removal efficiency.
- High Fe (III) in feed water can affect arsenic removal by forming Fe (III)-arsenic complexes, which cannot be removed by IX resins.
- Depending on water quality, removing arsenic, nitrate or fluoride may require different types of resin.
- Ion exchange is a best available technology (BAT) for arsenic, nitrate, and fluoride treatment as identified in the Safe Drinking Water Act.
- Concentration profiles in an IX column can result in chromatographic peaking, where more competitive ions such as SO_4^{2-} elute adsorbed $HAsO_4^{2-}$ from the resin and result in high effluent arsenic concentrations.
- Consider the feasibilities and economics of different vessel design configurations (e.g., single vessels versus lead-lag).

- Consider oxidation. Most SBAs do not remove uncharged As (III) when pH is under 9.0. Although most groundwater sources in the area contain arsenic (V), providing the flexibility to feed the primary disinfectant (e.g., sodium hypochlorite) chemical for pre-oxidation is recommended. This improves the system reliability and product water quality at minimal additional costs. However, excessive oxidant (> 0.1 mg/L free chlorine) may degrade the resin.
- Ion exchange resins need to be regenerated with a high concentration sodium chloride or other solution. In general, the regeneration waste from the ion exchange process represents 2 to 3% of the treated flow volume. Disposal of the regeneration waste is difficult. The regeneration waste contains high TDS and high concentrations of target contaminants. If containing a high level of arsenic, the waste may be considered hazardous. For small facilities, diluting the waste and discharging to the sewer may be an option, but would require permitting coordination.
- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated on a case-by-case basis with consideration for the economics of alternative treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.

IMPLEMENTATION PACKAGE FOR NF/RO

NANOFILTRATION/REVERSE OSMOSIS TREATMENT TECHNOLOGY

An NF/RO treatment facility generally consists of strainers, prefilters, optional pH adjustment chemicals, scale inhibitor chemicals, NF/RO membrane systems, disinfection chemicals, finished water storage, and finished water pumping. The NF/RO treatment technology basis of design is included in Table WT.H-1. The NF/RO process flow diagram is included in Figure WT.H-1.

Table WT.H-1 NF/RO Treatment Technology Basis of Design Water Technology Assessment City of Surprise			
Parameters	**Units**	**Values**	**Range / Notes**
Design Flows	mgd	1	1 ~ 10
Feed Water Arsenic Level	mg/L	0.03	Example
Arsenic Rejection Rate	%	99	When sulfate < 50 mg/L, verify with media supplier based on specific water quality
Recovery Rate	%	85	Assume no concentrate management
Treatment Water Loss	%	15	
Product Water Arsenic Goal	mg/L	0.008	City of Surprise Water Quality Standard
Flow Rate for Treatment	Gpm	514.1	Example
Flow Bypassed Treatment	Gpm	102.8	Example
Flow Rate to the Final Blended Stream	Gpm	616.9	Example
Treated Flow Percentage	%	83.3	Example
Prefiltration			
Type of Prefilters	-	Cartridge Filters - 5 micrometers nominal pore size. Optional Sand Strainer.	
Number of Prefilters	-	1 per train	
Target Feed Water SDI		≤ 3	
Membrane			
Design Flux	gfd	15	Detailed array design pending water quality information
Number of Stages	ea	2	2 or 3
Elements per Vessel	ea	7	7 for two-stage; 6 for three-stage
Array Design		4:2	4:2:1 for three stage
Design Recovery	%	85	80 to 85%
Potential Membrane Elements		Hydranautics ESPA2, Koch TFC-HR, Toray TM-720, Woongjin RE	Dependent on water quality data
Estimated Cleaning Interval		4 to 6 months	

Table WT.H-1 NF/RO Treatment Technology Basis of Design
Water Technology Assessment
City of Surprise

Parameters	Units	Values	Range / Notes
Chemical Pretreatment			
Optional pH Adjustment	-	CO_2 or Sulfuric Acid	Doses pending water quality
Fouling Control	-	King Lee Y2K Antiscalant	KingLee Pretreat Plus or Y2K; Avista Vitec 3000 & 4000; Professional Water Technologies Spectra Guard
Chemical Post Treatment			
Type of Treatment		Degasifier Tower	
Loading Rate per Degasifier	gpm/sf	18	15 to 20
Air / Water Loading	scfm/gpm	3	
Air Differential (inlet - outlet)	in water	4	
Optional pH Adjustment	-	Lime or Caustic Soda	Doses pending water quality
Disinfection			
Type of System	-	Bulk / Onsite Sodium Hypochlorite	
Typical Dose	mg/L	2	1 - 4 ppm
Residuals			
Concentrate Disposal	-	Sewer Discharge, if permitted. If sewer discharge is not permitted, concentrate management and disposal options can be cost prohibitive.	

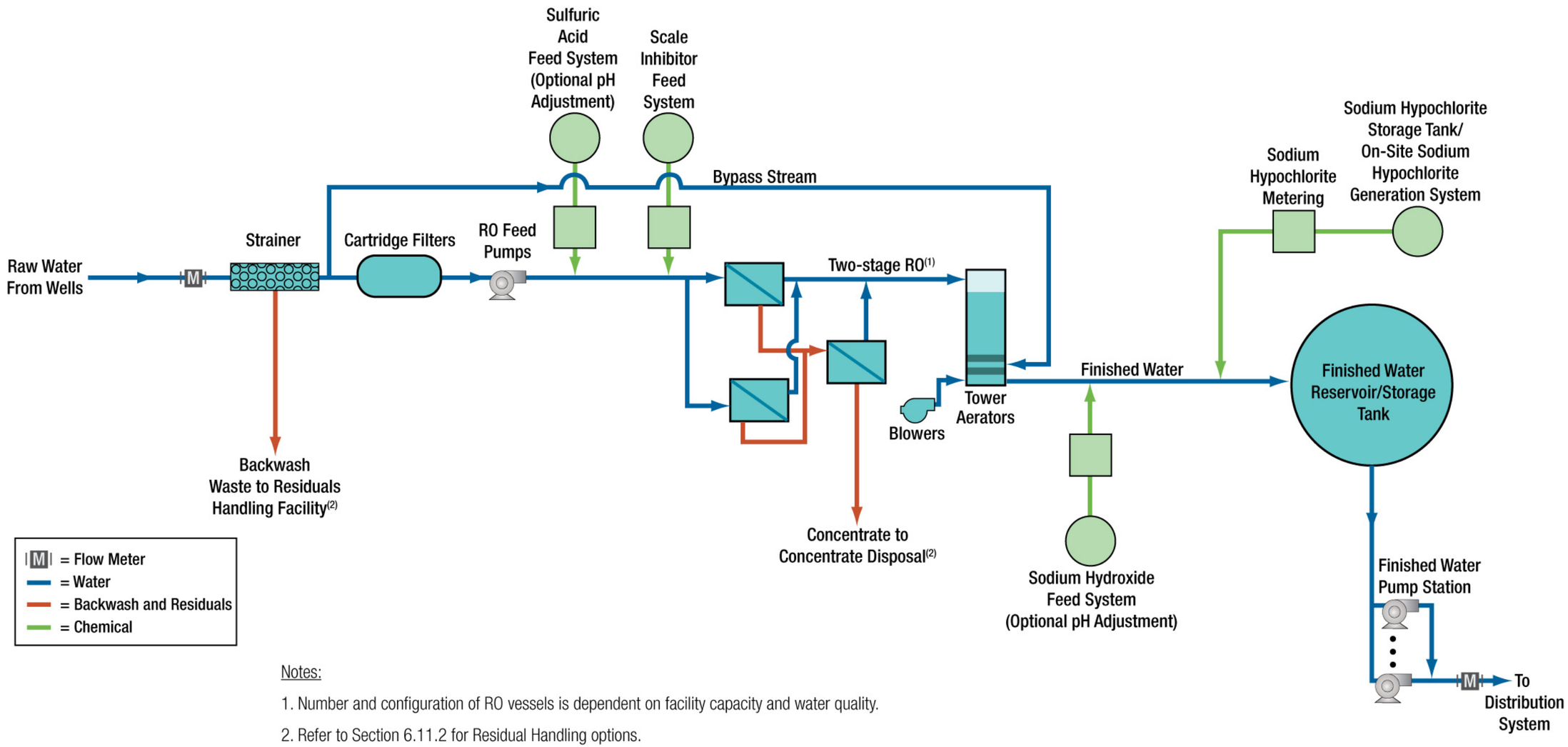
Notes:

(1) Information presented above is an interactive basis of design table. Blue cells are inputs. Engineering judgment is required to adjust the parameters.

(2) Basis of design presented is intended for planning level evaluation only. Parameters are subject to change pending the specific water quality, media selection, and site-specific considerations.

(3) The membrane replacement frequency and the allowable blending ratio depend on arsenic levels in the feed water and the specific water quality. The analysis presented above must be validated as part of the preliminary design.

(4) Recovery rates for nitrate and fluoride vary significantly depending on membrane selection. Recovery can be 90% or higher for RO membranes but is typically lower for NF membranes.



Notes:

1. Number and configuration of RO vessels is dependent on facility capacity and water quality.
2. Refer to Section 6.11.2 for Residual Handling options.

NANOFILTRATION/REVERSE OSMOSIS PROCESS FLOW DIAGRAM

FIGURE WT.H-1

CITY OF SURPRISE
WATER TECHNOLOGY ASSESSMENT REPORT

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NANOFILTRATION/REVERSE OSMOSIS DESIGN CONSIDERATIONS

The following list includes design considerations associated with NF/RO technology. This list should be reviewed when initially considering NF/RO technologies as well as during the preliminary and final design of any NF/RO treatment facilities.

- Parameters that can impact the membrane process may include, but are not limited to, pH, alkalinity, arsenic, phosphorous, silica, barium, calcium, magnesium, nitrate, vandium, fluoride, sulfate, iron, manganese, chloride, TOC, TDS, etc.
- Before implementing this option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This will provide opportunities for process optimization and cost reduction.
- The membrane design flux and the allowable blending ratios cannot be determined without actual water qualities. The analysis above presented an example which must be updated when the specific water quality data are available.
- When specific water quality data is available, the design Engineer should consult with the membrane supplier to finalize the selection of membrane products. Perform membrane modeling evaluations and optimize the array design. Pilot testing may be required for complicated applications. NF membranes have lower salt rejection than RO membranes and are slightly less efficient in removing mono-valent ions such as sodium, chloride, fluoride, and nitrate.
- A conventional oxidation process is not recommended. Excessive oxidant (> 0.5 mg/L free chlorine) may degrade membranes. High Fe (III) and manganese in the feed water can foul the membranes and reduce membrane life. If water containing iron or manganese will uptake more than 5 mg/L of oxygen, or has been chlorinated, Fe^{2+} (ferrous) is converted into Fe^{3+} (ferric), which forms insoluble colloidal hydroxide particles that may foul RO/NF membranes.
- NF/RO can remove multiple contaminants through one process, including inorganics (TDS, arsenic, nitrate, and fluoride) as well as organics and pathogens.
- RO is a best available technology (BAT) for arsenic, nitrate, and fluoride treatment as identified in the Safe Drinking Water Act.
- Depending on the water quality and the blending ratio, post-treatment may or may not be necessary.
- NF/RO has very low fouling concerns for groundwater applications at 85% recovery. Membranes may require cleaning in place every six months.

- The process may lose up to 15% water as concentrate (or brine). If sewer discharge is not an option, brine management can be cost prohibitive. Sewer disposal may be a short-term solution especially for small a facility, but requires a pretreatment permit and will impact the downstream wastewater treatment plant APP permit. Brine disposal via sewer could also increase the reclaimed water salinity and reduce its reuse potential.
- Discharge of residuals to the sanitary sewer is not acceptable unless approved by the City. Sanitary sewer discharge will be evaluated by the City on a case-by-case basis with consideration for the economics of residual treatment, the impacts on the sewer capacity, the water reclamation facility operations, water reclamation facility APP, reclaimed water quality, and City codes that limit discharge to the sewer.

SURPRISETREE™ WATER MODEL USER'S GUIDE

Engineers...Working Wonders With Water™

City of Surprise

Design Guidelines and Technology Assessments

SurpriseTree™ Water Model User's Guide

FINAL
April 2011

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City of Surprise

Design Guidelines and Technology Assessments

SurpriseTree™ Water Model User's Guide

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1.0 SURPRISETREE™ WATER MODEL

This document provides instructions to the City of Surprise and other users to assist in navigating and utilizing the SurpriseTree™ Water Model. The SurpriseTree™ Water Model is intended for use by the City of Surprise in determining the most technically feasible and economically acceptable water treatment technology options for its future groundwater treatment facilities. Preliminary basis of design, process flow diagrams, and design considerations included in the Water Technology Assessment Report establish the typical design parameters and configurations for the recommended technology options. They represent the minimum acceptable requirements for implementing these treatment technologies at the City's future WSFs and provide a documented starting point for the City and developer's Engineer.

1.1 Purpose of the SurpriseTree™ Water Model

Based on a review of available data from the City of Surprise's current wells in Special Planning Area (SPA) 1 and SPA 2, groundwater quality varies significantly. It is anticipated such variations could be even more significant when development in other SPAs occurs in the future. As discussed throughout the Water Technology Assessment Report, the optimum groundwater treatment technology for a new well greatly depends on the specific water quality (competitive ions, pH, etc.) and site-specific inputs such as facility size. For example, target contaminant levels and competitive ions in the groundwater can dramatically change the selection of adsorption media and ion exchange (IX) resins. In addition, it can impact the capacity of the media, the replacement and/or regeneration frequency, and the capital and O&M costs associated with the primary treatment as well as residuals handling. Selecting a technology without adequate water quality information can result in inadequate treatment and a wide variety of operation and maintenance challenges.

There is likely no single technology that meets the needs of all of the City's future WSFs. Consequently, in order to provide a more useful tool for the City in selecting the optimum treatment technology for future WSFs, a more holistic and flexible approach needed to be developed. To provide the City with a useful tool that could assess available treatment alternatives for a given set of water quality inputs and site-specific conditions, Carollo developed an innovative, advanced macro-based excel model named SurpriseTree™ Water. A copy of this model is located on a CD attached with this report.

Using SurpriseTree™ Water, the results of the technology alternative assessment are not limited to a single fixed set of recommendations. Instead, the model provides a dynamic and customized solution, which automatically generates the most technically feasible and cost effective treatment options in response to the water quality and site-specific condition inputs.

The SurpriseTree™ Water model computerizes the documentation of the evaluation methodology in a logical way. Criteria established by City staff and developer representatives (referred to as implementation-based criteria) are supplemented by performance-based evaluation and capital, O&M and lifecycle cost analysis developed by engineers. Weighting factors for the implementation-based criteria were developed by averaging the inputs from City staff and developer representatives. All weighting factors, ranking scores, and unit costs are fully adjustable by the City, providing significant flexibility to adjust to changing future conditions. The model employs a user-friendly spreadsheet structure, powered by macro-based selector buttons to make the site-specific analysis prompt and easy.

While the SurpriseTree™ Water model can provide detailed analyses for a given set of inputs, it is designed to be a master planning level tool. As with any similar application, the model and its outputs are only as accurate as the input information. For example, inputs like capital and O&M cost information must be updated regularly to ensure the recommendations are valid. Ultimately, the model provides a practical tool to document the City's decisions and incorporate the City's institutional and technical knowledge with technical information/data provided by the engineer. Through continuing efforts by the City (assisted by the engineer when necessary), this platform can be "calibrated" and improved to meet the City's needs now and in the future.

In summary, the SurpriseTree™ Water Model was created to assist in establishing a mechanism and an evaluation methodology for the City to perform site-specific evaluations when actual water quality and other site information is more clearly defined for a given facility. It provides a baseline for technology selection and outlines the general required design criteria and considerations for a specific application in an effort to give the City confidence in their ultimate treatment technology selection. However, it leaves detailed design decisions, facility layouts, and other site-specific decisions to the design engineer to promote more informed and effective decision making.

1.2 Intended Use of the SurpriseTree™ Water Model

The SurpriseTree™ Water Model provides the City of Surprise with a means to identify the most applicable treatment technologies for a well water supply based on water quality and site-specific conditions. A detailed water quality analysis should be performed for each new/proposed well to identify the primary and secondary parameters that may require treatment or may impact the treatment process selection or performance. In addition, site specific planning information (i.e. initial and ultimate facility capacity, site area available, etc.), should be evaluated to determine their potential impact on treatment technology selection.

As the intent of the model is to provide a master planning level tool, it is recommended that the City consider the top three to five ranked treatment processes for the new WSF. Once the treatment processes have been selected, the City can provide the developer with the corresponding implementation package from the Water Technology Assessment Report to use as a baseline for preliminary design.

This approach provides the developer with the flexibility to select the treatment technology that best fits their application and promotes a preliminary design based on actual source water quality, site-specific conditions, and current market conditions. The approach also helps to ensure that the City receives a facility that meets agreed upon performance and implementation based standards as well as minimum baseline design criteria for the associated technology. Finally, the approach provides opportunities for process optimization and promotes cost reduction for the City.

In general, the SurpriseTree™ Water Model is intended for use directly by the City of Surprise or their designated representatives. However, at the City's discretion, the model may be used/adapted by developer representatives to assist in determining applicable treatment technologies for a new source.

2.0 QUICK GUIDE FOR SURPRISETREE™ WATER MODEL

The following section contains a quick reference/demonstration guide for the SurpriseTree™ Water model. The basis for this demonstration is the City of Surprise Sierra Verde Well No. 1. Water quality data and site-specific information from the Sierra Verde Well No. 1 was used to outline the purpose and functionality of the various sections of the model. Refer to Section 3.0 for more detailed descriptions associated with how to use the model.

2.1 Introduction, Instruction Sheets and Tool Bars

After opening the SurpriseTree™ Water Model, the first interface is the Introduction Sheet. Clicking on the introduction image brings users to the Instruction/Help page. The "help" page is designed for first time users. Definitions of terms and symbols used throughout the model are defined as part of the sheet.

The tool bars across the top of the screen are accessible throughout the SurpriseTree™ Water model. Placing the mouse cursor over the icons displays the button's function. The user can be redirected to the associated sheet by clicking one of the tool bar options. The tool bar is shown below. The green arrows on each sheet can also be used to navigate to the next or previous page.

Home	**Project Information**	**Water Quality Inputs**	**Performance Based Weighting Factors**	**Implementation Based Weighting Factors**	**Decision Making Tool**	**Report**	**Costs**	**Decision Tree**	**Help / Instruction**

When closing out of the SurpriseTree™ Water model, be sure to go back to the Introduction Sheet and save the associated changes. This will allow the next user to begin with the Introduction Sheet the next time the file is opened.

2.2 Input Facility Information

2.2.1 <u>Quick Guide</u>

When the user clicks on the introduction screen, the SurpriseTree™ Water model will navigate to its Input 1- Information sheet.

Clicking on the facility information icon will also take the user directly to the Input 1 – Information sheet.

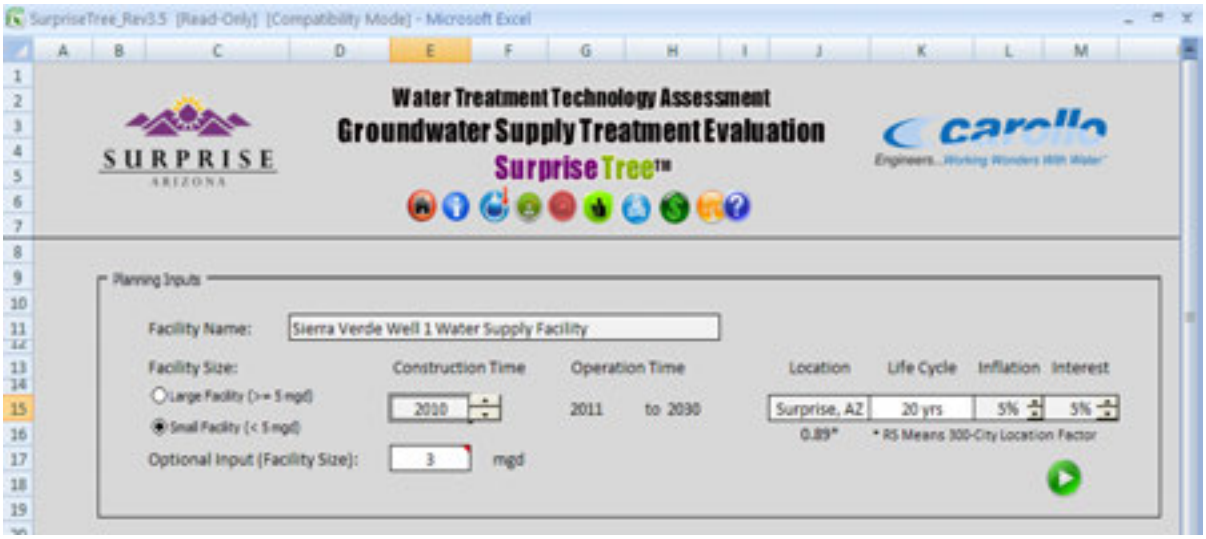
The user should input associated facility information in the activated cells.

Clicking the right arrow will proceed to the next page.

2.2.2 Other Items of Note

Refer to Section 3.2 for additional details.

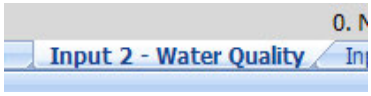
On the Input 1- Information sheet, the user enters the site-specific information for the facility as shown in the example screen capture below. The user must enter the facility name, the facility size, location, life cycle, inflation rate, and interest rate. In the example below (the Sierra Verde Well No. 1), the WSF size is 3 mgd. As part of the SurpriseTree™ Water model, any facility less than 5 mgd was considered to be a small treatment facility. The small facility treatment size will be used throughout the model to determine the most applicable treatment process. Based on the entered location, Surprise, Arizona, the model automatically identifies the RS Means 300 City Location factor to be 0.89. This factor is used in the model for the cost analysis. The entered information for life cycle, inflation rate, and interest rate is also used in the model as part of the cost analysis.



2.3 Input Water Quality

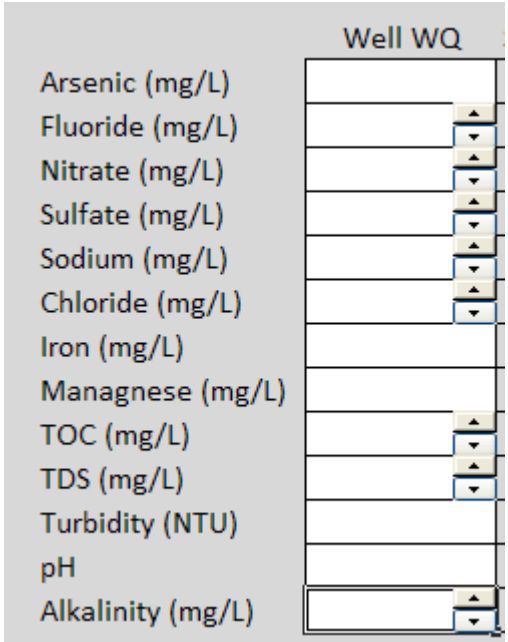
2.3.1 Quick Guide

The user can navigate to the Input 2 – Water Quality sheet by clicking on the associated tab

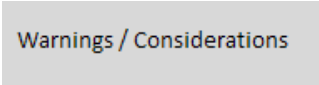


or by clicking on the water quality icon .

The user should input associated site specific water quality information in the activated cells.



Specific water qualities may result in associated warning or consideration messages. The user should carefully read and consider the warning and consideration messages



prior to proceeding.

Check the entered data.

Clicking on the right arrow will proceed to the next page.

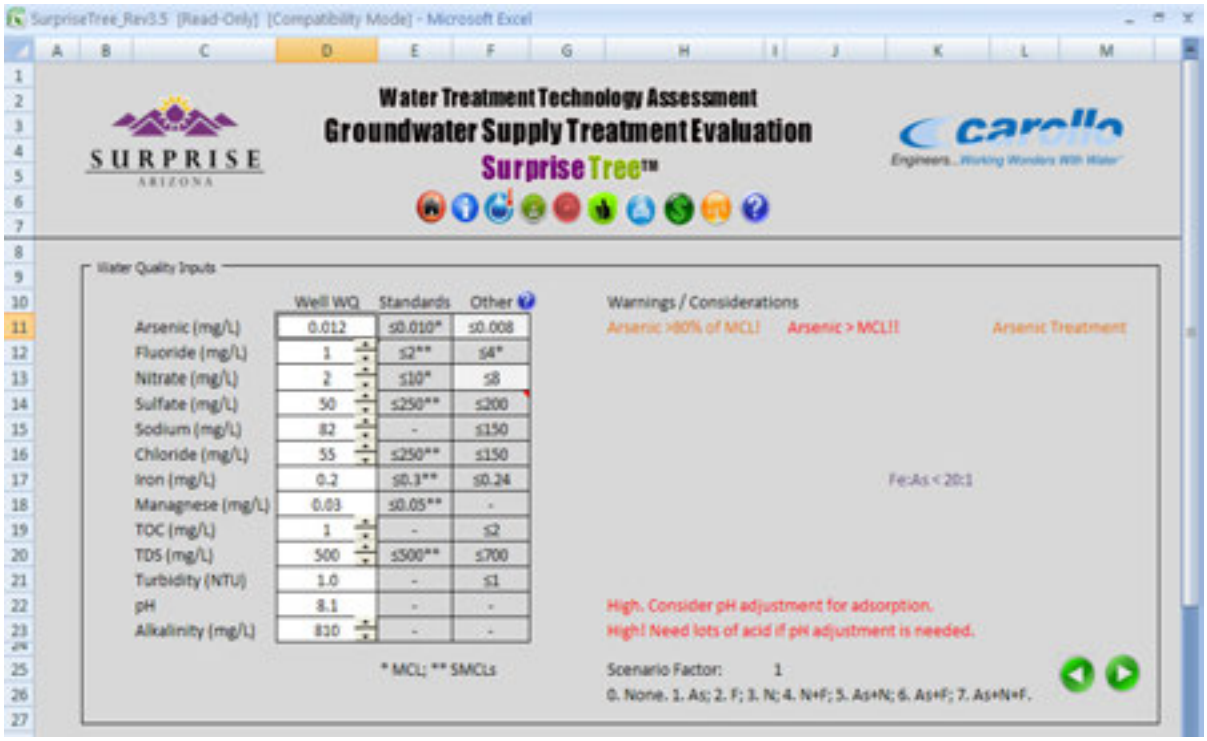
2.3.2 Other Items of Note

Refer to Section 3.3 for additional details.

On the Input 2 - Water Quality sheet, the user enters the site specific water quality information for the facility as shown in the screen capture below. In the example below (the

Sierra Verde Well No. 1 well completion report data from February 2004), the model identified the following Warnings/Considerations:

- Arsenic exceeds 80% of the MCL, and exceeds the MCL, thus requiring treatment.
- The Iron to Arsenic Ratio is less than 20:1. This will affect the treatment process recommendation.
- The pH is high, consider pH adjustment for adsorption.
- The alkalinity is high. Need a large amount of acid if pH adjustment is required.
- For this example, the scenario factor is 1, reflecting that only arsenic treatment is required.



2.4 Performance Related Weighting

2.4.1 Quick Guide

The user can navigate to the Input 3 – Weighting 1 sheet by clicking on the associated tab

or by clicking on the Performance Related Weighting icon .

The user can choose to utilize the default weighting factors or can adjust the factors accordingly.

Clicking on the right arrow will proceed to the next page.

2.4.2 Changing the Weighting Factors

The user should review the performance weighting factors, as previously identified by the engineer, and as shown in the screen capture below. The weighting factors were assigned to each performance based criterion on a 0 to 10 scale, with 0 representing the least important/applicable and 10 representing the most important/applicable. The weighting factors were assigned by the engineer and can be adjusted to reflect the relevance of different treatment categories to a specific target Contaminants of Concern (CoC). Placing the mouse cursor over each criterion displays a definition of the associated criterion.

Performance Based Weighting Factors

Does this option provide log-removal credits of pathogens? Does this option help to improve the pathogen kill by other process?

	Particle Removal	DBP Control	Pathogens	M		Nitrate Removal	Fluorid Remov
Oxidation	0	5	5			0	0
Arsenic	3	0	3	5	10	0	0
Fluoride	3	0	3	3	0	0	0
Nitrate	3	0	3	3	0	0	0
Disinfection	0	10	10	5	5	0	0

2.4.3 Resetting Weighting Factors

The user can adjust weighting factors as required based on sound engineering judgment and sufficient technical justification. Adjusting the weighting factors may also be helpful when performing a sensitivity analysis. The default settings can be restored by clicking the reset button [Reset Default].

2.4.4 Other Items of Note

Refer to Section 3.4 for additional details.

For the purposes of this demonstration, the performance based weighting factors were maintained at those established by the engineer. Based on the performance based weighting factors, the following can be inferred for this specific example:

- In the *Particle Removal*, *DBP control*, *Pathogens* and *Iron and Manganese Removal* columns, weighting factors were assigned to those processes that are capable of achieving the respective treatment.
- The *Arsenic Removal* column contains weighting factors for those processes that are capable of achieving arsenic removal, including the oxidation process, the arsenic treatment process, and the disinfection process.
- In the *Nitrate Removal* and *Fluoride Removal* columns, the weighting factors are 0 because neither nitrate or fluoride treatment is required based on the input water quality.

2.5 Implementation Related Weighting

2.5.1 Quick Guide

The user can navigate to the Input 4 – Weighting 2 sheet by clicking on the associated tab

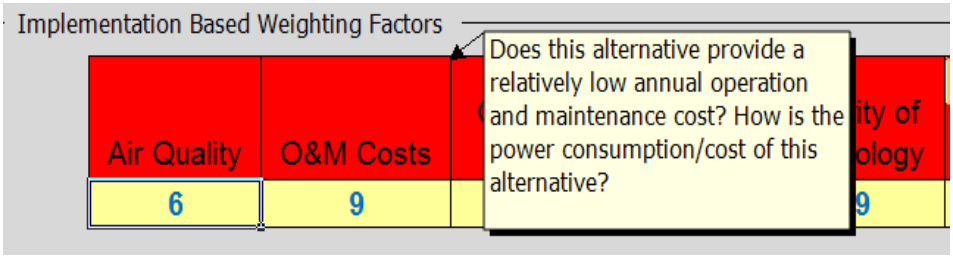
or by clicking on the associated Implementation Related Weighting icon .

The user can choose to utilize the default weighting factors or can adjust the factors accordingly.

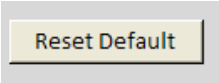
Clicking on the right arrow will proceed to the next page.

2.5.2 Changing the Weighting Factors

The user should review the implementation weighting factors, as previously identified by the City and developer representatives, and as shown in the screen capture below. The weighting factors were assigned to each implementation based criterion on a 0 to 10 scale, with 0 representing the least important / applicable and 10 representing the most important / applicable. Placing the mouse cursor over each criterion displays a definition of the associated criterion.



2.5.3 To Reset Weighting Factors

The user can adjust weighting factors as required. Adjusting the weighting factors may also be helpful when performing a sensitivity analysis. However, because the criteria were developed as part of a collaborative effort between the City and developers, the default settings should be utilized unless the user has a specific and justifiable reason to change the weighting factor. For example, a new SPA with low population density may justify a lower weighting associated with the “footprint” criterion. In this case, changes can be made by typing the new weighting factor in the “footprint” cell. The default settings can be restored by clicking the reset button 

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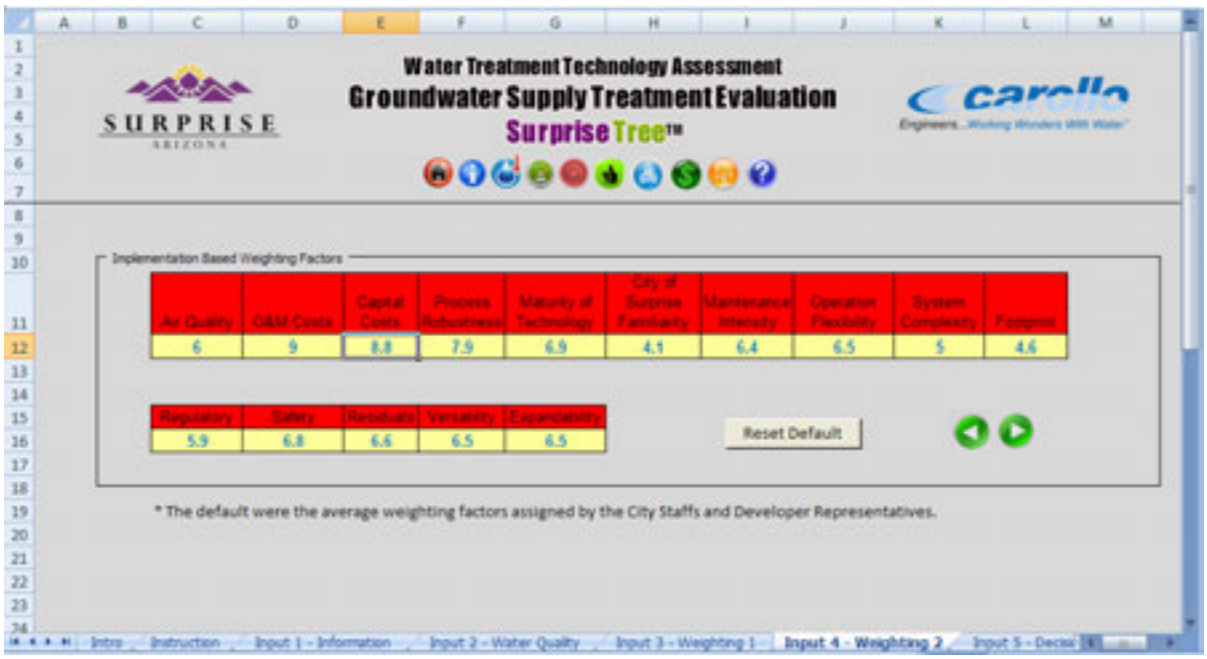
2.5.4 Other Items of Note

Refer to Section 3.5 for additional details.

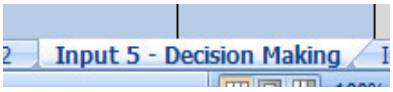
For the purposes of this demonstration, the implementation based weighting factors were maintained at those established by the City and developer representatives. Based on the implementation based weighting factors, the following can be inferred for this specific example:

- The *O&M Costs* criterion has the highest weighting factor of 9.0, implying that O&M costs are the most important implementation factor to the City and developers.
- The *Capital Costs* criterion has the 2nd highest weighting factor of 8.8.
- The *City of Surprise Familiarity* with a treatment technology has the lowest weighting factor of 4.1, implying that familiarity is the least important implementation factor to the City and developers.



2.6 SurpriseTree™ Recommendations

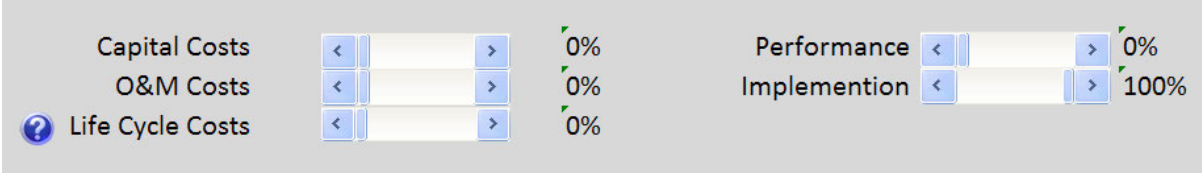
2.6.1 Quick Guide

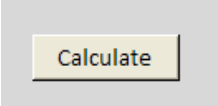
The user can navigate to the Input 5 – Decision Making sheet by clicking on the associated tab 

or by clicking on the associated Surprise Tree Recommendations icon .

The implementation based weighting factors represent a stand-alone comprehensive evaluation incorporating costs, process reliability, operational issues, regulatory and safety

issues, etc. To use the City assigned default weighting factors, the user should set the slide bars for performance, capital, O&M, and life cycle costs at 0% and the slide bar for implementation at 100%.



Click the calculate button 

and review the top recommended treatment processes for the specific water quality, site specific inputs and weighting factors.

Costs and performance are two major categories that could influence the technology selection. The user can consider performing a sensitivity analysis by assigning extra weighting for costs or performance by dragging the slide bars as described below.

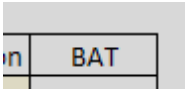
2.6.2 To Consider Extra Weighting for Costs

Keep the implementation slide bar at the 100% level and the performance slide bar at 0%. Drag one of the capital, O&M or life cycle bars to the appropriate weighting. Click the calculate button to determine changes in the recommendation. Change the setting and calculate again, if desired.

2.6.3 To Consider Extra Weighting for Performance

Keep the implementation slide bar at the 100% level and reset the slide bars for costs to 0%. Drag the performance bar to the appropriate weighting. Click the calculate button to determine changes in the recommendation. Change the setting and calculate again, if desired.

2.6.4 Best Available Technologies Identified

The SurpriseTree™ Water Model includes a column in the decision making tool sheet to identify whether a recommended technology is one of the Best Available Technologies (BATs) accepted by EPA. 

2.6.5 To Access the Implementation Packages

The SurpriseTree™ Water Model provides a hyperlink for each of the recommended technologies to allow the user to quickly access the implementation package for each

technology. Implementation packages include basis of design, process flow diagrams, and design consideration lists for the associated technology Click here for package.

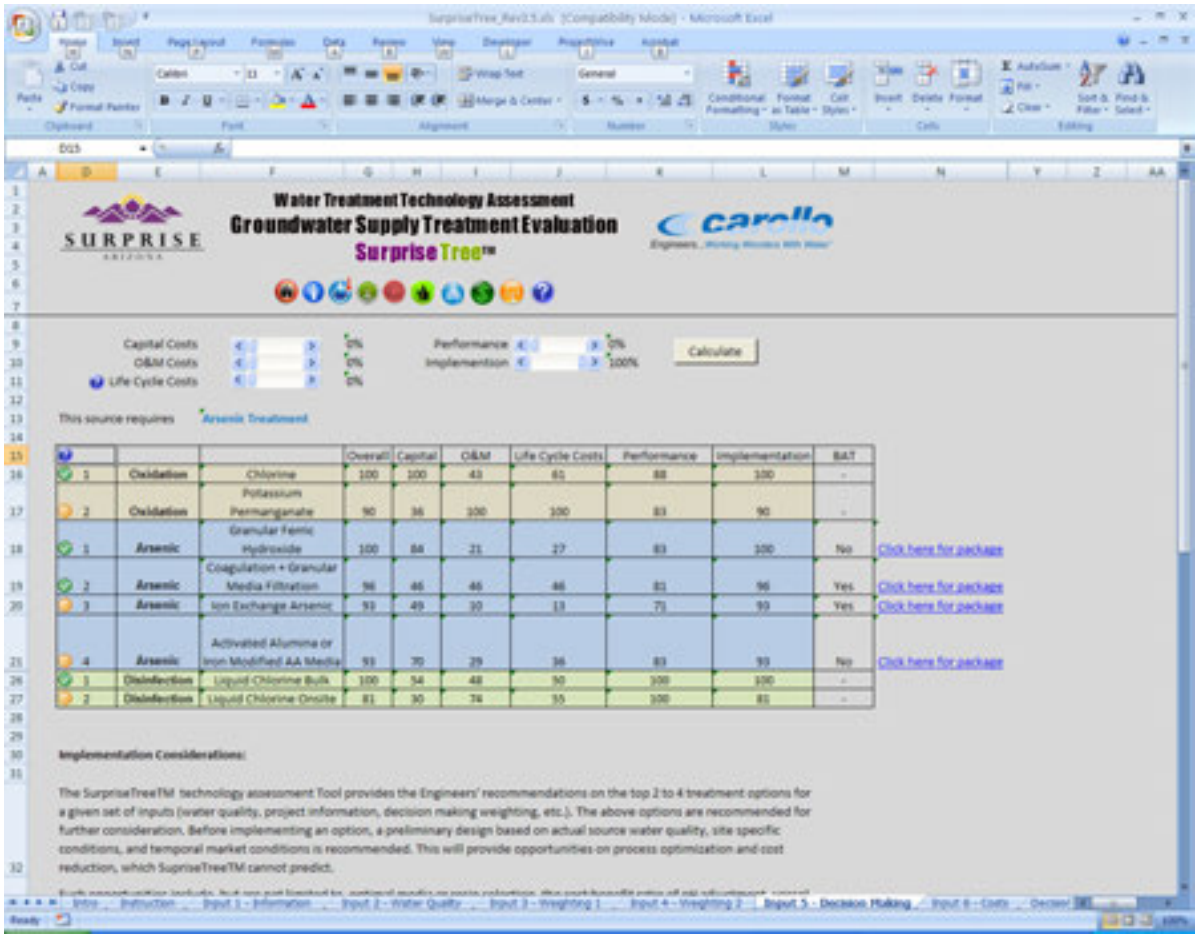
2.6.6 Other Items of Note

Refer to Section 3.6 for additional details.

The decision input sheet includes scale bars to provide quick, visual adjustment capability to determine the significance of the decision-making factors. As explained previously, the decision making is a three-tier process, including implementation based criteria, performance based criteria and costs.

For the purposes of this demonstration, the decision making factors were maintained at 100% implementation criteria based on City preference. The decision making sheet contains the top ranked treatment processes for the WSF. Each treatment process is given an overall score, a score based on capital cost alone, a score based on O&M cost alone, a score based on life cycle costs alone, a score based on performance based criteria alone and a score based on implementation based criteria alone. The overall score represents a normalized score for that treatment process while taking into consideration the weighting percentages of the decision making factors. The top recommended treatment process in each category is normalize to a score of 100. From the decision making sheet, the following interpretations can be inferred for this specific example:

- The top recommended oxidation treatment chemicals are chlorine and potassium permanganate.
- The top recommended arsenic treatment processes are adsorption using GFH or IMM, coagulation with granular media filtration, ion exchange, and adsorption using AA.
- The top recommended disinfection treatment processes are liquid chlorine in bulk form and liquid chlorine generated on-site.
- All of the top recommended treatment processes should be evaluated by the user and considered as potential treatment processes for the application.



2.7 Sensitivity Analysis of the Model

The SurpriseTree™ Model is sensitive to model inputs. As a model input is changed, the model output may change accordingly. This section provides several examples of the model sensitivity to input parameters. The City of Surprise Sierra Verde Well No. 1 was used again as the example facility throughout this demonstration.

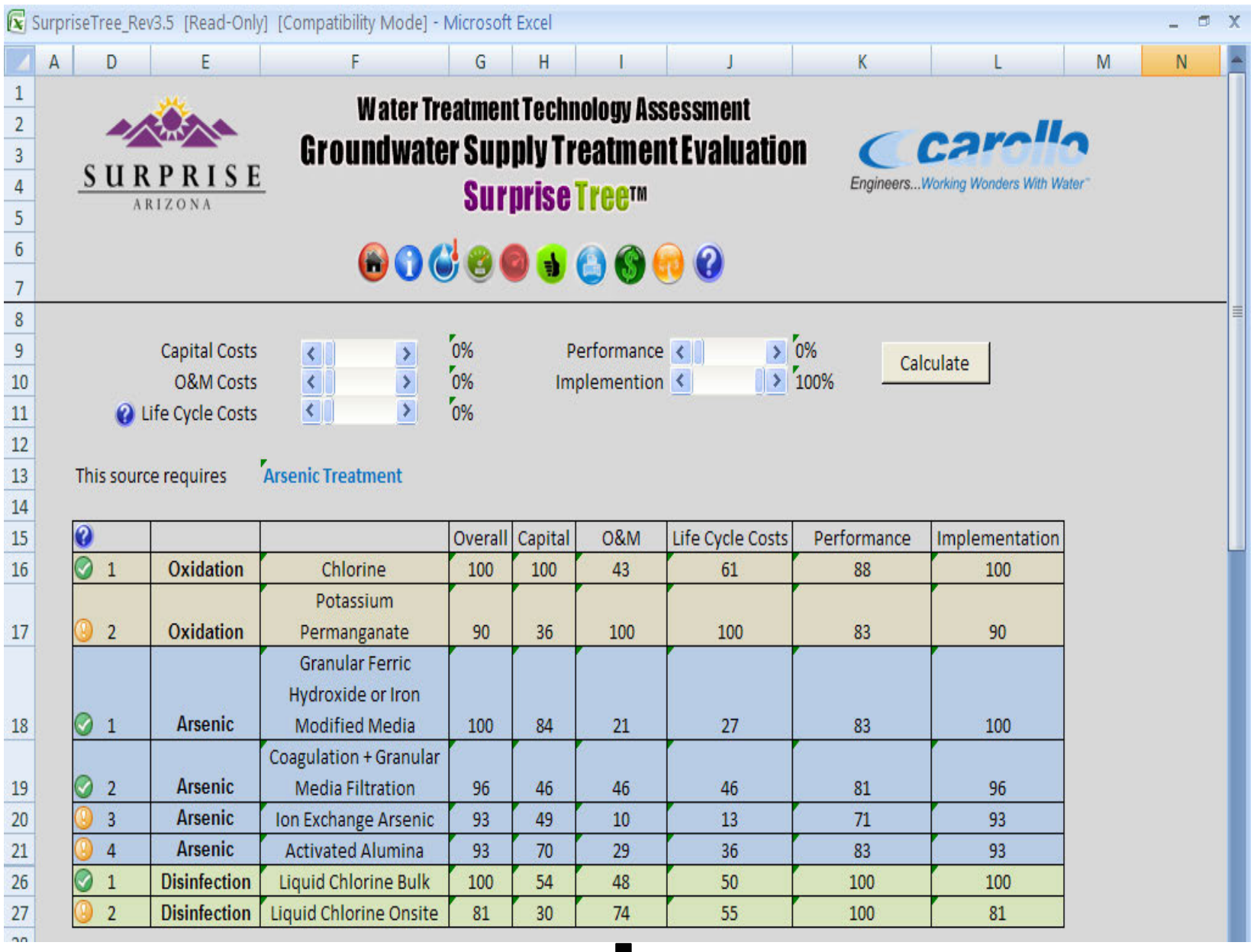
2.7.1 Changing Facility Size

The SurpriseTree™ model is sensitive to the facility size. The Sierra Verde Well No. 1 requires a 3 mgd treatment facility. For the purposes of this demonstration, 3 mgd is considered a small treatment facility. The input water quality identifies that only arsenic treatment is required. When the model is calculated on Input 5, it identifies the following top treatment technologies:

- Oxidation: Chlorine
- Arsenic Removal: Adsorption processes such as granular ferric hydroxide or iron modified media
- Disinfection: Liquid Chlorine Bulk solution.

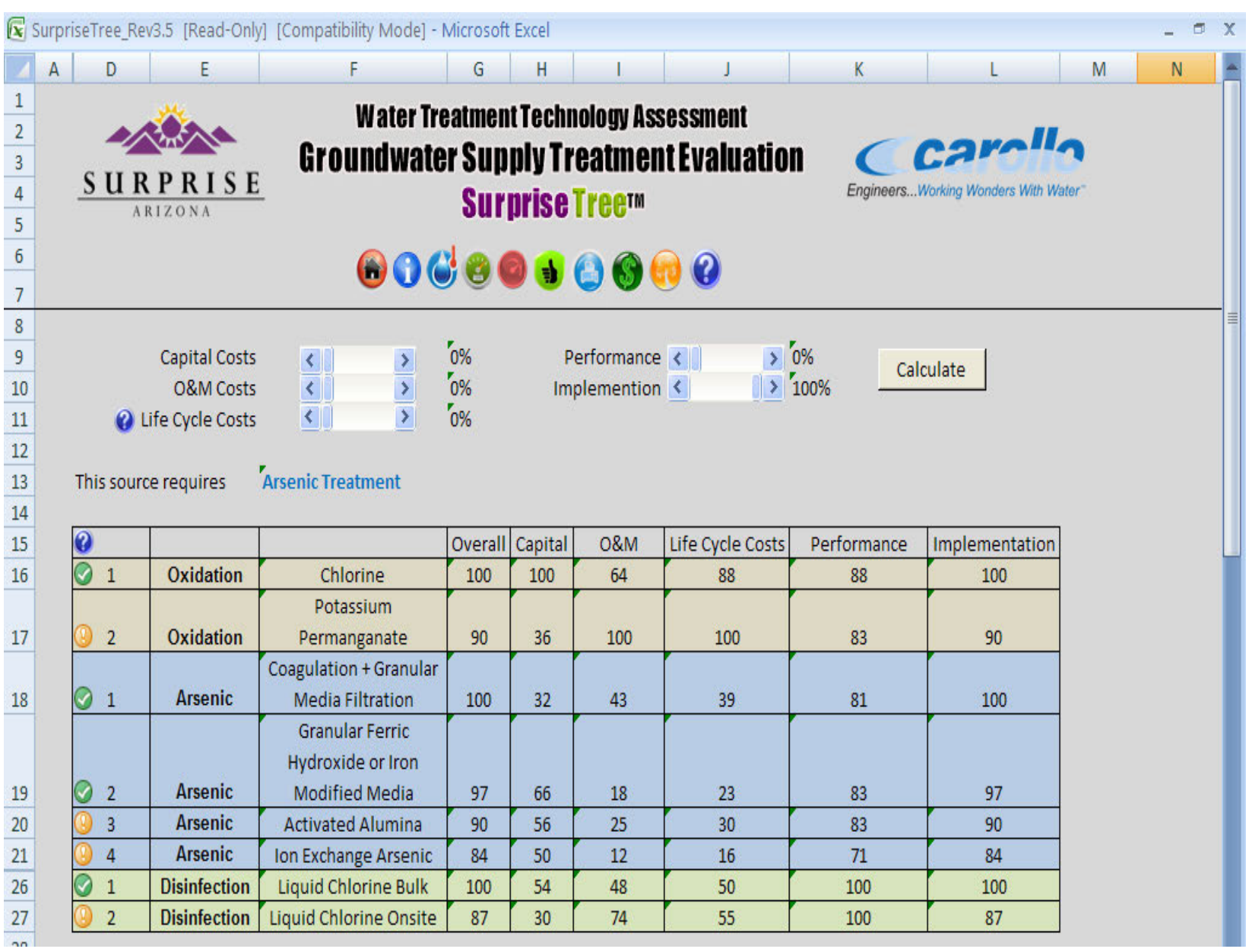
If the facility capacity is increased from 3 mgd to 10 mgd and all water quality inputs are kept the same, the recommended treatment technology for oxidation and disinfection remain the same (chlorine) but the recommended arsenic treatment technology is now coagulation with granular media filtration. The change in treatment recommendation is based on the fact that coagulation/filtration processes are more cost effective for large treatment facilities while adsorption processes are more cost effective for smaller treatment facilities. This demonstration shows the sensitivity of the model to site-specific criteria. A change in the design treatment flow can change the recommendation for treatment. A comparison of the recommended treatment technologies for a 3-mgd versus a 10-mgd treatment facility is illustrated on the following page.

Facility Size = 3 mgd



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Chlorine	100	100	43	61	88	100
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90
1	Arsenic	Granular Ferric Hydroxide or Iron Modified Media	100	84	21	27	83	100
2	Arsenic	Coagulation + Granular Media Filtration	96	46	46	46	81	96
3	Arsenic	Ion Exchange Arsenic	93	49	10	13	71	93
4	Arsenic	Activated Alumina	93	70	29	36	83	93
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81

Facility Size = 10 mgd



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Chlorine	100	100	64	88	88	100
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90
1	Arsenic	Coagulation + Granular Media Filtration	100	32	43	39	81	100
2	Arsenic	Granular Ferric Hydroxide or Iron Modified Media	97	66	18	23	83	97
3	Arsenic	Activated Alumina	90	56	25	30	83	90
4	Arsenic	Ion Exchange Arsenic	84	50	12	16	71	84
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100
2	Disinfection	Liquid Chlorine Onsite	87	30	74	55	100	87

2.7.2 Changing Decision Making Weighting Factors

The SurpriseTree™ model is also sensitive to the decision making weighting factors. The City of Surprise has standardized the model to be based on 100% implementation criteria. When the weighting is set at 100% implementation criteria based on the Sierra Verde Well No. 1, the following treatment recommendations are generated:

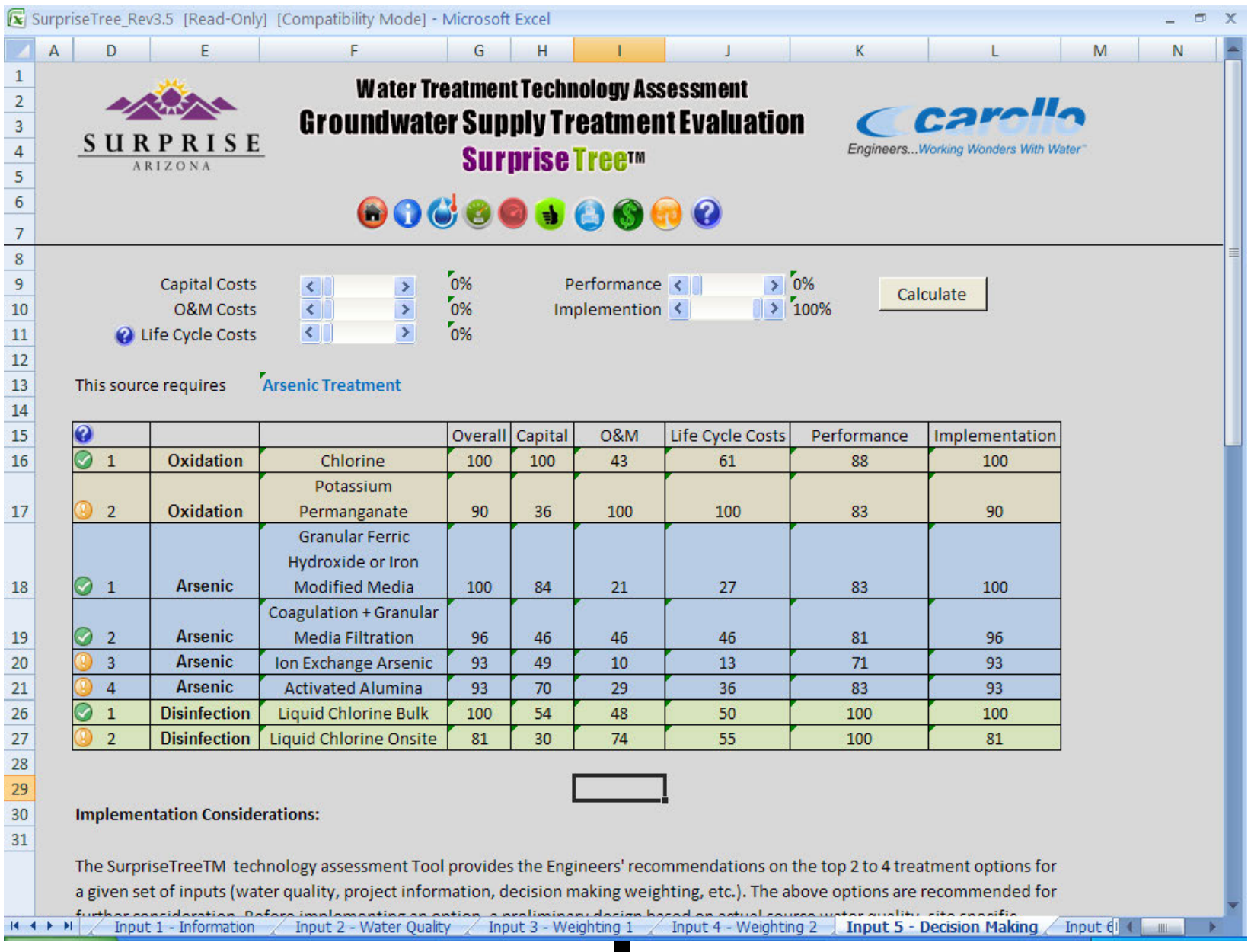
- Oxidation: Chlorine
- Arsenic Removal: Adsorption using granular ferric hydroxide or iron modified media
- Disinfection: Liquid chlorine bulk

These recommended treatment processes best meet the established implementation criteria. However, when the model is adjusted such that the performance criteria is weighted 100% (meaning only the performance of the technology is considered), while keeping all other parameters the same, the model produces the following recommendations:

- Oxidation: Ozone
- Arsenic Removal: Reverse osmosis
- Disinfection: On-site generated chlorine

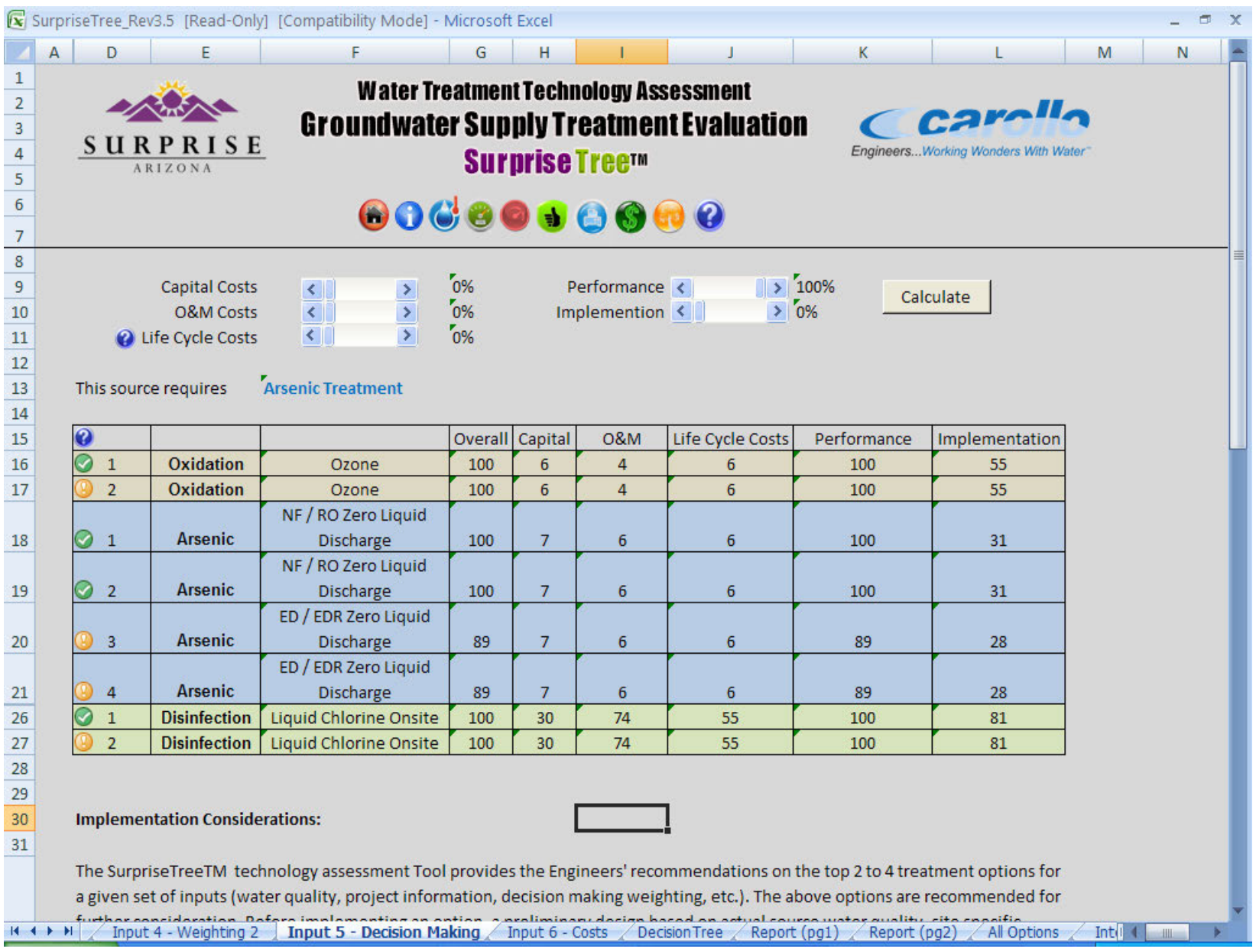
The top treatment processes based on 100% performance criteria produce the best quality water without any consideration for cost. This demonstration illustrates the sensitivity of the model to the weighting criteria used. A change in the weighting criteria can change the recommendation for treatment. A comparison of the recommended treatment technologies based on 100% implementation criteria versus 100% performance criteria is illustrated on the following page.

100% Implementation Based Criteria



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Chlorine	100	100	43	61	88	100
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90
1	Arsenic	Granular Ferric Hydroxide or Iron Modified Media	100	84	21	27	83	100
2	Arsenic	Coagulation + Granular Media Filtration	96	46	46	46	81	96
3	Arsenic	Ion Exchange Arsenic	93	49	10	13	71	93
4	Arsenic	Activated Alumina	93	70	29	36	83	93
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81

100% Performance Based Criteria



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Ozone	100	6	4	6	100	55
2	Oxidation	Ozone	100	6	4	6	100	55
1	Arsenic	NF / RO Zero Liquid Discharge	100	7	6	6	100	31
2	Arsenic	NF / RO Zero Liquid Discharge	100	7	6	6	100	31
3	Arsenic	ED / EDR Zero Liquid Discharge	89	7	6	6	89	28
4	Arsenic	ED / EDR Zero Liquid Discharge	89	7	6	6	89	28
1	Disinfection	Liquid Chlorine Onsite	100	30	74	55	100	81
2	Disinfection	Liquid Chlorine Onsite	100	30	74	55	100	81

2.7.3 Changing Water Quality

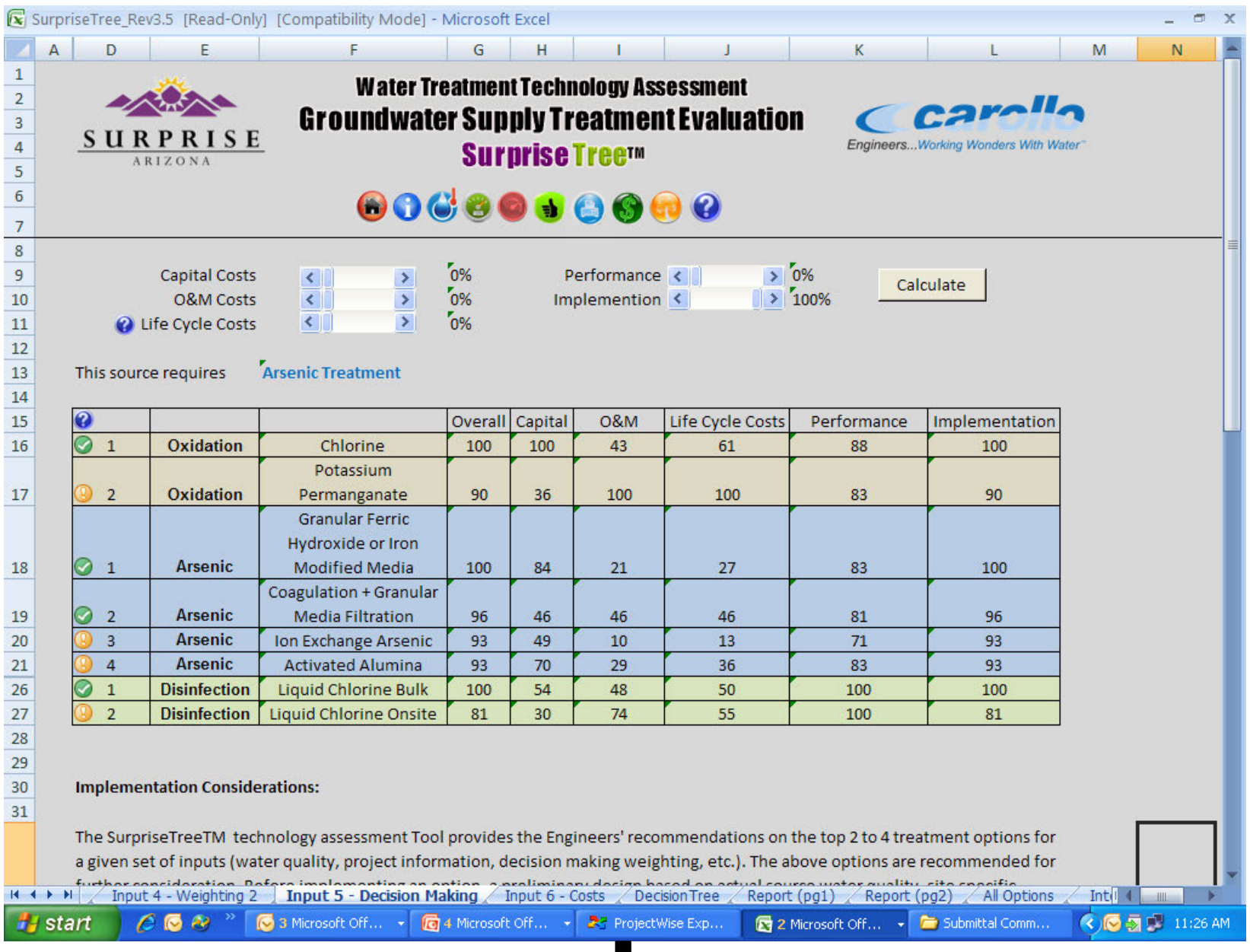
The SurpriseTree™ model is extremely sensitive to the input water quality. The Sierra Verde Well No. 1 requires arsenic treatment only. When the model is calculated, the recommended arsenic treatment process is adsorption using granular ferric hydroxide or iron modified media.

When a new set of water quality data that requires arsenic, nitrate, and fluoride treatment is input into the model (keeping all other parameters the same), the model now generates recommendations to accomplish treatment of arsenic, nitrate, and fluoride including:

- Arsenic Removal: Activated Alumina
- Fluoride Removal: Activated Alumina
- Nitrate Removal: Biological Filtration

There is synergy in recommending activated alumina as it can be used for both arsenic and fluoride treatment. This analysis illustrates the sensitivity of the model to the water quality inputs. A change in the water quality drastically changes the recommendation for treatment and the model can easily adapt for treatment of multiple contaminants. A comparison of the recommended treatment technologies for arsenic only versus arsenic, nitrate, and fluoride is illustrated on the following page.

Arsenic Treatment Only Required



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Chlorine	100	100	43	61	88	100
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90
1	Arsenic	Granular Ferric Hydroxide or Iron Modified Media	100	84	21	27	83	100
2	Arsenic	Coagulation + Granular Media Filtration	96	46	46	46	81	96
3	Arsenic	Ion Exchange Arsenic	93	49	10	13	71	93
4	Arsenic	Activated Alumina	93	70	29	36	83	93
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81

Arsenic, Nitrate and Fluoride Treatment Required

			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation
1	Oxidation	Chlorine	100	100	43	61	88	100
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90
1	Arsenic	Activated Alumina	100	70	29	36	75	100
2	Arsenic	Granular Ferric Hydroxide or Iron Modified Media	97	84	21	27	75	97
3	Arsenic	Coagulation + Granular Media Filtration	92	46	46	46	73	92
4	Arsenic	Ion Exchange Arsenic	90	49	10	13	65	90
1	Fluoride	Activated Alumina	100	86	100	100	73	100
2	Fluoride	Ion Exchange Fluoride	76	100	80	83	60	76
1	Nitrate	Biological Filtration	100	74	100	100	83	100
2	Nitrate	Ion Exchange Nitrate	89	100	41	49	70	89
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81

2.8 Update Costs

2.8.1 Quick Guide:

The user can navigate to the Input 6 – Costs sheet by clicking on the associated tab

or by clicking on the Costs icon .

The user can choose to utilize the default cost information or can adjust accordingly based on current market conditions, etc.

2.8.2 To Update the Cost Information

The SurpriseTree™ Water Model includes relative conceptual level costs for comparing the economics of each treatment technology. If updated or site specific cost information is available, the user can utilize Input 6 to override the default costs. Updated cost information can be entered into the *City's Adjustment* columns for unit capital and O&M costs.

	Facility Size: 1.83 mgd						
	Default		City's Adjustment		LCA Analysis		
	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Life Cycle ($/1000gal)
Oxidation	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Chlorine	$ 0.01	$ 0.02			$0.02	$0.02	$0.02
KMnO4	$ 0.04	$ 0.01			$0.04	$0.01	$0.02

The information should be entered in $/gallon for capital cost and $/1000 gallons for O&M costs. For the purposes of this demonstration, the costs are maintained as those developed by the engineer. Refer to Section 3.7 for additional information.

2.9 Print a Report

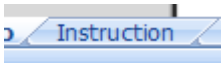
Once the preferred settings are input into Input Sheets 1 -5 and the model has been calculated on Input Sheet 5, the user can navigate to the Report (pg1) and Report (pg2) sheets by clicking on the associated tab

or by clicking on the Print Report icon.

If the user clicks the Print Report icon on the SurpriseTree™ tool bar from any page, a report will be generated automatically.

To customize the report, fill in the appropriate cells in the model and/or edit the Report 1 and Report 2 pages as appropriate.

2.10 Help

Help can be accessed from any page, by clicking the by clicking on the associated tab 

or the Question icon on the SurpriseTree™ tool bar. The user will automatically be redirected to the Help / Instruction page.

3.0 DETAILED DESCRIPTION

SurpriseTree™ Water Model is a Microsoft Excel© spreadsheet program that uses user input raw groundwater quality and site specific considerations to generate and rank treatment technologies based on specific criteria. The SurpriseTree™ Water program was customized for the City of Surprise water treatment evaluation and focuses on groundwater treatment processes for arsenic, nitrate, and fluoride. Section 2 presented a step by step example associated with how to use the model. A more detailed description of each component of the model is included in the following sections.

3.1 Introduction, Instruction Sheets and Tool Bars

After opening the SurpriseTree™ Water Model, the first interface is the Introduction Sheet. Clicking on the introduction image brings users to the Instruction/Help page. The "help" page is designed for first time users. Definitions of terms and symbols used throughout the model are defined as part of the sheet.

The tool bars across the top of the screen are accessible throughout the SurpriseTree™ Water model. Placing the mouse cursor over the icons displays the button's function. The user can be redirected to the associated sheet by clicking one of the tool bar options. The tool bar is shown in Figure 1. The green arrows on each sheet can also be used to navigate to the next or previous page.

Home	Project Information	Water Quality Inputs	Performance Based Weighting Factors	Implementation Based Weighting Factors	Decision Making Tool	Report	Costs	Decision Tree	Help / Instruction

Figure 1 SurpriseTree™ Water Model Tool Bar

When closing out of the SurpriseTree™ Water model, be sure to go back to the Introduction Sheet and save the associated changes. This will allow the next user to begin with the Introduction Sheet the next time the file is opened.

3.2 Input 1 - Information

The first input sheet in the model is the Information Sheet. The Information Sheet allows the user to input general information about the project. When a new WSF is planned, the facility must be designed in accordance with the City's current IWMP. The following planning level information should be determined by the City and input into the model:

- Facility Treatment Size
- Anticipated Operation Time
- Project Lift Cycle
- Interest Rate
- Inflation Rate

Some information input in the Information Sheet, such as the facility name and project description, is automatically transferred onto other sheets and the final SurpriseTree™ Water report. Other information, such as the facility size and construction time, is used throughout the model in the calculation of costs and various ranking scores. When the location is selected, the cost analysis is automatically adjusted using RS Means 300 City Location Factor. When the life cycle length is selected (20 years or 50 years) and the construction time is chosen, the operation life span will be automatically set to the year after the construction plus the life cycle length. When the inflation rates/interest rates are changed, the life cycle analysis is automatically adjusted. A screen capture of the SurpriseTree™ Water Input 1 – Information sheet is shown in Figure 2.

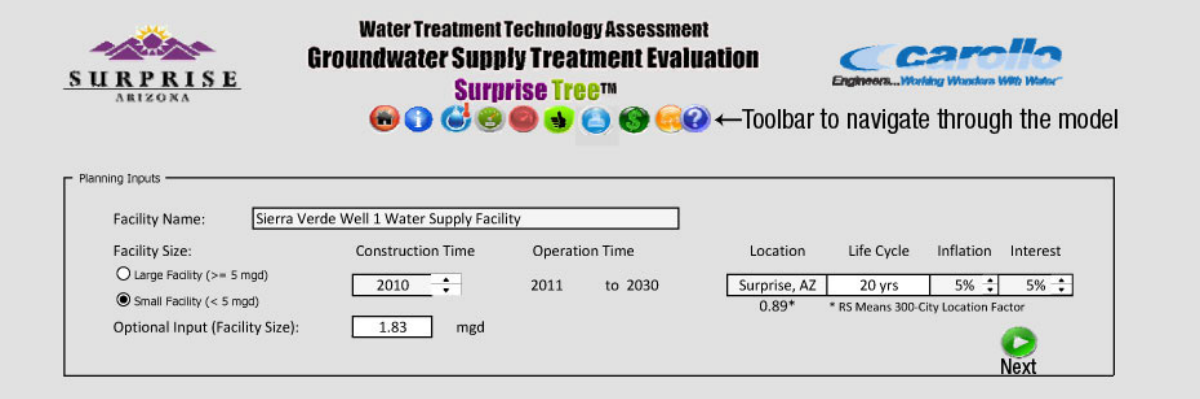


Figure 2 SurpriseTree™ Water Input 1 – Information

3.3 Input 2 – Water Quality

The second input sheet in the model is the water quality sheet. The groundwater quality data for the specific water supply should be input into SurpriseTree™ Water model to analyze the best treatment alternative for the application.. Figure 3 includes a screen capture of the SurpriseTree™ Water water quality input sheet. When a new well is proposed/drilled, a water quality analysis should be performed to identify the parameters

that may require treatment and/or may impact the selected treatment process. At a minimum, a water quality analysis should be performed to determine the levels of the following parameters:

- Arsenic
- Fluoride
- Nitrate
- Sulfate
- Sodium
- Chloride
- Iron
- Manganese
- TOC
- TDS
- Turbidity
- pH
- Alkalinity

Figure 3 SurpriseTree™ Water Input 2 – Water Quality

Warning messages and implementation considerations will be trigged when the input water quality data exceeds the City's water quality standards, other regulatory standards, or technical design thresholds. For example, when the input arsenic value is above 0.008 mg/L, a warning message indicates that the arsenic level is above the MCL and therefore requires arsenic treatment.

The water quality input sheet also defines an important parameter labeled Scenario Factor. Seven scenarios are defined in Table 1. The scenarios are used within the SurpriseTree™ Water model to identify the type of treatment that is necessary. The Scenario Factor also makes it easy for the user to identify what type of treatment is necessary based on the input water quality.

Table 1 SurpriseTree™ Water Scenario Factors SurpriseTree™ Water Model User's Guide City of Surprise		
Scenario Factors	**Abbreviation**	**Treatment Required**
0	None	No Treatment Other Than Disinfection
1	As	Arsenic Treatment
2	N	Nitrate Treatment
3	F	Fluoride Treatment
4	NF	Nitrate and Fluoride Treatment
5	AsN	Arsenic and Nitrate Treatment
6	AsF	Arsenic and Fluoride Treatment
7	AsNF	Arsenic, Nitrate and Fluoride Treatment

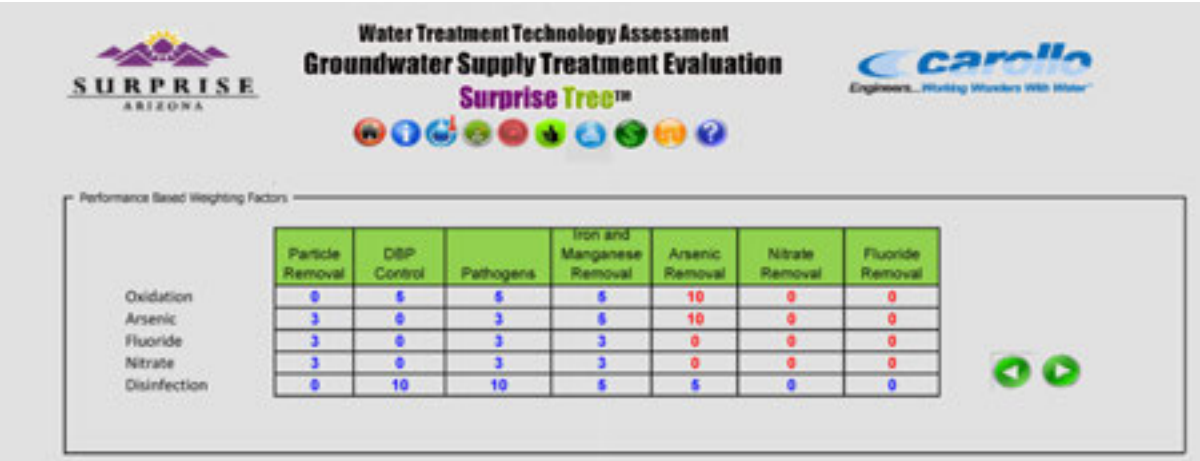
3.4 Input 3 – Weighting 1 Performance Based Criteria Evaluation

The third input sheet in the model is the performance based criteria evaluation sheet. In general, the two most important factors in the evaluation/selection of a technology are 1) The effectiveness and reliability of the technology alternative in removing the target CoCs and 2) The cost effectiveness (capital and O&M) of the alternative in achieving the City's water quality standards/treatment goals. As outlined in Section 6.3 of the Water Technology Assessment Report, the technology assessment was designed to address a full spectrum of evaluation factors while providing the flexibility to emphasize treatment performance and cost effectiveness through the use of a three-tire evaluation:

- Implementation based evaluation using a comprehensive set of criteria including capital and O&M costs, technology effectiveness, operability, implementability, and to a lesser extent, the environmental, economical, and social aspects. This set of criteria and weighting factors was developed by the City and the developer representatives.
- Performance based evaluation emphasizing technical feasibility and removal efficiency of target CoCs. This evaluation was developed by the Engineer and serves as an optional evaluation to supplement the primary implementation based criteria set developed by the City and the developer representatives.
- Financial analysis using order-of-magnitude level capital, O&M and life cycle costs. Because the implementation-based evaluation covers qualitative capital and O&M costs, this tier of evaluation can be considered as supplementary information to provide more accurate quantitative cost information. Inputs for the performance based criteria evaluation are presented in Figure 4 and defined in Table 2.

The performance based criteria are designed to provide more specific information on how a technology compares with other alternatives in terms of target CoC removal. The weighting factors were assigned to each performance based criterion on a 0 to 10 scale, with 0 representing the least important/applicable and 10 representing the most important/applicable. The weighting factors were assigned by the Engineer and can be

adjusted to reflect the relevance of different treatment categories to a specific target CoC. For example, the oxidation treatment category is important for arsenic removal but not for fluoride or nitrate removal. Therefore, a weighing factor of 10 is set for arsenic removal and weighting factors of 0 are set for fluoride and nitrate removal. Similarly, the disinfection category would receive a weighting factor of 10 for DBP control and pathogen reduction, but 0 for nitrate and fluoride removal. Because it is very likely that the primary disinfectant selected will also be used for pre-oxidation (which enhances arsenic removal), the disinfection category has a weighting factor of 5 for the Arsenic Removal criterion.



	Particle Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal
Oxidation	0	5	5	5	10	0	0
Arsenic	3	0	3	5	10	0	0
Fluoride	3	0	3	3	0	0	0
Nitrate	3	0	3	3	0	0	0
Disinfection	0	10	10	5	5	0	0

Figure 4 SurpriseTree™ Water Input 3 – Weighting 1

The user can place the mouse cursor over each criterion to display a definition of the associated criterion. As a supplemental evaluation focusing on technology performance, the performance based criteria evaluation is generally considered more flexible than the implementation based evaluation. However, because developing and updating these factors requires engineering judgment and sound technical justification, the default (which can be reset by clicking the reset button) should be used unless the user has a specific knowledge or understanding of the associated treatment technologies.

3.5 Input 4 – Weighting 2 Implementation-Based Criteria Evaluation

The fourth input sheet in the model is the implementation based criteria evaluation sheet. The implementation based criteria, which were developed by the City and developer representatives, are defined in Table 2. Nine individuals (City and developer) participated in assigning weighting factors for these criteria. The averaged weighting factors were used for the final ranking evaluation as presented in Table 3.

Table 2	Performance Based Criteria Definitions SurpriseTree™ Water Model User's Guide City of Surprise
Performance Criteria	**Definition / Description**
Particle Removal	Does this option remove or help to improve the removal efficiency of particles? Is it subject to fouling by particles?
Arsenic Removal	Does this option remove or help to improve the removal efficiency of arsenic? What is the expected removal efficiency?
Nitrate Removal	Does this option remove or help to improve the removal of efficiency of nitrate?
Fluoride Removal	Does this option remove or help to improve the removal efficiency of fluoride?
Iron and Manganese Removal	Does this option remove or help to improve the removal efficiency of iron and manganese? Is this option subject to iron and manganese fouling?
DBP Control	Does this option reduce the formation of chlorinated DBPs? Does this option produce other non-chlorinated DBPs (e.g. bromated) and emerging (non-regulated) DBPs?
Pathogens	Does this option provide log-removal credits for pathogens? Does this process help to improve the pathogen kill by other processes?

Table 3	Treatment Process Implementation Based Weighting Criteria as Assigned by City of Surprise and Developer Representatives Drinking Water Technology Assessment Report City of Surprise		
Water Process Screening Criteria	**Definition / Description**	**Average**	**Standard Deviation**
O&M Costs	What are the annual operation and maintenance cost for the alternative?	9.0	1.2
Capital Costs	What are the equipment costs, initial installation costs, and construction costs for the alternative?	8.8	1.4
Process Robustness	Does the alternative provide sufficient treatment stability with expected source water quality variations? Is it more reliable than the other alternatives?	7.9	0.6
Maturity of Technology	Is the alternative mature in design and operation?	6.9	1.6
City of Surprise Familiarity	Does the City of Surprise have operational experience with this alternative? Is the City's operations staff familiar with the process associated with this alternative?	4.1	2.5

Table 3	Treatment Process Implementation Based Weighting Criteria as Assigned by City of Surprise and Developer Representatives Drinking Water Technology Assessment Report City of Surprise		
Water Process Screening Criteria	**Definition / Description**	**Average**	**Standard Deviation**
Maintenance Intensity	What are the maintenance requirements associated with the alternative?	6.4	2.0
Operation Flexibility	Does the alternative allow flexible operation to meet process control goals?	6.5	1.7
System Complexity	How complex is the equipment and required operation of the alternative?	5.0	2.7
Footprint	How much land area is required for the alternative?	4.6	2.6
Regulatory	What are the regulatory coordination efforts associated with implementation & operation of the alternative?	5.9	2.8
Risks and Safety	Does the alternative present concerns associated with process safety such as hazardous materials handling and process risk management?	6.8	1.6
Residuals	What volume/type of residuals are produced by the alternative? How can the residuals generated by this alternative be treated/handled compared to other alternatives?	6.6	1.8
Versatility	Is the alternative versatile in removing multiple contaminants, including emerging concerns?	6.5	0.9
Expandability/ Ultimate Capacity	Does the alternative provide a configuration that allows easy future expansion using a module design concept (to accommodate the ultimate treatment capacity on the site)?	6.5	2.1
Air Quality Impacts	What volume/type of air pollutants/emissions does the alternative generate?	6.0	-

A screen capture of the implementation based weighting factors from the SurpriseTree™ Water model are illustrated in Figure 5. Placing the mouse cursor over each criterion displays the associated criterion definition. The user is permitted to adjust these weighting factors as appropriate. To reset to the default value (averaged weighting factors established by the City and the developer representative), simply click the reset button.

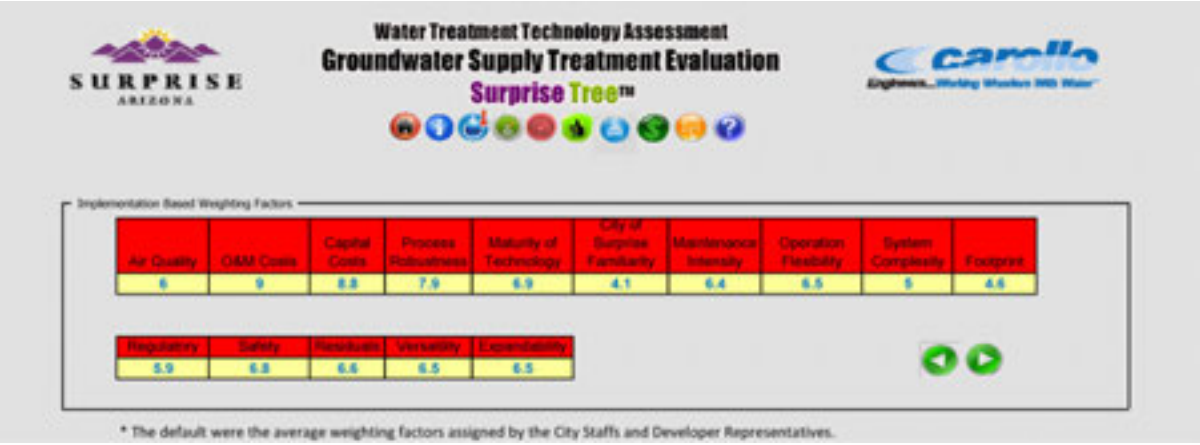


Figure 5 SurpriseTree™ Water Input 4 – Weighting 2

3.6 Input 5 – Decision Making

The fifth input sheet in the model is the decision making sheet. Using the implementation and performance criteria established on previous input sheets, each treatment alternative included for further evaluation in the SurpriseTree™ Water model is ranked on a 0 to 10 scale, with 0 representing the least favorable/effective and the 10 representing the most favorable/effective. The ranking scores were developed by the Engineer based on the qualitative descriptions presented in the series of tables at the end of each subsection of Section 6 of the Water Technology Assessment Report (for example, Table WT.32 for Performance Based Evaluation and Table WT.33 for Implementation Evaluation). The City's inputs are incorporated. Users can make changes to these scores at any time when running the analysis. The user can also perform sensitivity analysis by changing the water quality inputs and comparing the recommendations. After changing the inputs, simply click the calculate button to update the recommendation and avoid error values on the report.

The ranking scores are presented in Figure 6 and displayed on the "All Options" sheet in the model. For example, utilizing the primary disinfectant (e.g., bulk sodium hypochlorite) as a pre-oxidant is very effective and does not introduce significant additional capital and O&M costs. The chlorine (liquid form) alternative under the oxidation category receives scores of 10 under capital costs and O&M costs (under implementation evaluation), respectively and a score of 9 in the Arsenic removal category (under performance evaluation).

Category	Unit Operations	Recom-mendation	Normalized Unit Capital Cost Factor	Normalized Unit O&M Cost Factor	Normalized Life Cycle Cost Factor	Unit Capital Costs ($/gpd)	Relative Unit O&M Costs ($/gal)	Simple Life Cycle ($/gal)	Normalized Performance Total	Performance Total	Particle Fouling and Removal	DBP Control	Pathogens	Iron and Manganese Removal	Arsenic Removal	Nitrate Removal	Fluoride Removal	Normalized Implementation Total	Implementation Total	Air Quality	O&M Costs	Capital Costs	Process Robustness	Maturity of Technology	City of Surprise Familiarity	Maintenance Intensity	Operation Flexibility	System Complexity	Footprint	Regulatory	Safety	Residuals	Versatility	Expandability
Oxidation	Criterion Weight (CRW)	100	100	100	100				100	25	0	5	5	5	10	0	0	100	97.5	6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6	5.9	6.8	6.6	6.5	6.5
Oxidation	Chlorine	100	100	46	64	0.015	0.021	0.023	87.5	210	9	4	9	9	9	9	9	100.0	646	4	10	10	9	9	9	9	10	9	9	7	9	9	9	9	9
Oxidation	Potassium Permanganate	90	40	100	100	0.039	0.010	0.015	83.3	200	9	9	4	7	9	9	9	99.4	518	5	9	9	9	9	4	9	9	9	9	7	9	9	4	4	9
Oxidation	Chlorine Dioxide	64	13	17	20	0.117	0.058	0.074	100.0	240	9	7	9	9	9	9	9	94.9	412	4	3	3	7	9	2	3	9	9	9	9	9	9	9	9	9
Oxidation	Ozone	55	7	4	6	0.234	0.234	0.265	100.0	240	9	9	9	9	9	9	9	84.7	363	4	1	1	9	9	2	3	9	3	3	4	3	3	9	9	9
Arsenic	Criterion Weight (CRW)	100	100	100	100				100	21	3	0	3	5	10	0	0	100	97.5	6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6	5.9	6.8	6.6	6.5	6.5
Arsenic	Granular Ferric Hydroxide or Iron Modified Media	100	92	21	28	0.634	0.791	0.868	92.7	163	9	9	9	9	9	9	9	100.0	468	5	9	9	9	9	9	9	9	9	7	9	9	9	7	9
Arsenic	Coagulation + Granular Media Filtration	96	59	46	50	0.962	0.360	0.494	90.7	159	7	9	9	9	9	9	3	95.7	529	3	7	7	9	9	6	7	7	7	4	9	9	7	7	7
Arsenic	Ion Exchange Arsenic	80	50	9	13	1.163	1.773	1.932	71.1	148	9	9	9	4	9	9	7	92.6	579	9	9	9	9	9	6	9	9	7	7	9	9	9	9	9
Arsenic	Activated Alumina	80	83	33	41	0.701	0.508	0.604	92.7	163	9	9	9	9	9	9	9	92.6	516	1	9	9	9	9	2	9	9	9	7	9	7	9	7	9
Arsenic	NF / RO Sewer	83	27	23	24	2.195	0.725	1.025	100.0	197	10	9	9	9	10	9	9	83.4	527	9	4	4	9	9	4	9	9	9	9	4	7	9	10	9
Arsenic	Greensand	80	73	59	63	0.797	0.290	0.369	61.4	121	7	3	9	9	4	9	9	79.4	521	9	3	9	3	9	9	7	9	9	7	7	9	9	3	9
Arsenic	Coagulation + MFUF	79	39	40	39	1.508	0.418	0.624	92.7	163	9	9	9	7	9	9	3	79.3	[illegible]	3	9	9	9	9	6	9	9	9	9	9	9	9	9	9
Arsenic	Oxidation + Granular Media Filtration	72	0	0	0	0.583	0.165	0.245	34.0	67	4	3	9	9	9	9	9	73.1	463	9	7	7	9	9	9	9	9	9	9	9	9	9	3	9
Arsenic	Softening + MFUF	70	36	33	34	1.805	0.502	0.722	92.7	163	9	9	9	7	9	9	3	73.6	469	9	3	3	9	9	9	4	4	4	9	9	9	4	9	9
Arsenic	Oxidation + MFUF	69	0	0	0	1.239	0.223	0.393	42.1	83	9	9	9	7	9	9	9	95.3	463	9	9	9	9	9	9	4	9	9	7	9	9	9	9	9
Arsenic	ED / EDR Sewer	69	30	21	23	1.976	0.797	1.068	88.8	175	9	9	9	9	10	9	9	77.9	461	9	4	4	9	4	3	3	4	3	9	9	9	9	9	9
Arsenic	Softening + Granular Media Filtration	69	50	37	41	1.160	0.445	0.604	90.7	159	7	9	9	9	9	9	3	95.8	[illegible]	9	4	9	9	9	9	9	4	4	9	9	4	9	9	9
Arsenic	NF / RO Zero Liquid Discharge	31	7	6	6	8.781	2.898	4.101	100.0	197	10	9	9	9	10	9	9	[illegible]	394	3	0	0	9	1	3	1	3	1	1	1	3	1	10	3
Arsenic	ED / EDR Zero Liquid Discharge	28	7	5	6	7.903	3.188	4.271	88.8	175	9	9	9	9	10	9	9	78.8	157	3	0	0	9	1	1	1	3	1	1	1	3	1	9	3
Arsenic	OTHER																																		
Fluoride	Criterion Weight (CRW)	100	100	100	100				100	0	0	0	0	0	0	0	0	100	97.5	6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6	5.9	6.8	6.6	6.5	6.5
Fluoride	Activated Alumina	#DIV/0!	92	100	100	0.623	0.592	0.677	#DIV/0!	0	9	9	9	9	9	9	9	100.0	623	5	9	9	9	9	9	9	9	9	7	9	9	9	9	9
Fluoride	Ion Exchange Fluoride	#DIV/0!	100	71	75	0.574	0.829	0.907	#DIV/0!	0	9	9	9	4	9	9	7	97.8	575	3	9	9	9	9	9	9	9	9	7	9	9	7	9	9
Fluoride	NF / RO Sewer	#DIV/0!	26	62	66	2.195	0.725	1.025	#DIV/0!	0	10	9	9	9	10	9	9	92.8	545	9	9	9	9	9	9	9	9	9	9	9	9	9	10	9
Fluoride	ED / EDR Sewer	#DIV/0!	29	74	63	1.976	0.797	1.068	#DIV/0!	0	9	9	9	9	10	9	9	79.2	519	3	9	9	9	9	2	3	9	3	9	9	7	9	9	9
Fluoride	Coagulation + Filtration + Polishing	#DIV/0!	45	76	71	1.269	0.774	0.948	#DIV/0!	0	9	9	9	9	9	9	3	73.7	461	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Fluoride	Modified Softening + Filtration + Polishing	#DIV/0!	40	69	64	1.447	0.859	1.097	#DIV/0!	0	9	9	9	9	9	9	3	79.3	446	5	9	9	9	9	9	9	9	9	9	9	9	9	9	9
Fluoride	NF / RO Zero Liquid Discharge	#DIV/0!	7	20	17	8.781	2.898	4.101	#DIV/0!	0	10	9	9	9	10	9	9	31.3	394	3	0	0	9	1	3	1	3	1	1	1	3	1	10	3
Fluoride	ED / EDR Zero Liquid Discharge	#DIV/0!	7	19	16	7.903	3.188	4.271	#DIV/0!	0	9	9	9	9	10	9	9	28.7	157	3	0	0	9	1	1	1	3	1	1	1	3	1	9	3
Nitrate	Criterion Weight (CRW)	100	100	100	100				100	0	0	0	0	0	0	0	0	100	97.5	6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6	5.9	6.8	6.6	6.5	6.5
Nitrate	Biological Filtration	#DIV/0!	72	100	100	0.796	0.300	0.409	#DIV/0!	0	9	9	9	9	9	9	9	100.0	703	10	9	9	9	9	3	9	7	9	9	9	9	9	9	9
Nitrate	Ion Exchange Nitrate	#DIV/0!	100	36	45	0.574	0.829	0.907	#DIV/0!	0	9	9	9	4	9	9	7	99.9	624	9	9	9	9	9	7	9	9	9	7	9	9	9	9	9
Nitrate	NF / RO Sewer	#DIV/0!	26	41	40	2.195	0.725	1.025	#DIV/0!	0	10	10	9	9	10	9	9	92.4	579	9	9	9	9	9	3	9	9	9	9	9	7	9	10	9
Nitrate	ED / EDR Sewer	#DIV/0!	29	38	38	1.976	0.797	1.068	#DIV/0!	0	9	9	9	9	10	9	9	99.9	495	9	9	9	9	9	3	9	9	9	9	9	9	9	9	9
Nitrate	NF / RO Zero Liquid Discharge	#DIV/0!	7	10	10	8.781	2.898	4.101	#DIV/0!	0	10	10	9	9	10	9	9	23.1	394	3	0	0	9	1	3	1	3	1	1	1	3	1	10	3
Nitrate	ED / EDR Zero Liquid Discharge	#DIV/0!	7	9	10	7.903	3.188	4.271	#DIV/0!	0	9	9	9	9	10	9	9	26.6	157	3	0	0	9	1	1	1	3	1	1	1	3	1	9	3
Disinfection	Criterion Weight (CRW)	100	100	100	100				100	30	0	10	10	5	5	0	0	100	97.5	6	9	8.8	7.9	6.9	4.1	6.4	6.5	5	4.6	5.9	6.8	6.6	6.5	6.5
Disinfection	Liquid Chlorine Bulk	100	54	46	50	0.187	0.097	0.123	100.0	130	9	1	9	4	4	9	9	100.0	625	3	9	9	9	9	9	9	9	9	7	9	7	9	9	9
Disinfection	Liquid Chlorine Oxide	81	30	74	55	0.336	0.064	0.110	100.0	130	9	1	9	4	4	9	9	85.9	559	4	9	3	4	9	4	9	9	3	7	9	9	3	9	7
Disinfection	Chloramines	60	45	40	41	0.224	0.117	0.146	92.3	120	9	4	9	3	3	9	9	59.9	372	1	9	9	9	9	3	9	9	9	9	9	9	9	9	9
Disinfection	Gas Chlorine	54	100	100	100	0.101	0.047	0.061	100.0	130	9	1	9	4	4	9	9	71.4	449	1	10	9	9	9	3	9	9	9	9	9	9	9	9	9

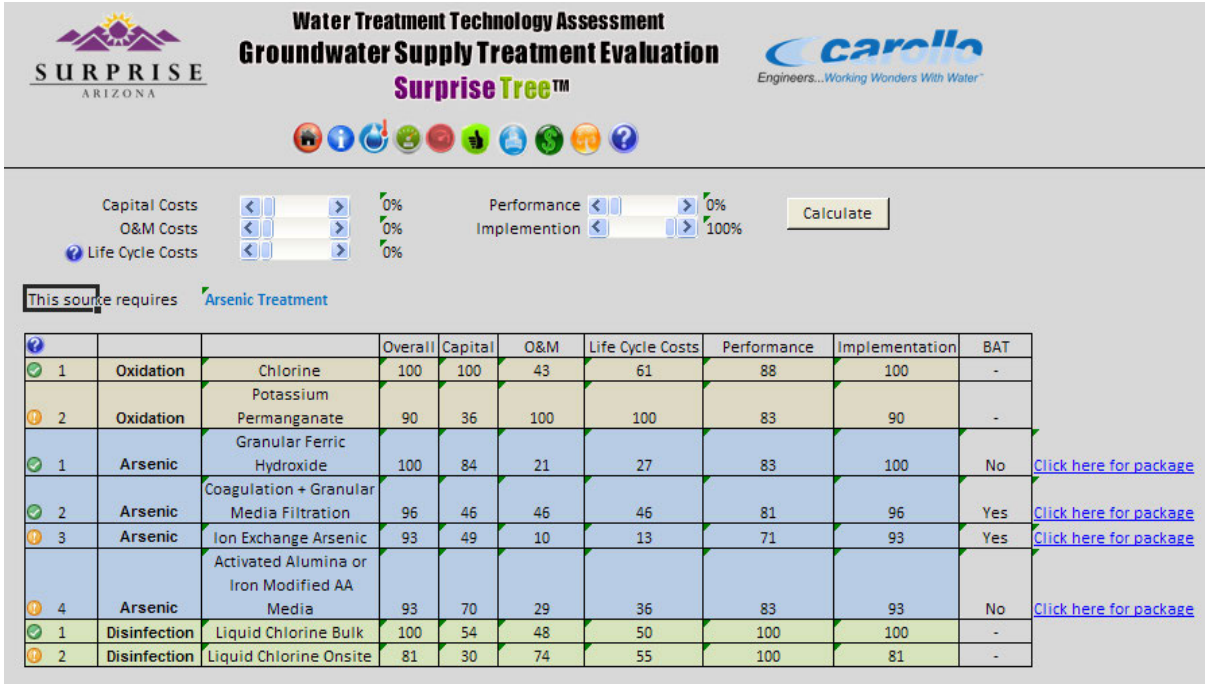
EXAMPLE

Figure 6 SurpriseTree™ Water All Options Treatment Process Ranking Table

The SurpriseTree™ Water model calculates the ranking scores using the following procedures:

- Implementation Scores for each Technology Alternative (e.g., GFH):
  - Total Implementation Score for a technology alternative (e.g., GFH) is the weighted average (summation of the products) of the score for each alternative (e.g., GFH) for a given criterion (e.g., Footprint or Expandability) and the corresponding Weighting factor for the given criterion (e.g., 4.6 or 6.5).
  - The total implementation score is then normalized to 100 by multiplying by 100 and dividing by the maximum Total Implementation Score for a technology alternative (e.g., GFH) in its category (e.g., adsorption).
  - The higher the score is, the better a technology alternative is considered based on this comprehensive evaluation.
- Performance Scores for Each Technology Alternative (e.g., GFH):
  - Total Performance Score for a technology alternative (e.g., GFH) is the weighted average (summation of the products) of the score for each alternative (e.g., GFH) for a given criterion (e.g., Arsenic Removal or Fluoride Removal) and the corresponding Weighting factor for the given criterion (e.g., 10 or 0).
  - The total performance score is then normalized to 100 by multiplying by 100 and dividing by the maximum Total Implementation Score for a technology alternative (e.g., GFH) in its category (e.g., adsorption).
  - The higher the score is, the better a technology alternative is considered relative to its performance/effectiveness in removing the target CoCs for the specific water quality.
- Financial Scores for Each Technology Alternative (e.g., GFH):
  - Capital Costs ($/gpd), O&M Costs and Life Cycle Costs ($/gal) are calculated for each alternative.
  - The cost score is a normalized score on a 100 scale, with the least expensive alternative being 100.
  - The higher the score is, the less expensive (the more favorable) the alternative is.

As illustrated in Figure 7, the decision input sheet includes scale bars to provide quick, visual adjustment capability to determine the significance of the decision-making factors. The bars can be adjusted as described below to determine the impacts of the various factors on technology selection.



			Overall	Capital	O&M	Life Cycle Costs	Performance	Implementation	BAT	
1	Oxidation	Chlorine	100	100	43	61	88	100	-	
2	Oxidation	Potassium Permanganate	90	36	100	100	83	90	-	
1	Arsenic	Granular Ferric Hydroxide	100	84	21	27	83	100	No	Click here for package
2	Arsenic	Coagulation + Granular Media Filtration	96	46	46	46	81	96	Yes	Click here for package
3	Arsenic	Ion Exchange Arsenic	93	49	10	13	71	93	Yes	Click here for package
4	Arsenic	Activated Alumina or Iron Modified AA Media	93	70	29	36	83	93	No	Click here for package
1	Disinfection	Liquid Chlorine Bulk	100	54	48	50	100	100	-	
2	Disinfection	Liquid Chlorine Onsite	81	30	74	55	100	81	-	

Figure 7 SurpriseTree™ Water Input 5 – Decision Making

As the primary evaluation factor, the implementation based evaluation can be used as a stand-alone evaluation. This can be achieved by setting the scale bars for performance and capital, O&M and life cycle costs at 0% and the bar for implementation at 100%. If the user wants to consider extra weighting for performance or cost effectiveness, adjustment can be made by setting the associated bars to the appropriate position. Normalized to 100, the final scores are weighted averages (summation of the products) of:

- The normalized implementation score times the implementation scale bar setting
- The normalized performance score times the performance scale bar setting
- The capital, O&M, and life cycle costs times the scale bar settings for each costs

The higher the final score, the better an alternative is ranked. The SurpriseTree™ Water Model Technology Assessment Tool provides recommendations on the top treatment options for a given set of inputs (water quality, project information, weighting factors, etc.). The top treatment options are recommended for further consideration. Before implementing an option, a preliminary design based on actual source water quality, site-specific conditions, and temporal market conditions is recommended. This approach will provide opportunities for process optimization and cost reduction.

3.7 Input 6 – Costs

The sixth input sheet in the model is the costs sheet. Inputs for the financial based criteria evaluation are defined in Table 4. Adjusted USEPA Cost Curves (to match recent project cost information) along with cost information from recently completed water treatment projects were used on a relative basis to compare treatment technologies. The costs were adjusted using ENR construction cost index and location factors. An order-of-magnitude capital cost per gallon of water treated along with an O&M cost per 1,000 gallons of water were estimated for each treatment technology. Detailed information associated with these reference costs can be found in Appendix D of the Water Technology Assessment Report. The Cost Input sheet from the SurpriseTree™ Water model is illustrated in Figure 8.

Table 4 Treatment Process Financial Based Criteria
SurpriseTree™ Water Model User's Guide
City of Surprise

Financial Criteria	Definition / Description
Capital Cost	What are the equipment costs, initial installation costs, and construction costs for the alternative?
Operation and Maintenance Cost	What are the annual operation and maintenance cost for the alternative?
Life Cycle Cost	What are the capital costs plus O&M costs over a 20 year period for the alternative?

3.8 Decision Tree

To summarize the recommendations from the SurpriseTree™ Water model for all seven scenarios (see Section 7.1.3 of the Water Technology Assessment Report), a decision tree was developed, as illustrated in Figure 9. The decision tree contains a series of branches which require a yes or no answer. The resultant answers create a path to potential treatment options. The decision tree provides a general overview of the available treatment options for removing any combination of arsenic, nitrate, and fluoride. However, the decision tree is intended to be a simplified representation and is not as sophisticated as the model itself.

As illustrated in Figure 9, proper source water selection (including proper well development) is the first choice for water supply management. The technology assessment report focuses on the evaluation of centralized treatment technologies that are applicable for the City's water supply facilities, assuming there is no treatment avoidance alternative available and a treatment facility must be constructed to provide reliable and safe drinking water for the City.

SURPRISE ARIZONA

Water Treatment Technology Assessment

Groundwater Supply Treatment Evaluation

Surprise Tree™

carollo Engineers...Working Wonders With Water

	Facility Size: 1.83 mgd						
	Default		City's Adjustment		LCA Analysis		
	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Unit Capital Costs ($/gpd)	O&M Costs ($/1000 gal)	Life Cycle ($/1000gal)
Oxidation	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Chlorine	$ 0.01	$ 0.02			$0.02	$0.02	$0.02
KMnO4	$ 0.04	$ 0.01			$0.04	$0.01	$0.02
ClO2	$ 0.11	$ 0.06			$0.12	$0.06	$0.07
Ozone	$ 0.22	$ 0.22			$0.23	$0.23	$0.27
Arsenic	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Oxidation + GMF (including Residuals)	$ 0.56	$ 0.16			$0.58	$0.17	$0.25
Activated Alumina (no pH adjustment)	$ 0.59	$ 0.56			$0.62	$0.59	$0.68
Activated Alumina (w/ pH adjustment)	$ 0.67	$ 0.48			$0.70	$0.51	$0.60
GFH	$ 0.60	$ 0.74			$0.63	$0.78	$0.87
IMM	$ 0.60	$ 0.74			$0.63	$0.78	$0.87
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
Greensand	$ 0.76	$ 0.27			$0.80	$0.28	$0.39
Oxidation + MFUF (including Residuals)	$ 1.18	$ 0.21			$1.24	$0.22	$0.39
Coagulation + MFUF (including Residuals)	$ 1.44	$ 0.40			$1.51	$0.42	$0.62
Coagulation + GMF (including Residuals)	$ 0.94	$ 0.34			$0.98	$0.36	$0.49
Softening + MFUF (including Residuals)	$ 1.53	$ 0.48			$1.61	$0.50	$0.72
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
Softening + GMF (including Residuals)	$ 1.10	$ 0.42			$1.16	$0.44	$0.60
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
Anion Exchange (<20 SO4)	$ 0.45	$ 0.56			$0.48	$0.59	$0.66
Anion Exchange (20-50 SO4)	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
Anion Exchange (200 SO4)	$ 1.11	$ 1.69			$1.16	$1.77	$1.93
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Fluoride	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Activated Alumina	$ 0.59	$ 0.56			$0.62	$0.59	$0.68
Ion Exchange Fluoride	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
Coagulation + Filtration + Polishing (including Residuals)	$ 1.21	$ 0.74			$1.27	$0.77	$0.95
Modified Softening + Filtration + Polishing (including Residuals)	$ 1.38	$ 0.82			$1.45	$0.86	$1.06
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Nitrate	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Ion Exchange Nitrate	$ 0.55	$ 0.79			$0.57	$0.83	$0.91
Biological Filtration (including Residuals)	$ 0.76	$ 0.29			$0.80	$0.30	$0.41
NF / RO Sewer	$ 2.09	$ 0.69			$2.20	$0.72	$1.03
ED / EDR Sewer	$ 1.88	$ 0.76			$1.98	$0.80	$1.07
NF / RO ZLD	$ 8.36	$ 2.76			$8.78	$2.90	$4.10
ED / EDR ZLD	$ 7.53	$ 3.04			$7.90	$3.19	$4.27
Disinfection	Enter new costs in the white cells to replace the Default Costs. (e.g. =0.022 or =C12*1.1).						
Gas Chlorine	$ 0.10	$ 0.04			$0.10	$0.05	$0.06
Liquid Chlorine Bulk	$ 0.18	$ 0.09			$0.19	$0.10	$0.12
Liquid Chlorine Onsite	$ 0.32	$ 0.06			$0.34	$0.06	$0.11
Chloramines	$ 0.21	$ 0.11			$0.22	$0.12	$0.15

Figure 8 SurpriseTree™ Water Cost Inputs

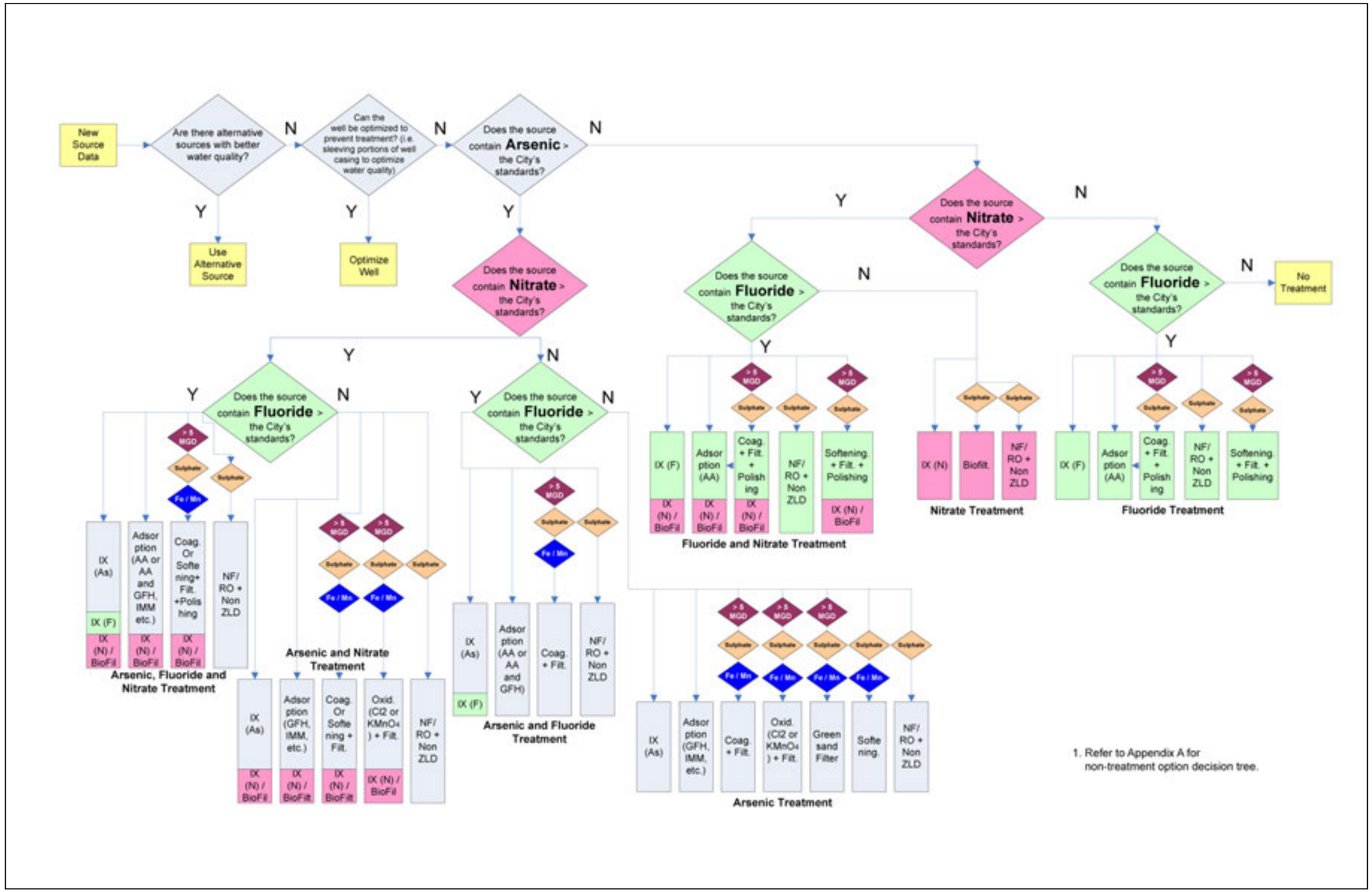


Figure 9 SurpriseTree™ Water Decision Tree for Arsenic, Nitrate and Fluoride Treatment

3.9 Additional Considerations

Once all applicable information is input, the SurpriseTree™ Water model can produce a report summarizing all input information and the associated model results. The report is a simple and convenient way to summarize and interpret the model output. An example SurpriseTree Water report is included in Figure 10.

3.10 Integration of SurpriseTree™ Water Model Output with the Technology Assessment Report

Once the model output has been created, it is recommended that the City consider the top three to five ranked treatment processes for the new WSF. Once the treatment processes have been selected, the City can provide the developer with the corresponding implementation package from Appendix E – Appendix H of the Water Technology Assessment Report to use as a baseline for preliminary design.