# Freeman Diversion Facilities Invasive Species Control Options Assessment and Engineering Feasibility Study

**FINAL**
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**Prepared For:**
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# Report Verification and Submission Record

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The technical data contained in this report were prepared under the supervision and direction of the undersigned whose seal as a professional engineer licensed to practice as such in the State of California is affixed below.

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| | |
|---|---|
| % | percent |
| °C | degrees Celsius |
| °F | degrees Fahrenheit |
| < | less than |
| > | greater than |
| µm | micrometer |
| µS/cm | micro Siemens per liter |
| ASR | aquifer storage and recovery |
| Blvd. | Boulevard |
| $CaCO_3$ | calcium carbonate |
| CDFW | California Department of Fish and Wildlife |
| CESA | California Endangered Species Act |
| cfs | cubic feet per second |
| $ClO_2$ | chlorine dioxide |
| DBP | disinfection by-product |
| DNA | deoxyribonucleic acid |
| DWR | California Department of Water Resources |
| ESA | Endangered Species Act |
| FERC | Federal Energy Regulatory Commission |
| FTE | full-time-equivalent |
| GPM/sf | galons per minute per square foot |
| HAAs | Haloacetic acids |
| HCP | multiple species habitat conservation plan |
| hr | hour |
| ITP | incidental take permit |
| $KMnO_4$ | potassium permanganate |
| MCA | multi-criteria analysis |
| MGD | million gallons per day |
| mg/L | milligrams per liter |
| $MnO_4^-$ | permanganate |

| | |
|---|---|
| MSHCP | multiple species habitat conservation plan |
| $Na_2SO_3$ | sodium sulfite |
| $NCl_3$ | trichloramine |
| NDMA | N-nitrosodimethylamine |
| $NH_2Cl$ | monochloramines |
| $NHCl_2$ | dichloramine |
| NMFS | National Marine Fisheries Service |
| No. | Number |
| NTU | nephlometric turbidity unit |
| O&M | operation and maintenance |
| P | phosphorus |
| Plan | Quagga Mussel Monitoring and Control Plan |
| PTP | Pumping Trough Pipeline |
| PVP | Pleasant Valley Pipeline |
| THMs | trihalomethanes |
| US | United States |
| USEPA | United States Environmental Protection Agency |
| USFWS | United States Fish and Wildlife Service |
| USGS | United States Geological Survey |
| UV | ultraviolet |
| UWCD | United Water Conservation District |

# Executive Summary

United Water Conservation District's (UWCD's) water system is designed to provide groundwater replenishment and water delivery for several cities, mutual water districts, and individual farms and agricultural entities on the Oxnard Coastal Plain. UWCD's water system is comprised of the Freeman Diversion that diverts surface water in the Santa Clara River for direct use and groundwater recharge in the Oxnard Forebay (Saticoy, Noble, Rose, Ferro and El Rio basins), the El Rio Water Treatment that supplies drinking water for O-H Pipeline users, and two agricultural irrigation systems known as the Pumping Through Pipeline (PTP) and Pleasant Valley (PV) reservoir. UWCD's system, having come under threat of infestation by quagga mussel due to its upstream colonization of Lake Piru Reservoir, has undergone development of control alternatives that are discussed in this report. The goal of implementing these control alternatives is to effectively prevent quagga mussels from passing through UWCD's system and into downstream stakeholder infrastructure.

This report documents a planning-level conceptual engineering feasibility study of alternatives available to UWCD for mussel control. These alternatives were formulated after considering UWCD system operations, prior mussel data and research, secondary negative impacts from various treatment technologies (e.g., production of regulated by-products and other issues that may negatively impact downstream drinking water supplies), and estimated planning-level costs. Developed alternatives were evaluated based upon their ability to provide maximum reduction of risk of mussel infestation in downstream (post-UWCD facilities) stakeholder infrastructure. Primarily, this infrastructure includes various groundwater supplies for subsequent drinking water, and the Pleasant Valley Pipeline (PVP) and Pumping Trough Pipeline (PTP) reservoirs (and their downstream-supplied agricultural users).

## Alternatives Evaluated

Veliger and mussel control options were considered to determine the baseline composition of resulting alternatives. These options were considered based upon their propensity to produce negative by-products, capability to successfully work in expected water quality from the Santa Clara River, capability to successfully work when applied in the application considered (i.e., in UWCD's water system), and their need for confirmatory bench- and/or pilot-scale testing. This assessment of treatment options resulted in the development of the following alternatives for veliger/mussel control:

1. **River Infiltration Gallery** – Construction of an engineered infiltration gallery in the Santa Clara River. This gallery would meet flow requirements for downstream stakeholders and would not include the use of treatment chemicals.

2. **Upper-System Chemical Feed** – Addition of either chlorine or potassium permanganate at two possible locations (either down-system of Freeman Diversion or below the Desilting Basin). Chemical treatment was considered as treating the full flow at these locations.

3. **Basin Infiltration Gallery** – Construction of an engineered infiltration gallery in one of UWCD's available recharge basins (no chemical use) to meet the flow requirements for downstream stakeholders. This option does not offer any protection within UWCD's facilities (e.g., veligers and any resulting mussels within UWCD's facilities would need to be managed by secondary, operation and maintenance [O&M] efforts).

4. **Increased Pumping / Aquifer Storage and Recovery (ASR) Improvements** – Construction of new groundwater pumping facilities to increase recharge basin capacity to supply water to downstream stakeholders. No treatment chemicals used with this alternative. This option does not offer any protection within UWCD's facilities (e.g., veligers and any resulting mussels within UWCD's facilities would need to be managed by secondary, O&M efforts).

5. **Lower-System Chemical Feed** – Addition of either chlorine or potassium permanganate at two possible locations (either before or after the Moss Screen). Chemical feed was considered as treating the full flow through the Moss Screen at either location. This option does not protect any facilities upstream of the Moss Screen.

6. **Chemical Feed Prior to Reservoirs** – Addition of chlorine or potassium permanganate immediately above the PVP and PTP reservoirs. This alternative treats only water that is being conveyed to the reservoirs and does not offer any protection within UWCD's facilities.

7. **Non-Capital / O&M-Only Controls** – Withholding installation of any capital facilities and only instituting monitoring and O&M-based control measures as necessary.

8. **Alternate Sources of Supply (e.g. Recycled Water)** – Introduction of an alternative source of water supply in lieu of surface water diversions. The average annual water demand for the PTP and PVCWD systems is 8,000 AFY and 24,000 AFY respectively. One potential source of recycled water supply is the City of Oxnard's (Oxnard) Advanced Water Purification Facility (AWPF) that currently has a finished water production capacity of 6.25 MGD (7,000 AFY). Oxnard is conducting a master planning effort that includes a feasibility study of expanding the AWPF up to 12.5 MGD (14,000 AFY). Recycled water is not anticipated to completely offset demand for surface water and thus additional sources would be required. This alternative was not evaluated further and is outside the scope of this analysis.

## Findings

Planning-level lifecycle costs were developed for these alternatives in order to produce a conceptual assessment of what one alternative may cost when compared against another. A summary comparison of these estimates (provided as a feasibility/planning-level rough-order-of-magnitude characterization) resulted in the following findings:

- Cost decreases as treatment/control is moved downstream through the UWCD system;
- The pumping/ASR alternative lifecycle cost is approximately mid-range when compared to other alternatives, and
- Chemical treatment immediately prior to the reservoirs may be similar in cost to the Non-Capital / O&M-Only Controls alternative.

A multi-criteria, qualitative analysis of the alternatives was conducted to further assist in selecting a recommended alternative. This analysis was conducted because there wasn't a unique, optimal solution for alternative selection. This qualitative process helped to promote use of decision-maker's preferences to provide a logical method for differentiating between alternatives. This analysis considered impacts in lifecycle cost, permitting, constructability, footprint, operational complexity, required additional testing, and overall risk protection. The result of the analysis produced the following ranking of the top three alternatives (Number 1 is the top-ranked alternative):

1. Increased Pumping / ASR Improvements;
2. Non-Capital / O&M-Only Controls; and
3. Chemical Feed Prior to Reservoirs.

## Recommendations

Based upon the system engineering and operating knowledge provided, available control options, potential negative impacts from some options, and planning-level cost estimates for mussel control alternatives, the following recommendations are made:

**1. Implement one or more of the following control alternatives**

a. Increased Pumping / ASR Improvements, or

b. Chemical Feed Immediately Before PTP and PV Reservoirs.

**2. After selecting one of the above alternatives, complete the following next-steps**

a. Implement monitoring for veligers and mussels throughout the UWCD system,

b. Finalize sizing, operating, and location/siting,

c. Quantify right-of-way and permitting issues,

d. Refine engineering and operations cost estimates, and

e. Conduct bench- and/or pilot-scale testing of O&M control needs within UWCD's system.

Regardless of implementation of the above, UWCD should implement elevated levels of monitoring and O&M-based controls throughout the UWCD system (from the Freeman Diversion through the Moss Screen and all Recharge Basins). This implementation may include continuous monitoring, intermittent application of chemical oxidants, and/or intermittent application of chemical or biological molluskicides.

# 1.0 Introduction

## 1.1 Background

United Water Conservation District (UWCD) is located in Ventura County, California and was created in 1950 under the Water Conservation Act of 1931 (Water Code Section 74000 et seq.) and is the successor to the Santa Clara Water Conservation District. The mission of the United Water Conservation District is to manage, protect, conserve and enhance the water resources of the Santa Clara River, its tributaries and associated aquifers, in the most cost effective and environmentally balanced manner. UWCD operates within the Santa Clara River Valley and the Oxnard Plain and covers approximately 214,000 acres in central Ventura County. In order to accomplish its mission UWCD operates a number of facilities to recharge the groundwater basins and enhance the water supplies within the District boundaries including: Santa Felicia Dam and Lake Piru Reservoir (Figure 1-1); Santa Felicia Dam hydroelectric power plant; the Piru Groundwater Recharge Basins; Freeman Diversion Facility; Saticoy Groundwater Recharge Basins (Saticoy, Noble, Rose and Ferro Basins); El Rio Groundwater Recharge Facilities and Wellfield; the Pleasant Valley (PV) and Pumping Trough (PTP) irrigation pipelines (surface water deliveries for in-lieu pumping) and; the Oxnard-Hueneme Pipeline system which delivers domestic potable water to the Cities of Oxnard, Port Hueneme, mutual water companies and Naval Base Ventura County.

**Figure 1-1. Construction of Santa Felicia Dam (October, 1955; Source UWCD)**

The quagga mussel (Dreissena bugensis) is indigenous to the Dnieper River area of the Ukraine and was introduced to the Great Lakes of the United States (US) in the late 1980s via ship ballast. As illustrated in **Figure 1-2**, Dreissenid mussels currently infest much of the Great Lakes Basin, the St. Lawrence Seaway, and the Mississippi River drainage system. The mussels have extended their range into the west including the Colorado River Basin, Oklahoma, and north Texas and have reached Southern California in the last few years. Concerns of quagga mussels in water supplies have prompted the Metropolitan Water District of Southern California, for example, to chlorinate Colorado River water supplies (De Leon 2008), and UWCD is now considering alternative quagga mussel control measures to limit movement of the species from Lake Piru Reservoir into other water bodies and into its water infrastructure.

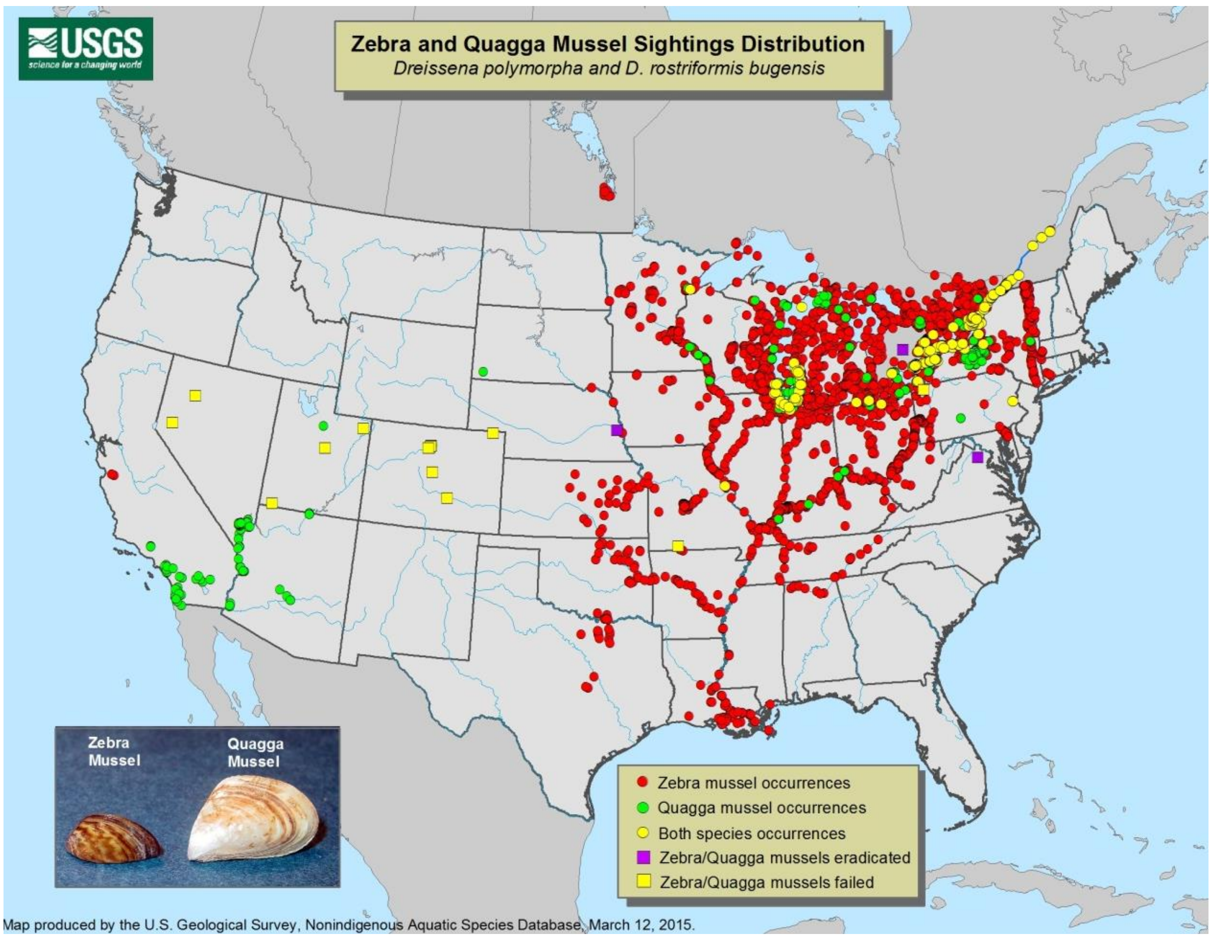


**Figure 1-2. United States Geological Survey (USGS) Data on the Extent of United States Invasive Mussel Occurrences (Source: USGS)**

Quagga mussels were first discovered in Lake Piru on December 18, 2013, during a routine inspection. Following discovery, UWCD staff contacted California Department of Fish and Wildlife (CDFW), and mussel samples were sent for analysis to the CDFW Shellfish Health Laboratory located on the campus of University of California, Davis' Bodega Marine Laboratory. UWCD notified CDFW, California Department of Water Resources (DWR), and operators of nearby surface water reservoirs of the findings. In September, 2015, UWCD issued the Quagga Mussel Monitoring and Control Plan (Plan) in accordance with California Fish and Game Codes §2301 and §2302 in response to the discovery of quagga mussels The Plan is now in its fourth draft version which was re-issued in July 2016. The Plan includes five elements: methods for delineation of infestation, including adults and veligers; methods for control and eradication of mussels and veligers; methods to contain the spread of mussels through water released at Santa Felicia; methods for decontamination of vessels; systematic monitoring plan for measuring changes in condition; and methods for working with CDFW in updating and making changes to the Plan to keep current with technology and changes. UWCD is required to prepare an annual report documenting the activities and findings both for the current year, as well as cumulative data, and include recommendations for modifications to the Plan, where appropriate. The annual report will be submitted to CDFW for review each year.

Preventing the movement of quagga mussels into new areas is a primary goal of the present effort. Human activities have spread mussels into many inland lakes and streams, usually through recreational boating, fishing, and diving practices. Steps such as draining live wells, cleaning vegetation off boat trailers, removing attached mussels from boat hulls, and not dumping bait into lakes or rivers can help prevent the spread of mussels and other exotics into non-infested waters. Once quagga mussels infest a water body or system, additional measures may be needed to prevent their spread to water bodies or systems that are hydrologically linked. The potential exists for the quagga mussel to enter UWCD infrastructure at Freeman Diversion via water released from Lake Piru (see locations illustrated in **Figure** 1-3). From Freeman Diversion, quagga mussels could be transported anywhere within UWCD's downstream water system, such as in conveyance systems and related facilities.

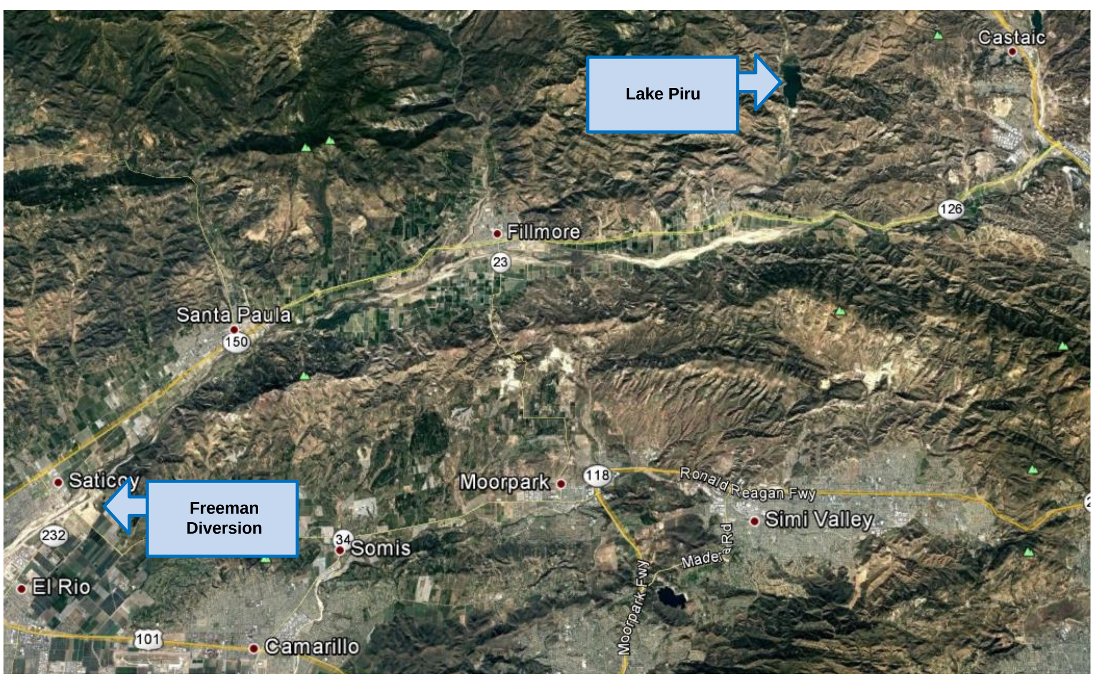


**Figure 1-3. Location of Lake Piru and Freeman Diversion**

UWCD facilities below the Freeman Diversion that need protection from quagga mussel infestation are illustrated in **Figure 1-4** and include the following: the diversion structure and associated infrastructure including the fish screen; the Freeman Canal; several pipelines; the desilting basin; the grand canal; the recharge facilities including El Rio, Saticoy and Noble; the Moss Screen (located upstream of the PVP and the PTP).

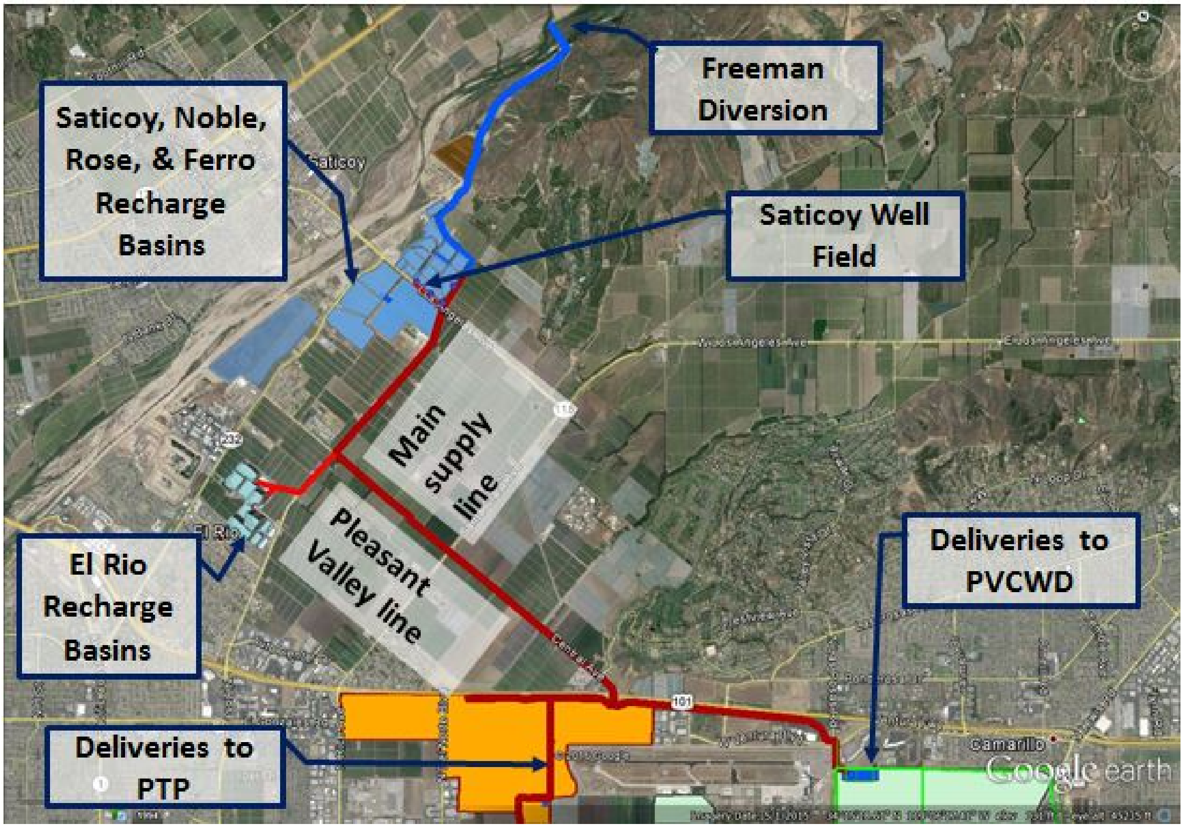


**Figure 1-4. Map of UWCD Facilities below Freeman Diversion**

Quagga mussel control facilities may potentially be located at several locations below Freeman Diversion, and these facilities must be effective enough to prevent infestation below the Moss Screen (immediately upstream of the deliveries to PTP and PVP), one of the overall quagga mussel management goals. Upstream of the Moss Screen, quagga mussel control may be accomplished with passive or intermittent treatments, but below it more aggressive measures would be required. The most sensitive environmental and water quality risks associated with quagga mussel control treatment include: treatment chemical residual impacts on agriculture and biota; risks of treatment chemical by-products on biota, agriculture, recharged groundwater, and potable water; and risks due to incomplete treatment (e.g., mussel veligers surviving treatment).

## 1.2 Project Need

UWCD is facing significant technical and operational challenges with the discovery of invasive quagga mussels at Santa Felecia Dam/Lake Piru Reservoir. Both UWCD and its customer stakeholders would like to implement a rapid, effective, and cost-efficient method for quagga mussel control below Freeman Diversion so that the mussels are prevented from infesting water system infrastructure. Infestation of the water system may result in increased maintenance costs and decreased delivery caused by the mussels attaching to infrastructure, reducing the area of flow and increasing roughness of conduits.

Control of quagga mussels is a complex challenge that may be costly both on water system operating budgets and ecosystems. Invasive mussel species have the ability to thrive in new environments where natural controls are absent. Man-made controls can include chemical, mechanical, and biological means, but each can have significant secondary effects. Evaluation of control mechanisms will require consideration of those secondary effects within the environmental and regulatory context. Chemical controls, for example, need to be consistent with allowances for discharges of water to recharge basins. Any new facilities needed to support quagga mussel control will be subject to cost and environmental impact review.

## 1.3 Project Goals

The project, limited to facilities below Freeman Diversion, and this document have the following goals:

1. Develop an understanding of the following UWCD-provided information: system operations, including system boundaries and operational scenarios; existing water quality and hydraulic data; review UWCD's prior mussel data and research.

2. Identify and develop quagga mussel control alternatives including control location, design, and operational options.

## 1.4 Purpose and Scope

UWCD retained AECOM for an engineering feasibility study to evaluate control options, which include operations and engineering alternatives for mussel control downstream of Freeman Diversion. The intent of this study is to present the alternative technical solutions for mussel control to UWCD so that the proper budgeting and planning can be implemented. The following tasks will be implemented for this study:

TASK 1: FEASIBILITY STUDY KICKOFF AND SYSTEM CONFIRMATION

- Confirm project understanding and approach.
- Confirm schedule and deliverables.
- Confirm system operations and design limitations.
- Confirm system stakeholders and needs.

TASK 2: IDENTIFY AND ASSESS ALTERNATIVE(S)

- Identify and develop mussel control alternatives, locational placement strategies, design and construction options, and operating options along with risks, costs, and mussel control benefits.
- Hold up to two workshops to discuss applicable alternatives and their specific costs and benefits.

TASK 3: SUMMARIZE AND CONFIRM BEST-FIT ALTERNATIVE(S)

- Confirm aspects of UWCD's chosen/best-fit mussel control alternative(s).
- Document the alternatives analysis process and the final result in a DRAFT Feasibility Study Project Report format.

TASK 4: FINALIZE FEASIBILITY STUDY

- Deliver final Feasibility Study Project Report (completion of the Feasibility Study).
- Discuss final report and its ability to allow UWCD to successfully progress into program implementation at final meeting.

# 2.0 Operations Description/System Boundaries

## 2.1 Description of UWCD Operations

### 2.1.1 Overview

Surface water is diverted from the Santa Clara River at the Freeman Diversion for the purpose of groundwater recharge and agricultural irrigation to reduce groundwater pumping (**Figure 2-1**). A maximum, permitted diversion of up to 375 cubic feet per second (cfs) is allowed. The ability to divert is highly variable and dependent on several factors, such as rainfall, river turbidity, and water released from Lake Piru.

**Figure 2-1** shows the surface water conveyance system from the Freeman Diversion through the conveyance system. Surface water is diverted at the Freeman Diversion structure (**Figure 2-2**). The water passes through a trash rack (**Figure 2-2**), two slide gates, a fish screen (**Figure 2-3**) and another set of gates before entering an open channel. The open channel enters two buried pipes before discharging into the desilting basin. A coagulant is added at the headworks of the pipelines prior to the desilting basin to aid in suspended sediment settling. The desilting basin discharges into an open channel and enters Basin B. The outlet of Basin B splits into two open channels – one feeding the Saticoy Recharge Basins (Saticoy, Noble and Rose Basins) via the ”Grand Canal”, the other passing through the Moss Screen and entering Main Supply Line.

From the discharge of the Moss Screen, the conveyance system is a series of buried pipes. The Main Supply Line splits at the intersection of Rose and Central Avenues. One split feeds the El Rio Recharge Basin while the other split is the main feeder to the PTP and PVP agricultural users. The entire system flows by gravity.

The primary end users include:

> **Saticoy Recharge Basin (Saticoy includes, Noble, Rose and Ferro)** – the Saticoy (133 acres) and Noble (92 acres) Recharge Basin are immediately downstream of the Desilting Basin. The Recharge Basin function as infiltration basins for the purpose of recharging the local aquifer. In addition to these basins, UWCD has capacity to send water to the Rose (92 acres) and in the future, Ferro (190 acres) basins.
>
> **El Rio Recharge Basins** – The El Rio Recharge Basins (81 acres) are downstream of the Moss Screen supplied through the Main Supply Line. The El Rio Recharge Basin function to recharge the local aquifer. Groundwater beneath the El Rio Recharge Basin is pumped and treated before entering into the Oxnard-Hueneme (O-H) Pipeline drinking water system. The groundwater is considered under the influence of the surface water and is directly impacted by the water quality of the surface water diversion.
>
> **Pleasant Valley County Water District and PTP** – The PVP and PTP supply agricultural users in the Pleasant Valley and Oxnard Plain. The water in these pipelines is used strictly for irrigation.

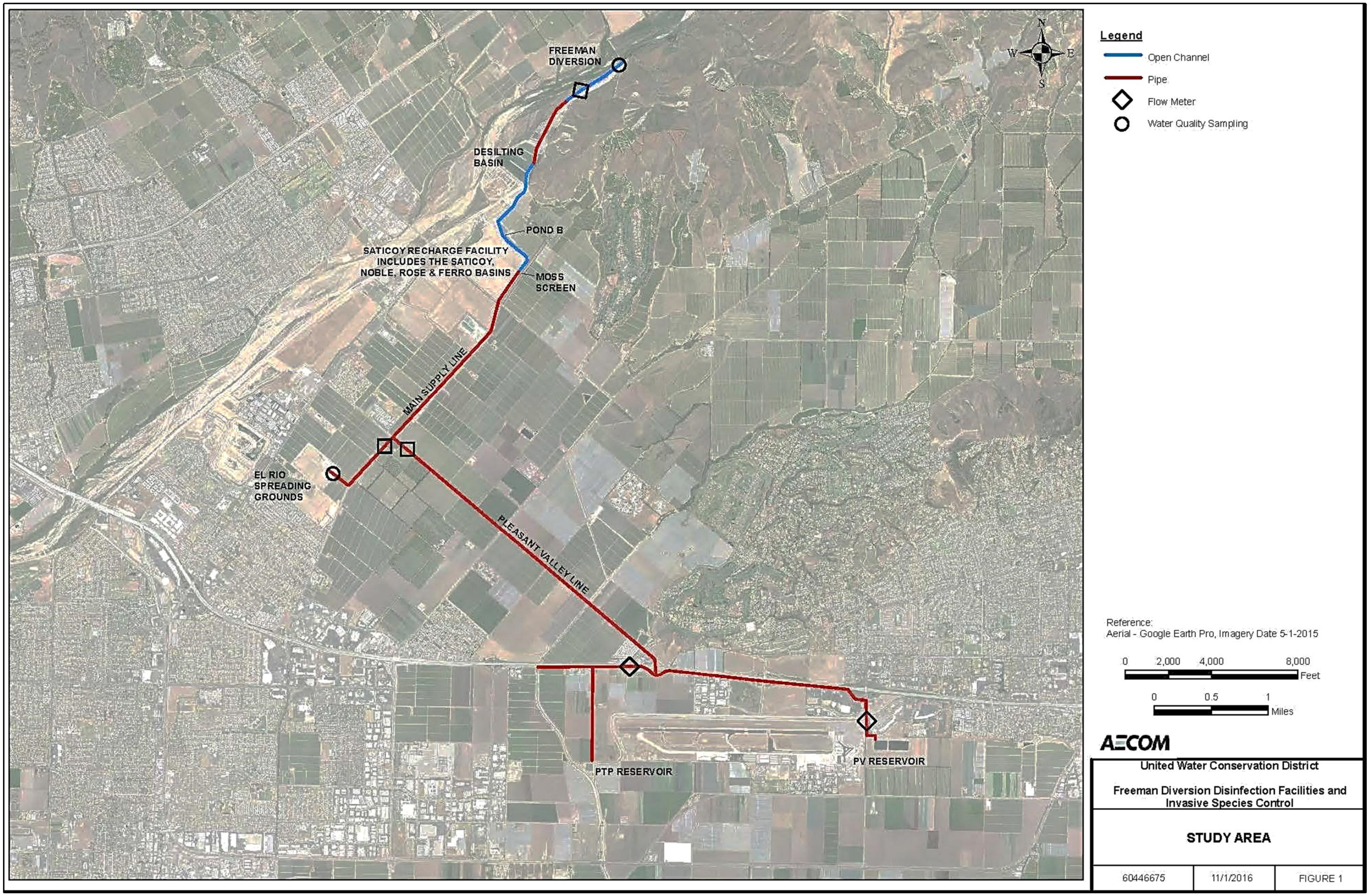


**Figure 2-1. Map of UWCD Study Area**

**Figure 2-2. Site Photograph of the Freeman Diversion Headworks Inlet Structure, Looking Upstream**

**Figure 2-3. Site Photograph of the Fish Screen at Freeman Diversion Headworks, Looking Downstream**

### 2.1.2 Raw Water Diversion Conditions

There are two primary conditions under which water is diverted through the Freeman Diversion from the Santa Clara River: annual conservation release from Santa Felicia Dam and before and after river flow events (high turbid winter storms). These are described below.

#### 2.1.2.1 Annual Conservation Release from Santa Felicia Dam

The annual conservation release typically occurs after Labor Day weekend and continues through the end of October. The release can begin earlier in August and/or extended through November depending on the hydrologic conditions in the downstream basins. The conservation release water that reaches the Freeman Diversion is typically characterized by low turbidity.

#### 2.1.2.2 High Turbid Winter Storms

Storm flows in the Santa Clara River are characteristically flashy and turbid. The river flows are generally not diverted if the turbidity is greater than 5,000 nephlometric turbidity units (NTUs). The initial storm water (first flush) is typically sent into the Noble Basin via the Grand Canal. These first flush flows are typically characterized by the highest turbidity.

### 2.1.3 Conveyance Facilities Design Flow Rates

System flow rates are summarized in **Table 2-1**. The Freeman Diversion Canal is designed to convey up to 1,000 cfs, but is permit limited to 375 cfs. The conveyance facilities between the Freeman Diversion and desilting basin are designed to convey this 375-cfs discharge.

The capacity of the Moss Screen Facility is 225 cfs where the water enters the 78-inch-diameter Main Supply Line. The balance of the flow can be diverted to the Saticoy recharge basins.

The Main Supply Line flow splits at the intersection of Rose Avenue and Central Avenue. The maximum flow that can be diverted to the El Rio Recharge Basins is approximately 130 cfs; however, the original design capacity was 150 cfs (hereafter we reference 130 cfs for this diversion). The 54-inch-diameter PVP continues down Central Avenue and has a design capacity of 75 cfs. The PTP connects to the PVP at Central Avenue and Ventura Boulevard (Blvd.) on the southern side of US Highway 101. The Grand Canal conveys water between the basins of the Saticoy Recharge Facilities: Saticoy, Noble, and Rose Recharge Basin and has a maximum capacity of 320 cfs. It should be noted that a new connection between the Rose and Noble basins can allow for increased diversions (volume, not instantaneous flows).

**Table 2-1. Maximum Flow Rates Below Santa Clara River**

| Location | Rate (cfs) |
|---|---|
| Freeman Diversion | 375 |
| Desilting Basin | 375 |
| Moss Screen | 225 |
| El Rio Pipeline | 130 |
| PVP | 75 |

#### 2.1.3.1 Flow Measurements

Flow is measured at four locations in the system as shown in **Figure 2-1**. The four metered locations are:

- Downstream of the Freeman Diversion (Measurements are taken in the open channel between the Freeman Diversion gates and the desilting basin.);
- On the El Rio Pipeline;
- On the PVP downstream of the El Rio Pipeline split;
- At Las Posas and Ventura Blvd, feeding PV Reservoir; and
- On the PTP just after the split from the PVP.

#### 2.1.3.2 Water Quality

Water quality samples are taken at Freeman Diversion and include temperature, suspended sediment, turbidity, conductivity, pH, calcium, hardness, and phosphorus. Turbidity measurements are also taken at the outlet of the desilting basin and at the El Rio discharge. The typical water quality measurement ranges are shown in **Table 2-2**.

**Table 2-2. Freeman Diversion Water Quality**

| Parameter | Range |
|---|---|
| Alkalinity, mg/L as $CaCO_3$ | 170 – 600 |
| Calcium, mg/L | 120 – 170 |
| Dissolved oxygen, mg/L | 6 – 11 |
| Hardness, mg/L as $CaCO_3$ | 235 – 700 |
| pH, units | 7.4 – 8.4 |
| Suspended solids, mg/L | 0 – 3,000 |
| Phosphorus, mg/L as P | 0.02 – 5.50 |
| Temperature, °F | 35 – 93 |
| Turbidity, NTU | <1 – 5,000 |

°F degrees Fahrenheit
$CaCO_3$ calcium carbonate
mg/L milligram per liter
< less than

### 2.1.4 Chemical Addition

A polymer is added above the desilting basin to enhance settling for river discharges with high turbidity. Chlorine is added to the PTP reservoir prior to distributing the water further downstream for agricultural irrigation. No other chemicals are added to the system.

### 2.1.5 Miscellaneous

There are a few small customers on the PVP along Central Avenue that divert water for agricultural purposes. These customers have historically accounted for 1 to 2 percent of the annual surface water deliveries.. At times the flow in the PVP is augmented or mixed with groundwater pumped from the Oxnard Forebay Basin.

The following seven operational scenarios have been provided by UWCD for consideration. An additional operational scenario may be also be developed by UWCD.

1. Annual Conservation Release from Santa Felicia Dam: The annual conservation release typically occurs after Labor Day weekend and continues through the end of October. The release can begin earlier in August and/or extended through November depending on the hydrologic conditions in the downstream basins. The low turbidity water diverted at the Freeman Diversion will vary between 200 and 375 cfs. The capacity of the Moss Screen facility is 225 cfs where the water enters the 78-inch-diameter Main Supply Line.

2. Main Supply Line: The entire flow or the balance of the flow can be diverted to the Saticoy recharge basins (Saticoy, Noble, and Rose Basins). The flow splits again at the intersection of Rose Avenue and Central Avenue. The maximum flow that can be diverted to the El Rio Recharge Basins is approximately 130 cfs, reduced from the original design capacity of 150 cfs. The 54-inch-diameter PVP continues down Central Avenue and has a design capacity of 75 cfs. The PTP connects to the PVP at Central Avenue and Ventura Blvd. on the southern side of US Highway 101. The highest irrigation demand is during the month of October.

3. Saticoy Well Field: The Saticoy well field consists of four shallow wells, approximately 300 feet deep. The wells are typically considered conjunctive use to supplement irrigation demands. Each well has a capacity of 3 to 5 cfs, depending on groundwater levels, and with a 20-cfs maximum combined capacity. The wells can also be used to draw down the water table when mounding occurs beneath the Saticoy basins due to recharge operations and/or reduced pumping in the forebay. The well field was designed to match to production capacity of the PTP lower aquifer system wells. The well field cannot meet the combined demand of the PVP and PTP systems. Expansion of the Saticoy well field may be an alternative treatment method to the use of the Moss Screen facility. Additional pumping instead of surface water deliveries may be a water accounting concern for the Fox Canyon Groundwater Management Agency.

4. Highly Turbid Winter Storm: The Freeman Diversion has a maximum capacity of 375 cfs. Storms flows in the Santa Clara River are characteristically flashy and turbid. The river flows are generally not diverted if the turbidity is greater than 5,000 NTUs. In addition UWCD must provide (bypass through the existing fish ladder) water for fish migration, which can reduce the total volume of water diverted. Polymer flocculants are added to the diverted river water to increase the deposition of sediment in the desilting basin. The initial storm water diversion is typically sent into the Noble Basin via the Grand Canal.. The maximum capacity of the Grand Canal is 320 cfs, which can be maintained for a limited time. The irrigation demands are usually very low or non-existent during winter storms and most the diverted water is directed into the Saticoy Recharge Basins (Saticoy, Noble, Rose) and El Rio recharge basins. The irrigation demand can resume almost as soon as the storm front moves through the watershed.

5. Base Flows: The base flow in the Santa Clara River may run 15 to 30 cfs in the vicinity of Freeman Diversion. Most of the water delivered during base flow is diverted to the PVP and PTP systems unless water quality (i.e., nitrates, total dissolved solids) and/or pumping levels in the O-H well field require that the surface water be directed to El Rio.

6. Drought Conditions: When the available storage in the Forebay is 80,000 acre-feet or greater, all diverted surface water must go to groundwater recharge. There are no deliveries to the PVP and PTP system. Water quality issues and/or pumping levels at the O-H well field may require all available surface water to go to El Rio.

7. Increased Diversion Capacity: UWCD is considering filing an application to increase the maximum diversion capacity to 750 cfs during peak storm periods. UWCD would divert highly turbid water during high river flows which would have fewer environmental affects compared to diversions during low flows. UWCD is also considering modifying the Saticoy canal system to convey highly turbid flows directly to the Ferro Basin (375 cfs to 750 cfs).

# 3.0 Regulatory Setting

Activities at the Freeman Diversion facility must comply with both Federal and California Endangered Species Acts (ESA and CESA, respectively). The current and future O&M activities at the Freeman Diversion facility have the potential to affect the federally endangered southern California steelhead in addition to other species that are listed or could become listed in the future. UWCD is developing a multiple species habitat conservation plan (MSHCP or HCP) in support of obtaining an incidental take permit (ITP) under section 10(a)(1)(B) of the ESA and CESA, for its current and future operations at the Freeman Diversion facility and nearby Recharge Basin. UWCD has proposed a list of 12 species to be covered under the HCP and ITP (**Table 3-1**).

As part of the permitting process, UWCD has been working with the National Marine Fisheries Service (NMFS), the United States Fish and Wildlife Service (USFWS), and California Department of Fish and Wildlife (CDFW) to develop the required conservation measures for the ITP that minimize and mitigate the effects of the covered activities on the covered species to the maximum extent practicable. UWCD is proposing to include the construction and operation of a new fish passage facility and modified water diversions as their conservation measures. Additionally, UWCD is seeking a long term for its ITP (i.e., 50 years) which in combination with conservation measures will give local stakeholders a measure of certainty about the permitting requirements associated with the Freeman Diversion facility.

The Santa Felicia Dam is an additional component of the UWCD's water resources management and because it provides hydroelectric power generation, is regulated by a license issued by the Federal Energy Regulatory Commission (FERC). The FERC license has various terms and conditions that UWCD must satisfy to remain in compliance with state and federal regulations. Some of the requirements are associated with structural engineering, water quality, and public safety. Others pertain to management of biological and land resources, and recreational opportunities and facilities.

In compliance with requirements in the FERC license and associated biological opinion issued by NMFS, UWCD developed a Water Release Plan for Lake Piru. The Water Release Plan establishes minimum flow releases to lower Piru Creek based on specific triggers. It also specifies rates at which releases are to be increased and decreased. Depending on the time of year and what triggers are met, minimum releases can range from 5 to 200 cfs.

Depending on the alternative selected other regulatory constraints include Federal and California Clean Water Acts, Federal and California Environmental Acts, California Streambed Alteration Agreements, and Federal Emergency Management Agency Conditional Letter of Map Revision.

**Table 3-1. Species Proposed for Coverage Under the Habitat Conservation Plan**

| Species | Federal Status | State Status | Critical Habitat Present in the MSHCP Area* |
|---|---|---|---|
| Southern California steelhead *(Oncorhynchus mykiss)* | E | SSC | Yes |
| Tidewater goby *(Eucyclogobius newberryi)* | E | SSC | Yes |
| Least Bell's vireo *(Vireo bellii pusillus)* | E | E | Designated critical habitat on the Santa Clara River falls outside of MSHCP area |
| Southwestern willow flycatcher *(Empidonax traillii extimus)* | E | E | Yes |
| California least tern *(Sternula antillarum browni)* | E | E, FP | No |
| Santa Ana sucker (*Catostomus santaanae*) | T | None | No |
| Pacific lamprey *(Entosphenus tridentatus)* | None | None | No |
| Western pond turtle *(Emys marmorata)* | None | SSC | No |
| Two-striped garter snake *(Thamnophis hammondii)* | None | SSC | No |
| Yellow warbler *(Dendroica petechia)* | None | SSC | No |
| Western yellow-billed cuckoo *(Coccyzus americanus occidentalis)* | T | E | No designated critical habitat on Santa Clara River |
| Yellow-breasted chat *(Icteria virens)* | None | SSC | No |

E = endangered
T = threatened
SSC = California Species of Special Concern
FP = Fully Protected
* = Critical habitat for a threatened or endangered species, as designated by NMFS or USFWS under section 4 of the ESA, is or is not present in the MSHCP covered area

# 4.0 Quagga Mussel Biological Description

Quagga mussels are non-endemic bivalve mollusks native to the Balkans region of Europe and introduced into the Lake Erie in roughly 1989, subsequently spreading to many freshwater water bodies across the US. They are relatively small mussels, roughly ¾ inch wide and 1½ inches long that can live from 3 to 5 years. They attach themselves to the substrate by byssal threads, and can inhabit both soft and hard substrates as long as they have a hard surface for attachment.

Quagga mussels are dioecious (separate male and female animals) with external fertilization of eggs. With external fertilization, synchronization of spawning is important. They achieve synchronization by responding to the presence of food (phytoplankton) likely in conjunction with other environmental stimuli. Large females can produce up to one million eggs per year.

In contrast to other freshwater bivalves, within a few days following fertilization, eggs develop into planktonic veligers. This free-swimming larval stage allows quagga mussels (and other *Dreissena* mussels such as the closely related zebra mussels [*Dreissena polymorpha*]) the ability to disperse widely and quickly with water currents. Veligers swim with the currents for 3 to 4 weeks, feeding on plankton. At the appropriate point in their development and upon finding the appropriate substrate, the veligers settle to the bottom and attach themselves by their byssal threads. Rates of development are affected by temperature with warmer temperatures favoring faster development reducing the time needed for individuals to reach sexual maturity. An interesting aspect of this developmental feature is that fertilized eggs released from adults in a flowing system are not likely to remain in the system long enough to settle back in the same area. Recruitment to that facility will need to come from an upstream source that will require environmental conditions in the stream that are favorable for survival of veligers for several weeks.

On the other hand, quagga mussels have the ability to detach from and reattach to the substrate thereby allowing them to move even as small adults. A consequence of this behavior could be that eradication of adults from one area in a facility may open substrates for recruitment by individuals from other areas within that same facility, depending on the flow regimes within the facilities and the access of mobilized individuals to the newly opened substrates.

Warmer water temperatures also affect viability of eggs with higher temperatures resulting in shorter viability. At 12 degrees Celsius (°C), eggs are viable for about 5 hours (hrs), while at 24°C eggs are viable for only about 2 hrs. This observation indicates that higher temperatures negatively affect spawning success. Warmer waters also affect spawning by causing it to occur earlier in the year in more southerly states where warmer water occurs earlier in the year or even year around, with the result that spawning and settling events may even occur year around.

In addition to temperatures affecting spawning timing and success, quagga mussels show a small range of various other environmental parameters within which they survive optimally. Factors that contribute to overall success include alkalinity, calcium availability, pH, temperature, oxygen availability, and total hardness. Many of these factors work synergistically where sub-optimum conditions for one parameter can narrow the optimal or even operational range for another parameter. For example, quagga mussels show differential susceptibility to stressors such as low oxygen or toxins such as chlorination based on water temperature. Whereas chlorine concentrations of 0.5 mg/L results in 100-percent (%) mortality of adult mussels only after 25 days of exposure at 9°C to 15°C, 100% mortality was achieved in only 9 days at water temperatures between 18°C and 22°C. By exposing quagga mussels to treatments when one environmental parameter is putting them in stress, the effectiveness of other treatments may be increased or the required duration of the treatment to achieve the desired effect may be shortened.

Emersion (exposure to air after being submerged) is not well tolerated by dreissenid mussels. Tolerance is affected by temperature, relative humidity, and density of individuals. At increasing temperatures, the time to mortality decreased for both adults (McMahn et al. 1993) and veligers (Schwaebe 2013). Also, relative humidity is inversely related to mortality with lower relative humidity resulting in higher mortality at a given temperature. Components of a water conveyance system that can be exposed to air, particularly when temperatures are elevated and relative humidity is low may have more success at killing resident quagga mussels.

Quagga mussels can be found at deeper depths and a wider array of substrates than zebra mussels. Attached quagga mussel adults occupy habitats from near the water surface to a depth of 30 meters or more. In addition, quagga mussels can live on soft substrates more readily than can zebra mussels, which provide them a wider range of habitats to occupy. Based on the morphology of their shells, it appears that quagga mussels are better suited to calmer, deeper waters where currents are less strong. Where they have co-occurred, quagga mussels have replaced zebra mussels in many locations. This wider range of potential substrates that quagga mussels can survive in may make eradication methods that have been successful for zebra mussels less effective than for quagga mussels. Furthermore, quagga mussels may settle and establish populations where zebra mussels would not be expected to be found so could be more difficult to eradicate due to the wider diversity of habits that would require treatment.

# 5.0 Control Options

At this time, there is no identified single treatment process that has been shown to provide absolute control of mussels. Typically, control is achieved by a combined effort of multiple treatment approaches and/or operational controls. Regardless of the control options implemented, the ability to achieve long-term success in the control of mussel attachment is dependent upon implementation of a robust monitoring program.

## 5.1 Water Quality

Treatment for the control of quagga mussels in UWCD's system below Freeman Diversion will need to be able to not only protect against the veliger attachment, but also provide veliger eradication to prevent downstream infestation. To contemplate the effectiveness of different treatment techniques, it is important to identify water quality conditions that allow infestation to occur. **Table 5-1** summarizes water quality conditions that both inhibit and promote quagga mussel infestation as adapted from Mackie and Claudi (2010).

**Table 5-1. Water Quality Criteria Relating to Quagga Mussel Infestation Potential (adapted from Mackie and Claudi, 2010)**

| Parameter | Unsustained Infestation (Adults Do Not Survive) | Low Infestation (Veligers May Not Survive) | Moderate – High Infestation |
|---|---|---|---|
| Alkalinity, mg/L as $CaCO_3$ | <30 | 30-45 | >45 |
| Calcium, mg/L | <10 | 10-15 | >15 |
| Chlorophyll-a, µg/L | <2 or >25 | 2-2.5 or 20-25 | 2.5-20 |
| Conductivity, µS/cm | <30 | 30-60 | >60 |
| Dissolved Oxygen, mg/L (% saturation) | <2 (25%) | 5-7 (25%-50%) | >7 (>50%) |
| Hardness (total), mg/L as $CaCO_3$ | <30 | 30-45 | >45 |
| pH, units | <7.0 or >9.5 | 7.0-7.5 or 9.0-9.5 | 7.5 to 9.0 |
| Secchi depth, meters | <0.1 or >8 | 0.1-0.2 or 2.5-8 | 0.2 to 2.5 |
| Phosphorous (total), µg/L | <5 or >50 | 5-10 or 30-50 | 10-30 |
| Temperature (mean summer), $^{o}$F | <64 | 64-68 or >83 | 68-83 |

> greater than
µS/cm micro Siemens per liter

If water quality could be controlled by a form of treatment, the most likely adjustable parameters could be pH (reduced below 7) and dissolved oxygen (reduced below 2 mg/L). Control of water pH and oxygen will be discussed in more detail below. It should be noted that there is a synergism between the parameters such that the effectiveness of one treatment may be heightened by the animals already being in a stressed condition (e.g., at elevated temperatures).

The chemical, biological, and physical treatment options to control quagga mussels include a range of actions. Each viable option needs to be considered carefully as a mussel control strategy at UWCD's facilities and not only needs to provide an effective barrier against ingress into its water system, but it also needs to provide downstream protection against mussel colonization if the barrier is not 100% effective. Each control option has subsets to consider before an option can be further considered as an alternative that can be considered as appropriate for use in UWCD's system.

Below, summaries of the options for treatment are provided and followed by more detailed evaluations of each of the subset options.

## 5.2 Chemical Treatment Options

The major advantage offered by most chemical treatments is that they can be engineered to protect an entire water facility. Disadvantages include strict regulations and extensive control requirements for discharging of water with residual toxic chemicals into the environment.

Many chemical treatments have been tested and chlorination is the most widely used. In the past, chlorination systems have gained wider acceptance because of the cost-effective control of quagga mussel infestations. However, due to tighter environmental and drinking water restrictions on the formation of chlorinated disinfection by-products (DBPs) such as trihalomethanes (THMs) and Haloacetic acids (HAAs), other oxidizing chemicals such as potassium permanganate and ozone have been used. This is a significant concern for domestic water wells in the El Rio area.

Various chemical solutions have been proven as effective toward shocking/killing mussel veligers and infestations. Popular chemical solutions that have been used include the following:

- Potassium Permanganate;
- Chlorine;
- Chloramine;
- Chlorine dioxide;
- Ozone;
- Ultraviolet Light (UV);
- Copper Sulfate; and
- Molluskicides.

This section examines each of the chemical treatments advantages and disadvantages.

### 5.2.1 Potassium Permanganate

Potassium permanganate (as $KMnO_4$) is an oxidizing chemical commonly used in municipal facilities for water purification. Its primary use is for oxidation of iron and manganese (prior to their removal by filtration) and for control of taste and odor compounds that can occur from algal production. Potassium permanganate is a purple-colored chemical whose use as a disinfectant was originally developed in the 1800s. It is a strong non-chlorine oxidant with a long history of safe use in drinking water, wastewater, and chemical manufacturing industries and is commonly used in municipal facilities for water purification. The active portion of the chemical compound, permanganate ($MnO_4^-$), is not a thermodynamically stable form of manganese when dissolved in water; thus, it tends to oxidize very slowly in water with the evolution of oxygen as follows:

$$4MnO_4^- + 4H^+ \rightarrow 4MnO_2 + 2H_2O + O_2$$

As $KMnO_4$ is an oxidizer, it has been observed that adult mussels retract their siphons while the chemical is passed through water. It has also been observed to kill veligers.

#### 5.2.1.1 Advantages

A summary of the advantages of potassium permanganate includes the following:

- It does not produce DBPs.
- It can be applied at a low chemical dose (≤1 mg/L as $KMnO_4$) to reduce veliger densities and prevent settlement/attachment of mussels.
- Only a slightly increased dose is required to control adult mussels (approximately 2 mg/L as $KMnO_4$).

#### 5.2.1.2 Disadvantages

Some of the disadvantages of potassium permanganate include the following:

- Cost and effectiveness have limited municipal use of potassium permanganate to control zebra mussels.
- Unlike chlorine, potassium permanganate does not eliminate mussels except only when applied at a high, continuous dosage.
- It can be less effective than chlorine.
- It typically costs more than chlorine.
- Overdosing can result in an unacceptable pink coloration of water.
- It is not acutely toxic to the veligers, so continuous application is required.
- It requires a long contact time (likely 3 hrs or longer).

#### 5.2.1.3 Summary

Potassium permanganate may not be able to provide a complete control barrier against veligers and mussels, but it can provide effective residual chemical protection against them. It is also unknown if the chemical will work properly in highly turbid water. However, it is possible that the chemical can be applied following turbid water events and/or after turbidity is settled in order to provide treatment against veligers that may have entered the system.

### 5.2.2 Chlorine

Chlorine is available in hypochlorites of sodium, potassium, or calcium; chlorine and chlorine dioxide gases; and sodium chlorite. It is typically applied by gas or liquid slurry of sodium hypochlorite and is commonly used in drinking water treatment as a chemical oxidant and microbial disinfectant. Use of chlorine has been the dominant control method for mussels in both Europe and North America, and remains the least expensive and most popular method for control. After dosing into waterways and allowing a residual to persist, chlorine is able to effectively kill or prevent settling of planktonic veliger larvae in water systems. Chlorine controls mussels through the effects of oxidation, consisting of either direct toxic effects on adults, inhibition of settlement and growth of veligers, or weakening of byssal thread attachments.

The unfortunate consequence of applying chlorine is the formation of regulated DBPs such as THMs and HAAs. Therefore, when used for mussel control, it needs to be applied at the most suitable time, for the shortest duration possible, and at the lowest concentration possible.

#### 5.2.2.1 Advantages

Some of the advantages of chlorine include the following:

- It kills mussels.
- Adult mussels will close at concentrations of from 1 to 2 mg/L and remain closed for up to 2 weeks, altering reproductive cycles.
- It is relatively inexpensive.
- It works in most raw water systems and can work in highly turbid water (although bench-scale chlorine demand and decay testing is required to confirm).
- It is toxic at low concentrations and quickly loses toxicity without bioaccumulating.
- It can be applied with simple mechanisms.

#### 5.2.2.2 Disadvantages

Drawbacks of chlorination include the following:

- Discharge presents problems if formation of DBPs (such as regulated THMs and HAAs) are formed above regulatory levels.
- Chemical storage and dosing infrastructure would need to be properly designed and constructed to protect against leaks (either if using gas or liquid chlorine solutions).
- Transport and storage of gaseous or liquefied chlorination products involves risk.

#### 5.2.2.3 Summary

Chlorine can provide a near complete control barrier against veligers and mussels, but it can only do so if an effective residual is achieved. Chlorine can still work well in highly turbid water, however it may require significantly greater doses of chlorine than is economically feasible to overcome the demand that turbid water may impart. Furthermore, DBP formation may become excessive when trying to overcome elevated water turbidity. However, it remains possible that chlorine can be applied following turbid water events and/or after turbidity is settled in order to provide treatment against veligers that may have entered the system. As it is unclear how much chlorine would need to be applied to water in UWCD's system at this time, bench-scale demand/decay tests are required to determine if these chlorine dosing levels are problematic.

### 5.2.3 Chloramine

Chloramine (as monochloramine, $NH_2Cl$) is formed by the combination of chlorine and ammonia. It can be formed naturally when chlorine is applied to raw water if natural ammonia is present, or ammonia can be applied in conjunction with chlorine. Chloramine chemistry is complex, but the basis of forming the proper type of chloramine species is based upon some key factors which include:

1. First establishing a residual level of chlorine;
2. Adding ammonia to achieve a ratio of chlorine:ammonia between 4:1 and 4.5:1; and
3. Maintaining a residual which typically is not greater than 3 mg/L of total chloramine.

By changing the chlorine:ammonia ratio, species other than monochloramine can be formed. These species include dichloramine ($NHCl_2$) and trichloramine ($NCl_3$) which are less effective oxidants and can actually impart negative taste or odors in water. Chloramine is a much slower reacting oxidant than chlorine, but still form THMs and HAAs. Furthermore, chloramines can also form their own type of nitrogen-containing DBPs, which include N-nitrosodimethylamine (NDMA).

#### 5.2.3.1 Advantages

Some of the advantages of chloramine include the following:

- Fewer THMs and HAAs may form than chlorine.
- The residual is longer-lasting than chlorine.

#### 5.2.3.2 Disadvantages

Drawbacks of chloramine include the following:

- They are a less powerful oxidant than chlorine.
- It requires both chlorine and ammonia to be stored and fed.
- Exact dosing requirements for effective mussel control would need to be determined.
- Although they form fewer THMs and HAAs than with chlorine, they can also form other DBPs (such as NDMA).

- Highly turbid water may cause excessive chloramine demand, making treatment ineffective.
- Successful implementation will likely require first establishing a residual level of chlorine and then the addition of ammonia, which may be very challenging operationally in UWCD's system and may still form excessive levels of THMs and HAAs (due to the residual contact time of chlorine).

#### 5.2.3.3 Summary

Chloramine may be able to provide an effective barrier against mussels, but operational challenges in establishing proper chloramine residuals may be significant. Chloramine will first require a chlorine residual and then a follow-up addition of ammonia at the proper chlorine:ammonia ratio. The application of chloramine becomes even more complicated when water is turbid as there may be significant operational challenges in establishing an effective residual. Chloramine may form fewer THMs and HAAs than chlorination, but also form other nitrogen-containing DBPs such as NDMA. As it is unclear what level of residual chloramine would need to be applied to water in UWCD's system at this time, bench-scale demand/decay tests are required to determine if chlorine and ammonia dosing levels are problematic.

### 5.2.4 Chlorine Dioxide

Chlorine dioxide ($ClO_2$) is an oxidant and disinfectant that has been used in the US water treatment industry since the mid-1900s. It is created by combining chlorine (either gas or liquid) with liquid sodium chlorite. $ClO_2$ reacts more selectively with dissolved materials and does not react with organic matter to form THMs and HAAs. A challenge with $ClO_2$ is that it cannot be applied at a dose any greater than approximately 1 mg/L because it dis-associates into its own DBPs: chlorite (regulated) and chlorate (anticipated to be regulated in the future). If applied at greater dosages, regulatory levels for chlorite or chlorate can be violated. Mussel control with $ClO_2$ depends upon concentration, time, water quality, and temperature. For veliger control, it is likely that only a low residual of $ClO_2$ is required: up to 0.5 mg/L. However, it is expected that highly turbid water will severely restrict $ClO_2$ effectiveness due to increasing the demand of $ClO_2$ above the dosage limit to restrict prohibitive formation of chlorite.

#### 5.2.4.1 Advantages

Some of the advantages of $ClO_2$ include the following:

- Unlike the hypochlorite reaction, it does not produce THMs and HAAs.
- It may require less treatment contact time when compared to chlorine or chloramines.
- It may be more effective against adult mussels than chlorine or chloramines.

#### 5.2.4.2 Disadvantages

Disadvantages of $ClO_2$ include the following:

- It requires two chemicals to be stored and fed – either sodium hypochlorite and sodium chlorite, or sodium chlorite and hydrochloric acid.
- It dissociates to chlorite and chlorate – chlorite is currently regulated, and chlorate is expected to be regulated in the future.

- Highly turbid water may cause an excessive $ClO_2$ demand, making treatment by $ClO_2$ ineffective.

- Use of $ClO_2$ may not offer significant advantages over chlorine when cost and ease of use are considered.

- $ClO_2$ must be manufactured on-site with the use of specialized equipment.

#### 5.2.4.3 Summary

$ClO_2$ may be able to provide excellent control against veligers and mussels, but it can only do so if an effective residual is achieved. If $ClO_2$ needs to be dosed when water turbidity is elevated, it may not be able to be used effectively even if the appropriate residual can be achieved (due to DBP formation of chlorite). However, it is possible that $ClO_2$ can be applied following turbid water events and/or after turbidity is settled in order to provide treatment against veligers that may have entered the system. As it is unclear how much $ClO_2$ would need to be applied to water in UWCD's system at this time, bench-scale demand/decay tests are required to determine if $ClO_2$ dosing levels are problematic.

### 5.2.5 Ozone

Ozone has been applied in the water industry in Europe and the Americas for more than a century. It is a very effective and much stronger oxidant/disinfectant than chlorine-based chemicals and therefore requires much shorter contact times to achieve the same levels of organism control. Ozone must be applied to the water in gas form and also must be generated on-site with ozone generators that are typically fed with evaporated liquid oxygen. Ozone reacts very quickly in water and does not form any THMs or HAAs, but can form excessive levels of bromate (another regulated DBP) if raw water contains bromide. Specialty ozone generators and equipment is needed to produce and feed ozone into a water system and during ozone residual contact with the water, the system must be covered and allow for off-gas treatment. This covered type of system is required to collect any potential ozone off-gas so that it can be destroyed and converted back to oxygen before discharge. However, after this contact time, there are no residual chemical disinfectants present in the water.

Unfortunately, literature has indicated that very long contact times are required when using ozone to control veligers. Although the typical ozone contact time in drinking water treatment is less than 15 minutes, Mackie & Claudi (2010) indicate that 100% mortality of veligers and postveligers could only be achieved with a minimum of 5-hr contact time (ozone residual equals [=] 0.5 mg/L, temperature between 15-20$^{o}$C). This extensive contact time would require unachievable sizes of covered ozone contactors; typically designed as enclosed concrete basins or in-pipe systems. Furthermore, ozone residual effectiveness is a function of water temperature and can be negatively impacted by turbid water events.

#### 5.2.5.1 Advantages

Some of the advantages of ozone include the following:

- It can provide effective mussel control without forming THMs or HAAs.

- It is a much stronger oxidant than chorine.

- It does not leave residual chemical in the water following treatment.

#### 5.2.5.2 Disadvantages

Disadvantages of ozone include the following:

- Bromate above regulatory levels may form.
- There is a much greater cost than for other chemical disinfectants.
- The required size of the ozone contactor to achieve 5-hr of contact time will likely be excessively large to be cost effective.

#### 5.2.5.3 Summary

Ozone will likely be rendered inappropriate to use due to the negative impact from turbid waters as well as from the requirement for design/construction of a 5-hr enclosed contactor. These negatives will likely outweigh any benefits from reduced DBP formation or the lack of chemical residual in treated water.

### 5.2.6 UV Light Treatment

UV light is a physical treatment process which uses light rays to provide disinfection. Reactors require low-turbidity water to pass through reactors in order for (a) the lamps and lamp sleeves to remain undamaged and (b) the light pathways to effectively reach target organisms. This requirement may be problematic during high-turbidity events experienced by UWCD. Reactors are manufacturer-specific designs which include in-pipe systems with lamps inserted counter- or co-current with flow and in-channel systems with lamps suspended from submerged racks. UV light produces no DBPs and also has no chemical residual in treated water. The mode of action for UV light is the instantaneous impact that UV has in the disruption of target-organism deoxyribonucleic acid (DNA). This DNA disruption typically inactivates the target organism (rendering it unable to reproduce), but does not kill it. Some studies have shown that UV can inactivate veligers, but testing would need to be conducted in UWCD water to determine appropriateness of the technology.

#### 5.2.6.1 Advantages

Some of the advantages of UV light treatment include the following:

- There is no formation of THMs or HAAs.
- There is no residual chemical in the water following treatment.

#### 5.2.6.2 Disadvantages

Disadvantages of UV light treatment include the following:

- Power costs are high;
- A chemical disinfectant will still be required after UV light treatment, as live veligers are expected to pass through UV treatment (100% kill/inactivation is not expected).
- High turbidity events will likely render the technology ineffective.

#### 5.2.6.3 Summary

Success with UV irradiation will rely very closely upon how well its process design is able to compensate for all water quality and hydraulic fluctuations. It is anticipated that within the potentially elevated turbidity water matrix, UV light treatment (on its own) may be a very high-cost and ineffective solution. UV light treatment does not impart a residual disinfectant into the water, and only works if there is a direct line-of-sight between the UV lamps and the target organisms. Even if a pristine, low-turbidity water quality were to be passing through the UV reactors, they could only provide a reduction in veligers and not a total eradication. Therefore, additional treatment such as a chemical treatment will still be required following UV light treatment.

### 5.2.7 Deoxygenation

As per **Table 5-1** reduction of dissolved oxygen (deoxygenation) below 2 mg/L will prevent mussel growth and attachment. Addition of chemicals that can deoxygenate water may be effective in controlling veligers. This technique is currently being evaluated for its application in ship ballast water (by diffusing nitrogen gas into water to displace most of the dissolved oxygen) and chemical deoxygenation is used in various industrial water applications. There are other methods that can deoxygenate water which include membranes. In the application for UWCD's system, it is assumed that nitrogen diffusion and membranes would not be feasible due to both the volume of water treated and the level of turbidity in the water.

With regard to chemical deoxygenation, use of an oxygen scavenger is required such as with sodium sulfite ($Na_2SO_3$). The chemical methods of water deoxygenation are based upon binding the dissolved oxygen with the oxygen scavenger; where the scavenger is oxidized by the dissolved oxygen, such as in the following equation:

$$2Na_2SO_3 + O_2 \rightarrow 2Na_2SO_4$$

Sodium sulfite can be added to water, which it will then turn into inert sulfate downstream. This method is simple to use, and disadvantages for UWCD's system are as yet unknown. Furthermore, the amount of time that the water is required to be oxygen-free in order to kill veligers is unknown. This option requires further investigation before it is found to be applicable to UWCD's system.

### 5.2.8 pH Control

Another water quality control, per **Table 5-1**, is to either reduce or increase water pH until it is at a level that mussels will not live. Specifically, this control involves pH ranges below 7 and above 9.5. As downstream drinking water and discharge waters will likely need to be kept between a pH range of 6.5 and 8.5, there is a potential to reduce pH to between 6.5 and 7 to inhibit veliger/mussel life cycles. The reduction of pH can be achieved by dosing industrially-available water treatment chemicals such as sulfuric acid.

### 5.2.9 Copper Sulfate

Copper based salts in low doses have been shown to work well as biocides against mussels. Unfortunately, the presence of excess copper ions in water can be deleterious to a number of aquatic organisms including fish, algae, plants, and others. Controlling the dose can be difficult making this approch risky and not recommended for the UWCD System.

### 5.2.10 Molluskicides

Due to the potential for toxicity to nontarget organisms and bioaccumulation, it is anticipated that this option is not feasible. Furthermore, the use of molluskicides is more likely to be applicable only to lake systems (such as Lake Piru) where water is still and established mussel colonies already exist. It is possible that their use may be applicable for O&M control methods (non-flowing conditions where water is stagnant and mussels are observed to be attaching to system infrastructure) and should be investigated further for those applications.

## 5.3 Biological Treatment Options

Biological control methods are not widely used, especially in non-lake/conveyance infrastructure systems. Although the cost for implementing biological controls can be low, the effectiveness of introducing a species to control quagga mussels is unknown (and may likely only be effective in enclosed, still-water lake environments such as Lake Piru). Additionally, unintended consequences of introducing a predatory biological species may occur, and because of this, biological controls must be authorized by the United States Environmental Protection Agency (USEPA). There are some biological control products available on the market, but they are not addressed in this report. Due to the above, biological control methods are not considered feasible for UWCD’s system. It is possible that biological treatment options may be applicable for O&M control methods (non-flowing conditions where water is stagnant and mussels are observed to be attaching to system infrastructure) and should be investigated further for those applications.

## 5.4 Physical Treatment Options

Physical mussel control can be accomplished by thermal, mechanical, or manual methods. Thermal treatment is effective at removing quagga mussels, but requires a source of heated water. Nearby power plants can provide the heated water, but requires new pipelines to be constructed. Mechanical methods are commonly used and require personnel to operate and maintain. Divers may be used or cofferdams may be constructed in conjunction with using pumps to dry out intake systems. These are labor intensive processes.

### 5.4.1 Thermal

Thermal treatment is typically used when heated water (such as from a power plant) is readily available. Because mussels are capable of extensive temperature acclimation, the raw water system would need to be heated to high temperatures (above 100 $^{o}$F) to achieve 100% eradication. It is expected that heated water is not available nearby to the required application point in UWCD’s system, and the cost to heat the large volume of water that may pass through UWCD’s system would be excessive. Because of the above, thermal treatment is not considered feasible for this application.

### 5.4.2 Filtration

Although there is very little information available in the literature, it is believed that filtration could be an effective technology for preventing passage of veligers and mussels. To be successful, the filter technology used would need to operate with an appropriate pore size, be kept free from attaching organisms, and operate without any organism passage through the filter. Two types of filter approaches are discussed in this section: an infiltration gallery and mechanical/media filtration. A challenge with any filter technology will be in its ability to function properly when the highly turbid stream flow s enters UWCD’s system.

### 5.4.2.1 Mechanical and Media Filtration

For UWCD's system, installation of a filter technology is believed to be both too expensive and possibly ineffective. Filters (either mechanical or media-based) would need to operate with an effective backwash system that consists of approximately between 1 and 3% of the treated water flow. Furthermore, the amount of material removed from the filter system – in that 1 to 3% of flow – would include a tremendous amount of suspended solids and turbidity, and require to be discharged for treatment elsewhere. Lastly, there would likely need to be chemicals used (such as coagulants and polymers) to optimize filtration performance. Because of these issues alone, filtration would likely be the most expensive and challenging type of system to operate and maintain. Furthermore, there is information from the literature that indicates problems with the use of filtration, such as the following Mackie & Claudi (2010) summary of testing of various filter mesh sizes:

- A 97% veliger exclusion was observed when using either a 40-micrometer (µm) strainer or a 60-µm nominal mesh filter (i.e., 3% passage of veligers was realized).
- Testing of a 57-µm absolute screen filter allowed the passage of veligers of up to 100 µm in size.
- Testing of a 120-µm absolute mesh filter allowed passage of veligers up to 200 µm in size.

For the above reasons, filter technologies are not recommended as a viable option for further consideration.

### 5.4.2.2 Infiltration Gallery

Infiltration galleries are typically installed in riverine systems for withdrawal of water in a manner that has minimal or zero impact to aquatic species. These systems are sub-riverbed engineered systems that are constructed with media cover as shown in **Figure 5-1** to (a) mimic the riverbed and (b) protect the gallery from entraining aquatic organisms. Because these galleries are installed below the riverbed, if they operate properly, it is possible that they can prevent mussels from passing downstream, but unclear if they will be an effective protection against veligers. A typical design may include upper layers of protective large rock followed by layers of cobbles, drain gravel, pea gravel, and coarse sand. Intake pipelines will then be screened. Based upon veliger capacity to break through filter technologies as described in the previous section, it is highly likely that an infiltration gallery will allow veliger passage.

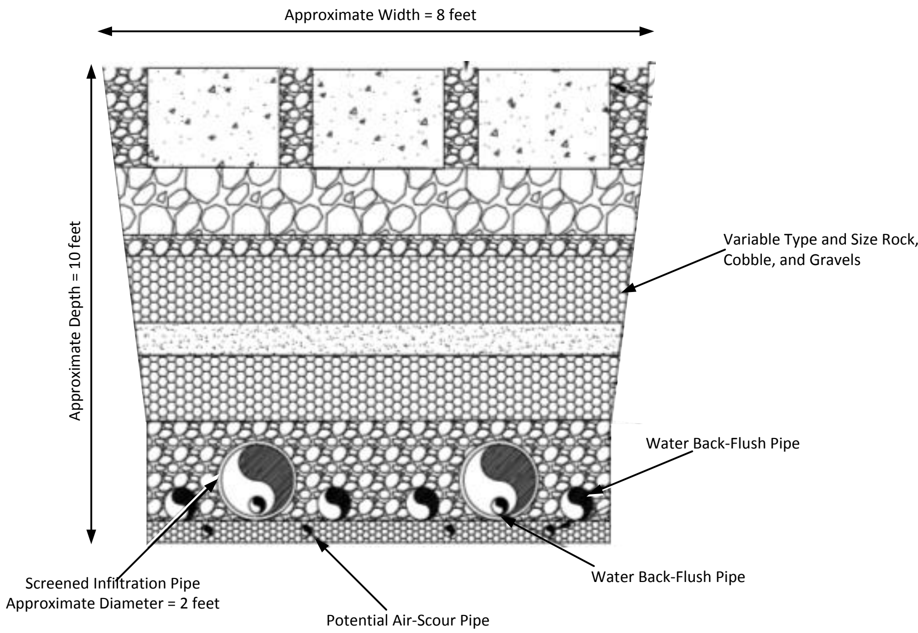


**Figure 5-1. Example Infiltration Gallery Design**

## 5.4.3 Coatings and Resistant Materials of Construction

It is possible that the use of special coatings (less effective long-term) and smooth surfaces (material selection) can play a significant role in discouraging mussel attachment in many structures. However, the use of coatings has had mixed success in the industry and it is unclear how this could be applied to the extensive water system downstream of UWCD's conveyance facilities. Due to these unknowns, it has been determined that specialized coatings and/or materials of construction are not practical solutions for UWCD's veliger/mussel control needs.

## 5.4.4 O&M Responses

There are several responses to mussel infestation that can be applied in a more passive response. These would include various treatments that occur in specific locations, as described below.

### 5.4.4.1 End-of-Season Treatment

End-of-season treatment is used for systems that can tolerate limited fouling. Treatments are applied once during the year, after the spawning season or at the end of the growing season to increase chemical effectiveness and reduce required concentrations as individual mussels are fatigued and weakened.

### 5.4.4.2 Periodic Treatment

Periodic treatment is used to eliminate adult mussels that have accumulated since the previous application. For this approach, limited infestations are tolerable. Because treatments are more frequent, infestations will be smaller. The chemical concentration and exposure time should be comparable to end-of-season values, though the total removed biomass will be smaller.

#### 5.4.4.3 Intermittent Treatment

Intermittent chemical treatment will prevent initial mussel infestation where fouling must be prevented. Dosing at frequent intervals (e.g., 6, 12, 24 hrs) destroys veligers that have settled since the previous treatment. Veligers are more susceptible to oxidizing chemicals than are adult mussels. Therefore, the concentration of the chemical and exposure times should be considerably less than if adults were the target. If grown mussels are found in the system and sections of the system with these mussels can be taken off-line for long durations, application of molluskicides could also be a possible intermittent O&M control method.

#### 5.4.4.4 Semi-continuous Treatment

Because mussels will stop filtering and close their shell when exposed to a toxic substance, frequent on-off cycling of chemicals (such as chlorine) is more effective than continuous chemical treatments. Treatment schedules can be adjusted to 15 minutes on and 15 to 45 minutes off. Semi-continuous treatment is ideal for facilities where several discrete systems require treatment, resulting in less chemical usage than continuous chlorination.

#### 5.4.4.5 Continuous Treatment

Continuous chemical treatment is designed for facilities that cannot tolerate any level of fouling. Low chemical concentrations applied continuously prevent any post-veliger settlement and is stressful enough to either kill adult mussels or cause them to detach and move out of the system. Continuous treatment is carried out for the entire mussel breeding season.

#### 5.4.4.6 Manual or Mechanical Scraping

Manual or mechanical scraping is typically used when chemical methods are not appropriate. Physical method such as carbon dioxide pellet blasting or scraping are typical. High-pressure water jet cleaning with pressure between 27,600 and 68,900 kilo-pascals (4,000 to 10,000 pounds per square inch) would also be an efficient physical means of removal.

Although mechanical and manual scraping can be an effective removal of adult quagga mussels, it can be a lengthy process to insure completeness of removal of quagga mussels for length of the pipe. Additionally, collection and disposal of removed mussels can cause incidental exposure elsewhere. Another disadvantage is that manual or mechanical scraping is repetitive and requires frequent operation and maintenance.

Without a proactive or preventative means of treatment, the reactive approach of physical removal would again become necessary over time. This treatment method is feasible but not desirable due to the labor required.

## 5.5 Summary of Control Options

**Table 5-2** summarizes the control options described above, along with brief descriptions of their benefits and challenges when considered for use. Key issues that must be considered prior to using many of these options is if their use within the operational constraints of the UWCD system will be negatively impacted by water quality or operational characteristics.

**Table 5-2. Summary of Control Options**

| Category | Option | Benefits | Challenges |
|---|---|---|---|
| Chemical | Potassium Permanganate | • Operates at a low dose<br>• A single chemical needed<br>• Low DBP risk (no THMs, HAAs) | • Continuous feed is optimal (start/stop flow is problematic)<br>• Inhibited by turbid water events<br>• Increase in Oxnard plain salinity |
| | Chlorine | • Very effective oxidant<br>• A single chemical needed<br>• Also controls other microbes | • Elevated DBP risk<br>• Inhibited by turbid water events<br>• Continuous feed is optimal (start/stop flow is problematic)<br>• Increase in Oxnard plain salinity |
| | Chloramines | • Lower DBP risk than chlorine (no THMs or HAAs) | • Very long contact time needed<br>• Multiple chemicals needed<br>• Inhibited by turbid water events<br>• NDMA production (DBPs)<br>• Increase in Oxnard plain salinity |
| | Chlorine Dioxide | • Effective oxidant<br>• No chlorinated DBPs | • Chlorite and chlorate production risk (DBPs) may inhibit dosage<br>• Multiple chemicals needed<br>• Inhibited by turbid water events<br>• Increase in Oxnard plain salinity |
| | Ozone | • Short contact time<br>• No chlorinated DBPs<br>• No chemical residual | • Extreme cost (infrastructure and power requirements)<br>• Inhibited by turbid water events<br>• Extensive operation and maintenance (O&M) requirements to properly maintain the system |
| | Deoxygenation | • Unknown at this scale of use | • Requirements for system contact times are unknown<br>• Long-term effectiveness unknown<br>• Continuous feed is optimal<br>• Increase in Oxnard plain salinity |
| | pH Control | • Unknown at this scale of use | • Accuracy of pH control for this application unknown<br>• Long-term effectiveness unknown<br>• Continuous feed is optimal<br>• Increase in Oxnard plain salinity |
| | Copper / Potassium Sulfate | • Effective biocide<br>• Effective when properly applied (typically during still water and/or within lakes/reservoirs) | • Drinking water copper regulations<br>• Turbid water may inhibit effectiveness<br>• Requires still water (flow may be too rapid to work properly)<br>• Increase in Oxnard plain salinity<br>• Possible negative impacts for irrigation water and crop application |
| | Proprietary Molluskicides | • Effective when properly applied (typically during still water and/or within lakes/reservoirs) | • Turbid water may inhibit effectivenessRequires still water (flow may be too rapid to work properly) |

| Category | Option | Benefits | Challenges |
|---|---|---|---|
| Biological | Proprietary Molluskicides | • Possibly effective when applied in still water (lakes/reservoirs) | • Novel/innovative, unclear if it will work in this type of application<br>• May be inhibited by turbid water events; may require still water |
| Physical | Ultraviolet Light | • No DBPs<br>• No chemical residual | • May also require use of a chemical for proper protection<br>• Requires low-turbidity water<br>• Elevated power costs |
| | Thermal | • Very effective | • Requires a local heat source (power plant, oil refinery) to cost effectively elevate temperature<br>• Temperature reduction too costly |
| | Filtration | • Can be very effective (as in the case of groundwater aquifer injection/storage, and recovery) | • Mesh filters will likely not work with elevated turbidity, and possibly not control veligers<br>• Engineered filters are novel for this use; they should be tested |
| | Coatings / Resistant Materials | • Can be effective | • Novel; very limited availability<br>• Very hard to apply in a large system<br>• Veligers not affected |
| | Turbulence | • Does not allow veligers to attach to infrastructure<br>• Various levels of veliger mortality can be experienced at various mixing intensities | • Very location-specific; cannot be used throughout the system.<br>• May require high-head and controlled high-velocity engineered systems. |
| | Alternative Sources | • Implementing an alternative, veliger-free source (such as indirect potable reuse recycled water) | • Capital and O&M costs are outside the scope of this report and yet to be determined.<br>• Source availability has not been identified within this report. |
| | O&M | • Can be effective<br>• Possibly the lowest cost option | • Veligers may not be affected<br>• Requires extensive monitoring |

For example, some of the issues that must be considered with several of the options include whether or not the following will impact treatment effectiveness:

- Elevated levels of DBPs that may impact downstream drinking water regulatory requirements (either chlorinated DBPs such as THMs and HAAs or other technology-specific DBPs);
- Changes in water quality impacting the mode of control (e.g., elevated turbidity causing a chemical control option to be less effective);
- Changes in water quality or operation negatively impacting the integrity of the control option (e.g., turbidity and solids that damage UV reactor lamps or cause excessive scouring that may damage sensitive infrastructure);
- Implementation of a control option in a manner significantly different than previously experienced (e.g., biocides and biological controls have been effective when used in lakes/reservoirs, but have not been typically used in flowing systems); and
- Use of a technology with expectations it will be effective, but requiring bench- and/or pilot-scale testing to confirm effectiveness (e.g., use of an engineered media infiltration gallery).

# 6.0 Locations of Control

**Figure 6-1** illustrates a flow diagram of the UWCD and downstream stakeholder systems along with mussel colonization risk ratings for infrastructure. This risk interpretation was developed by inspecting UWCD facilities and evaluating operational controls used to move diverted river water through the system and on to downstream stakeholders. The system has three distinct regions, as follows:

- Upstream of the Freeman Diversion
  This infrastructure includes Lake Piru and the Santa Clara River. This section of UWCD facilities is not considered in the present study.
- UWCD operated facilities after Santa Clara River
  This infrastructure has been rated as either having low- or medium-risk characteristics with regard to mussel infestation. In other words, it may be acceptable to implement lower-cost, seasonal or operational-type controls to protect these facilities against mussel infestation.
- Stakeholder facilities
  This infrastructure is rated at a high-risk with regard to mussel infestation, requiring consistent and continuous protection to prevent passage of veligers and colonization by mussels.

Based upon the regions presented above, previously described control options (**Section 5.0** ) will be further considered into various alternatives so that they can provide the level of risk protection desired. A brief description of each of the unit processes and operations in the system are provided below.

## 6.1 Lake Piru

Quagga mussel management in Lake Piru is addressed in the Lake Piru Quagga Mussel Monitoring and Control Plan (2016) and is outside the scope of the present study.

## 6.2 Santa Clara River

Riverine control for quagga mussels is very unlikely. First, it is expected that permitting requirements will render riverine control infeasible. It is also expected that the extensive area of Santa Clara River is too great to render effective management of any invasive mussels (**Figure** 1-3).

## 6.3 Facilities

The following facilities are illustrated in **Figure 2-1** and **Figure 6-1**.

### 6.3.1 Headworks

The Headworks consist of several features, including a fish screen, a trash rack, gates, and other infrastructure. This infrastructure may be a good candidate for physical control options that prevent the attachment of mussels to the infrastructure surfaces; however, chemical treatment cannot be recommended at the Headworks because of possible exposure of fish and other non-targeted species.

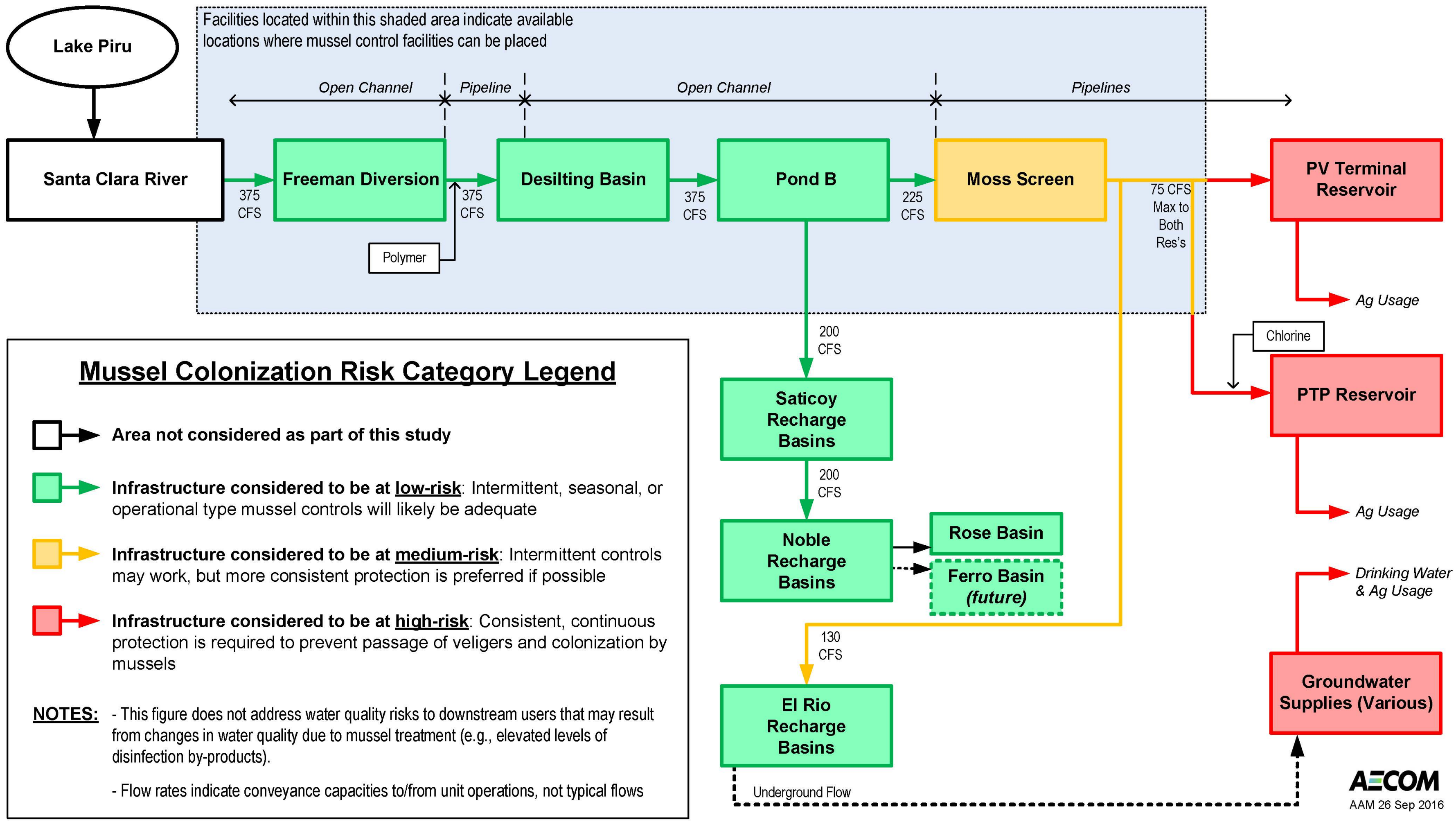


**Figure 6-1. Infrastructure Overview and Locations Requiring Veliger/Mussel Control**

### 6.3.2 Freeman Canal

The Freeman Canal transports water from the headworks to the pipelines through which water passes on the way to the desilting basin. Like the Headworks, the Canal may be a good candidate for physical control options. Some chemical options may be appropriate at the downstream end of the Canal as water enters the pipelines to the Desilting Basin.

### 6.3.3 Pipelines

The pipelines to the desilting basin are composed of 81-, 60- and 48-inch-diameter lines with a total capacity of 375 cfs. Both chemical and physical treatment may be appropriate as river water enters the pipelines, or within the pipelines.

### 6.3.4 Desilting Basin

The desilting basin can operate both in- and off-line by way of a gate. The capacity of the basin is 700 acre feet. Several chemical options, as well as regular dry-out, may be applicable at this location.

### 6.3.5 Grand Canal

The Grand Canal is an earthen structure with a maximum capacity of 320 cfs. There are two constrictions in the Canal. The first is a three barrel 48-inch culvert with a maximum capacity of 320 cfs, and is located downstream of the access road at South Mountain. The second constriction is an inverted siphon 1,000 feet downstream of the culvert, and has a maximum capacity of 275 cfs. The Canal is the conduit between the desilting basin and Pond B, and chemical treatment options may be applicable at this location.

### 6.3.6 Pond B

Pond B is the distribution facility to the Grand Canal which conveys water to the Saticoy Recharge Basin and the Moss Screen. The Pond may be appropriate for chemical treatment options.

### 6.3.7 Saticoy, Rose & Noble Recharge Basins

The Saticoy, Rose and Noble Recharge Basins consist of 17 infiltration basins with a wetted area of 336 acres. Infiltration rates have been recorded as high as 10 feet per day. The maximum discharge to them is 320 cfs from the Grand Canal. Because the water that enters the basins infiltrates a great distance into the ground, these facilities act as a physical barrier to the migration of quagga mussels in the system.

### 6.3.8 Saticoy Well Field

The Well Field is adjacent to the Recharge Basin and is designed to manage infiltration mounding. The Well Field can also act as a supplementary irrigation water source of up to approximately 20 cfs. Because the Recharge Basins act as a physical barrier to quagga mussel migration, treatment at the Well Field is not needed.

### 6.3.9 Moss Screen

The Moss Screen is designed to act as a barrier to certain kinds of filamentous algae before water enters the pipelines to El Rio and the PVP and PTP. The maximum capacity of the Screen is 225 cfs. Both physical and chemical treatment options may be appropriate at this location.

### 6.3.10 Main Supply Pipeline

The Main Supply Pipeline is a 78-inch-diameter line with a maximum capacity of 225 cfs. The Pipeline may be appropriate for chemical control options at its upstream end.

### 6.3.11 El Rio Pipeline

The El Rio Pipeline is a 48-inch-diameter line that directs up to 130 cfs from the Moss Screen to the El Rio Recharge Basin. To prevent mussel migration in the pipeline, treatment alternatives need to have been addressed prior to water entering the pipe.

### 6.3.12 PVP/PTP Pipeline

The PVP/PTP is a 54-inch-diameter line that directs up to 75 cfs from the Moss Screen to the PTP and PVP end users. To prevent mussel migration in the pipeline, treatment alternatives need to have been addressed prior to water entering the pipe.

## 6.4 Locational Treatment Applicability

Based upon the control options discussed in **Section 5.0** and the available locations for placing treatment discussed in **Section 6.0**, a brief summary of control option placement applicability has been developed and is presented in **Table 6-1**. Control categories of chemical, biological, and physical are listed against several possible locations throughout the UWCD system. The applicability of control options are ranked as either 'yes', 'no', or 'maybe' as an introduction to how these options will be further evaluated next as possible alternatives in **Section 7.0**.

The UWCD system does not have locations amenable to use of biological controls because biological controls require long-term exposures, which is not possible in a flowing system. However, it should be noted that it may be possible to apply biological controls as an O&M-based spot treatment if zero flow was to exist for an extended period of time (hence the 'maybe' rating for the desilting pond). This type of application could be considered (if their use meets NSF certification requirements for drinking water) if O&M controls are required in parallel with a selected treatment alternative.

**Table 6-1. Anticipated Treatment Applicability**

| Location | Anticipated Treatment Control Applicability | | |
|---|---|---|---|
| | Chemical | Biological | Physical |
| Within Santa Clara River | No | No | Yes |
| Freeman Diversion | Yes | No | No |
| Desilting Pond | Yes | Maybe* | No |
| Ponds and Recharge Basins | Yes | No | Yes |
| Moss Screen | Yes | No | No |
| PV / PTP Reservoirs | Yes | No | No |

* Possible O&M applicability (if compounds meet NSF certification)

# 7.0 Alternatives Analysis

Prior to developing viable control alternatives, operating criteria and preliminary assessments of the potential for control options' success were determined. This section first presents information on operating criteria and option assessment for further consideration. Resulting control alternatives are then presented, which describe how various remaining viable 'options' can fit into the unit operations and processes operated by UWCD.

## 7.1 Operating Criteria for Alternatives

Before considering alternatives for mussel control, system design and operations criteria were quantified. These criteria were established as baseline conditions for any resulting alternatives, which were developed for the project. Criteria were used in developing cost opinions for treatment alternatives.

Resulting criteria include the design flow assumptions:

- Alternatives treating water at Freeman Diversion: 375 cfs;
- Alternatives treating water before/after the Desilting Basin: 375 cfs;
- Alternatives treating water before the Moss Screen: 225 cfs;
- Alternatives treating water after the Moss Screen: 225 cfs;
- Alternatives treating water sent to downstream stakeholders: 75 cfs; and
- Operating condition as a worst-case scenario: 4 months per year at design flow.

## 7.2 Qualifying Treatment Options

To develop viable alternatives, treatment options described previously in **Section 5.0** were assessed for their capability of preliminarily meeting mussel control risks described in **Figure 6-1**. As a result, several options were removed from further consideration due to various reasons which included operational, engineering, water quality, or cost prohibitive issues.

**Table 7-1** summarizes the chemical, physical, and biological options that were removed from further consideration. Note that there are additional items not included in this table but were also excluded from further consideration (e.g., screening and mechanical filtration) because they were considered of extremely high cost and/or impractical and still requiring the addition of chlorine.

**Table 7-1. Treatment Options Removed from Consideration**

| Option Description | Reasons Removed |
|---|---|
| **Chemical** | |
| Chloramines | Multiple chemicals are needed such as chlorine and ammonia which both complicates operations and causes the option to be much more costly than chlorine alone. Also, it is seen to be less effective than chlorine alone which causes additional concern over its effectiveness. |
| Chlorine dioxide | Multiple chemicals required (acid and chlorine) which complicate operations. It is also unclear if a dose can be achieved which could overcome water quality conditions (such as elevated turbidity) and establish an effective residual that effectively controls veligers/mussels. Elevated dosing will lead to increased concern of chlorite and chlorate formation (drinking water DBPs). |
| Ozone | Costly construction of either a pipeline or covered basin contactor would need to be considered, along with significant capital costs and operating power draw for the ozone generators. This option would require costly asset management for ozone generator equipment and be complex to operate. In addition, ozone does not provide a residual disinfectant and therefore if treatment failed, infestation may be at significant risk. |
| pH control | Likely requires the need to maintain a tight control of pH in a range of approximately 6.5 to 6.8 units so as to not violating other water quality requirements. Concerns include: actual effectiveness of this operating range is unknown; ability for pH to be maintained for the proper length of time through UWCD's system is unknown (possibility for several-hours retention); and ability to maintain operations during highly fluctuating ranges in water quality is unknown. |
| Metal sulfates (e.g., copper sulfate) | Typically applied under static conditions (lake or reservoir) requiring lengthy retention time/contact with the target organisms to be effective. It was determined that this option would not work in the highly dynamic, flowing UWCD system. |
| **Physical** | |
| UV light | UV is not seen as 100% effective, and it also does not provide a residual, therefore, risk for surviving veligers is too great. Furthermore, damage to UV lamps would be expected due to the significant increase in turbidity / solids migrating through the system. |
| Temperature control | Increasing or decreasing bulk water temperature for the duration of time required for effective veliger kill is cost prohibitive. |
| Coated / resistant materials | This is a developing area of control which leads to concerns about its effectiveness. Due to the extensive system / conveyance surface area for mussel attachment it is determined that this is not a practical solution. |
| **Biological** | |
| Molluscicides | Same reasons as for metal sulfates. |
| Pathogenic predators | Same reasons as for metal sulfates and molluscicides. |

## 7.3 Control Alternatives

Control options that were further developed into treatment alternatives include the following:

- Chemical control with chlorine;
- Chemical control with potassium permanganate;
- Physical control using filtration (engineered media filters and natural filtration through groundwater recharge/infiltration and recovery); and
- Non-capital intensive operations and maintenance which includes monitoring and spot treatments for veligers/mussels as needed (note that this option would include addressing interim measures and/or intermediate treatments and manual controls).

Note consideration of implementing any of the following alternatives should also include the practice of performing regular, effective system monitoring for veligers and attached mussels. The need for proper monitoring cannot be overstated.

Resulting alternatives, described below in flow order through the UWCD system, include:

1. River Infiltration Gallery
2. Upper-System Chemical Feed
   2a. Freeman Diversion
   2b. Desilting Basin
3. Pond Infiltration Gallery
4. Increased Pumping from Recharge Basin
5. Lower-System Chemical Feed
   5a. Prior to Moss Screen
   5b. After Moss Screen
6. Chemical Feed Prior to Reservoirs
7. Non-Capital Facility Control

### 7.3.1 River Infiltration Gallery

This alternative (Number [No.] 1) is illustrated in **Figure 7-1** and includes the construction of an engineered infiltration gallery in the Santa Clara River. The gallery would be constructed to meet the flow requirements of the downstream stakeholders (75 cfs) and is not expected to require the use of treatment chemicals. **Figure 7-1** illustrates how use of this alternative is estimated to provide protection to the downstream stakeholders (denoted in blue as 'infrastructure protected') both from the infiltration gallery and due to the supply of water from the El Rio recharge basins (the latter offers natural protection from veligers and mussels due to subsurface groundwater filtration already in place). Note that UWCD facilities and equipment are not protected against mussel infestation with this alternative, and secondary measures are necessary. For example, veliger spot-treatment and mussel removal O&M measures will likely be required intermittently across the Desilting Basin, recharge basins, Moss Screen, and conveyances in-between these facilities and the recharge basins.

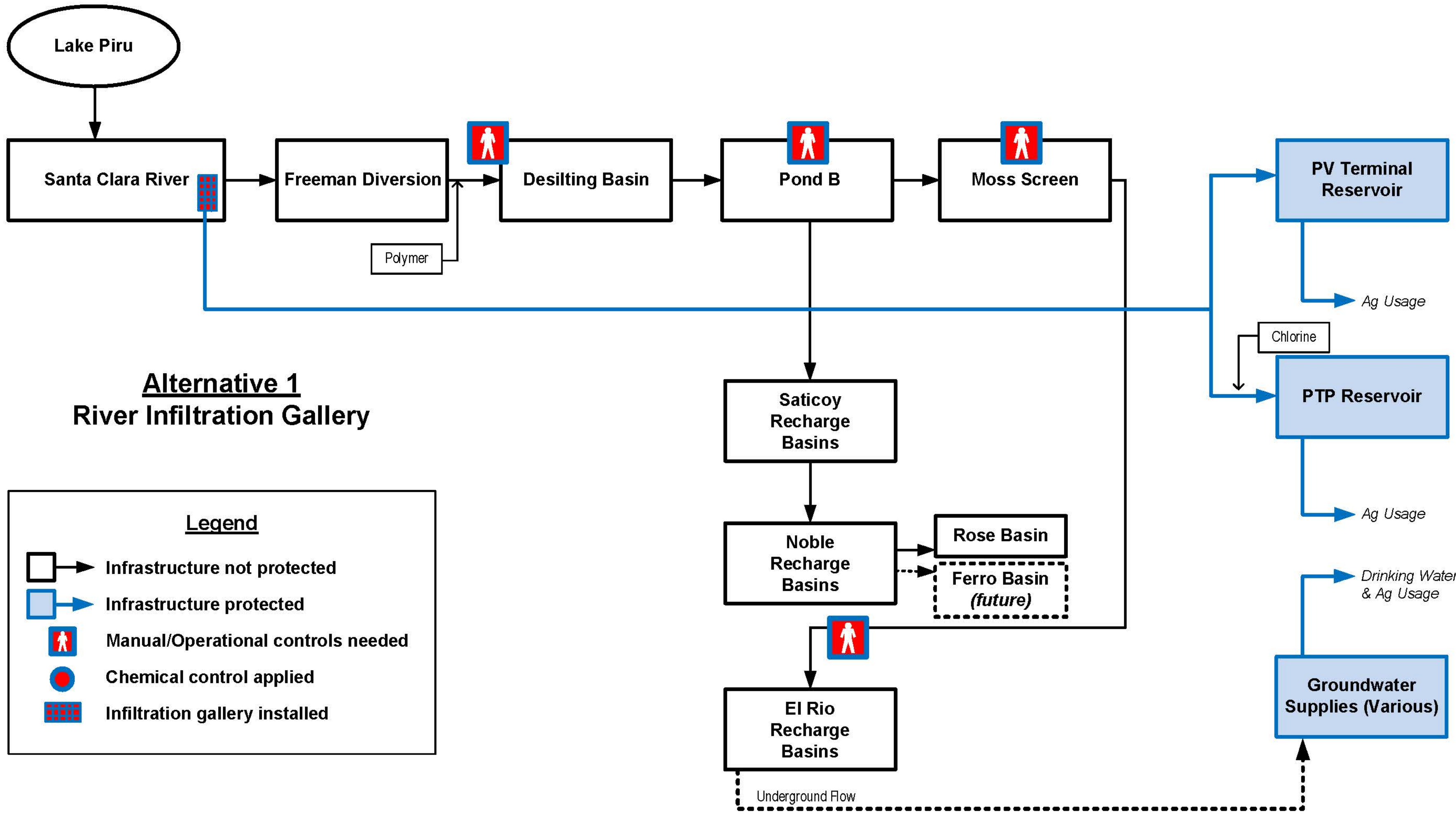


**Figure 7-1. Alternative 1: River Infiltration Gallery**

#### 7.3.1.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B**. As a summary, these include the following:

- Flow of 75 cfs (49 million gallons per day [MGD]),
- Gallery constructed permeability ranging from a low-end, conservative permeability estimate of 1.5 GPM/sf to a more typical permeability of 3.0 GPM/sf,
- Required gallery surface area redundancy factor of 1.25 with three individual galleries for operational redundancy,
- Flow equalization tank storage ranging from 70,000 to 170,000 gal,
- Power costs for providing up to 15 feet of lift to treated water, and
- Conveyance pipeline ranging from 3 to 5 miles in length.

#### 7.3.1.2 Mode of Action and Challenges

The control method used to protect against veliger passage and subsequent mussel attachment is the action of filtration provided by stratified levels of media.

Challenges with this option include several environmental, operational, and engineering issues. It would be difficult to construct within the river (i.e., permitting and environmental constraints). UWCD would need staffing to operate this new treatment system effectively and conduct the necessary seasonal gallery O&M requirements. Furthermore, O&M treatment for veligers/mussels would be required throughout the unprotected UWCD system. There are also unknown concerns with regard to damage that could result to the gallery during extremely elevated storm flows that may damage the infrastructure by scouring protective materials and filter media. Lastly, although filter media is expected to be an effective control barrier against veligers, it is recommended that pilot-scale testing is conducted to verify this as it is not a standard technique that has been used elsewhere.

### 7.3.2 Upper-System Chemical Feed

This alternative involves the addition of chemicals at two different sub-alternative locations: at Freeman Diversion or the Desilting Basin. These sub-alternatives (2a and 2b) are illustrated in **Figure** 7-2 and **Figure 7-3**, respectively. These alternatives are based upon adding chemical to the full flow at these locations, 375 cfs (242 MGD). Chemical treatment at the two different locations was considered because of benefits that may be realized as follows:

- Treatment at Freeman Diversion (2a) would be designed to protect the entire UWCD and downstream stakeholder systems, and
- Treatment at the Desilting Basin (2b) would require significantly less chemical feed than at Freeman Diversion due to the removal of solids through the basin, but require O&M treatment in the Desilting Basin.

Differences in infrastructure protection are illustrated by the denoted blue process designations in **Figure 7-2** and **Figure 7-3**. All stakeholders would be protected under either sub alternative.

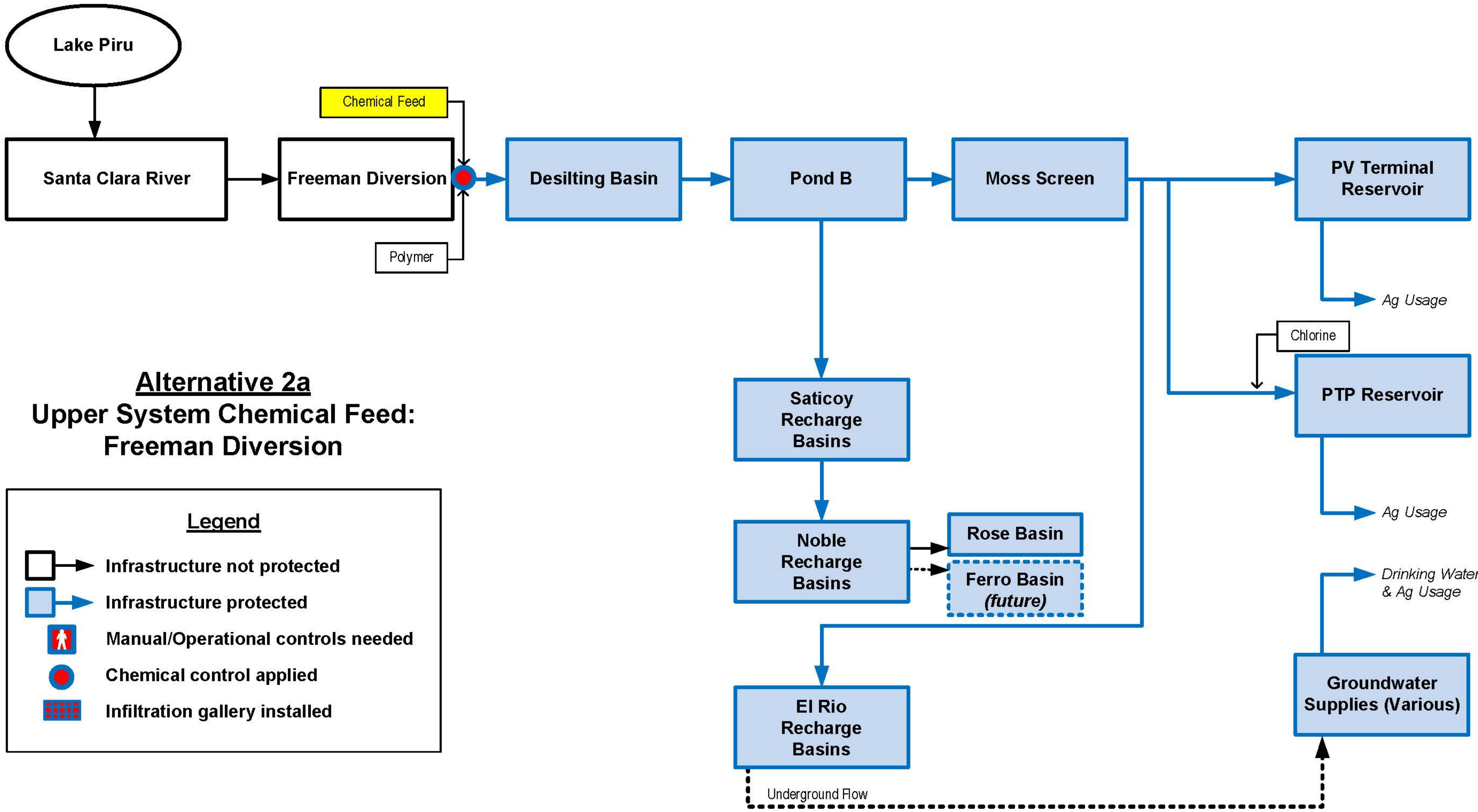


**Figure 7-2. Alternative 2a: Upper System Chemical Feed at Freeman Diversion**

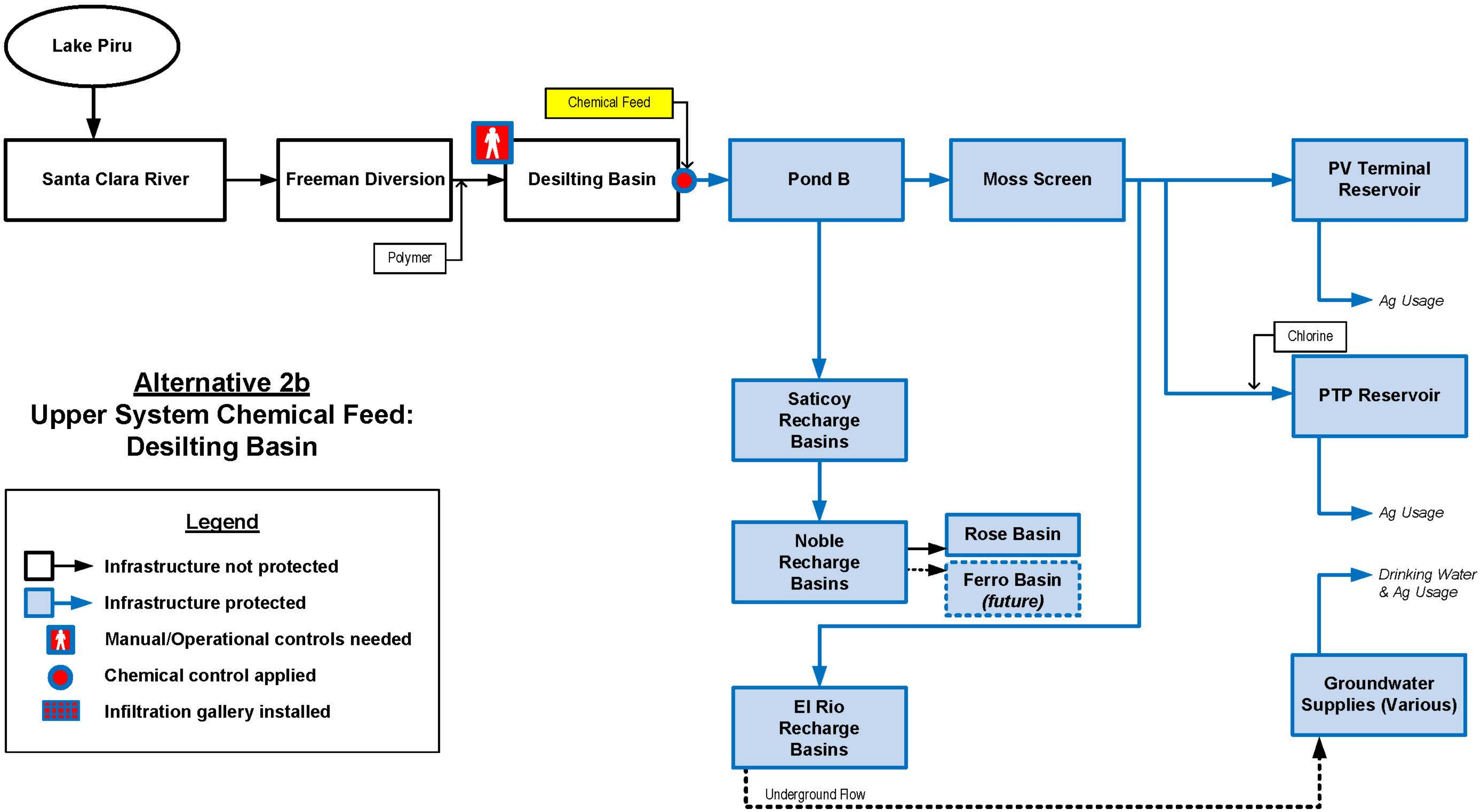


**Figure 7-3. Alternative 2b: Upper System Chemical Feed at Desilting Basin**

#### 7.3.2.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B.** As a summary, these include the following:

- Flow of 350 cfs at either location;
- Estimated chemical dosing of chlorine between 20-30 mg/L (2a) or 10-15 mg/L (2b), or estimated dosing of potassium permanganate between 3-8 mg/L (2a) or 2-5 mg/L (2b);
- Design redundancy factor of 1.25;
- Use of gas-fed systems for the chlorine facilities due to anticipated lower lifecycle cost and easier operations expected when compared to bulk liquid; and,
- Conveyance piping ranging from 200 to 500 feet.

#### 7.3.2.2 Mode of Action and Challenges

The control method used to protect against veliger passage and subsequent mussel attachment is the action of oxidation provided by either chlorine or potassium permanganate.

Challenges with this option include several environmental, operational, and engineering issues. First, the chemical dose addition ranges are estimated and would need to be confirmed by bench- and/or pilot-scale testing. Chemical dosage would need to be sufficient to overcome chemical demand and decay rates that would be experienced across the range of water quality conditions that exist. Residual levels of chemical would need to be sustained in a manner such that it lasts sufficiently through the UWCD system to provide a barrier of acceptable organism control (upward of 99 to 100% kill). Also, the application of chemical would need to be sufficient to control veliger passage during start/stop conditions. Permitting such a large facility may also be a challenge, but is not included in the evaluation for this preliminary/conceptual analysis.

The resulting chemical feed systems would require sufficient O&M to maintain equipment and offer sustained chemical quality while the systems are not operating. This alternative would also bring practical challenges surrounding the need for UWCD to develop staffing that will operate this new treatment system effectively and conduct the necessary seasonal O&M requirements.

Lastly, with the addition of chlorine, there are expected to be significant levels of DBPs formed which may impact downstream drinking water stakeholders. The level of DBPs formed would need to be quantified during bench- and/or pilot-scale testing.

### 7.3.3 Pond Infiltration Gallery

This is Alternative No. 3 (illustrated in **Figure 7-4**), involving the construction of an engineered infiltration gallery into one of UWCD's available recharge basins. This gallery is expected to be much easier to permit/construct than the gallery proposed for Alternative No. 1 in the Santa Clara River as it would be situated within UWCD-owned and operated facilities.

Similar to Alternative 1, the gallery would be constructed to meet the flow requirements of the downstream stakeholders (75 cfs) and is not expected to require the use of treatment chemicals.

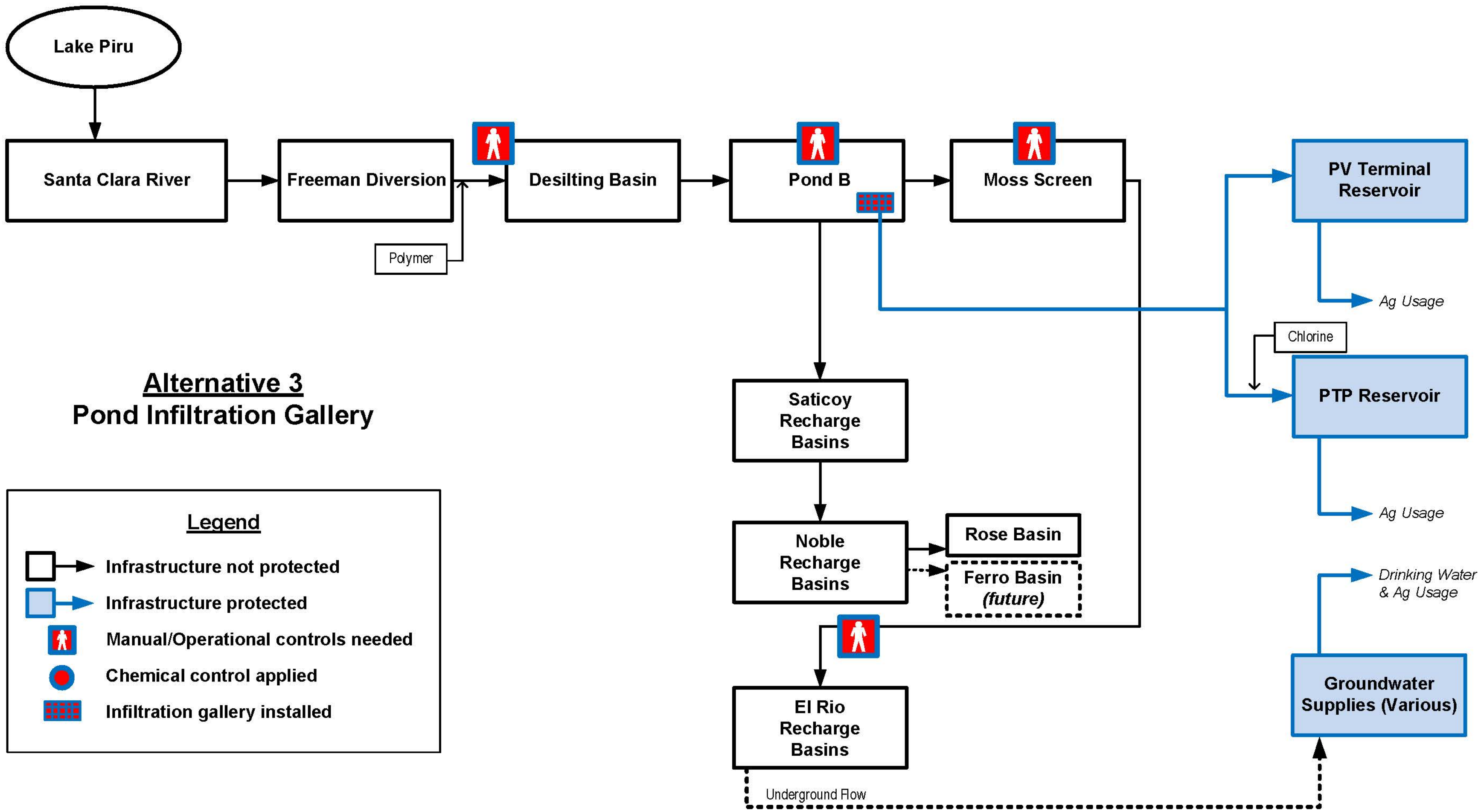


**Figure 7-4. Alternative 3: Pond Infiltration Gallery**

#### 7.3.3.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B.** As a summary, these include the following:

- Max flow of 75 cfs (49 MGD),(when in service)
- Gallery constructed permeability estimated to consistently allow 3.0 GPM/sf,
- Required gallery surface area redundancy factor of 1.1 with 3 individual galleries for operational redundancy,
- Flow equalization tank storage ranging from 70,000 to 170,000 gal,
- Power costs for providing up to 50 feet of lift to treated water, and
- Conveyance pipeline of up to 1,000 feet.

#### 7.3.3.2 Mode of Action and Challenges

As with Alternative No. 1, control method used to protect against veliger passage and subsequent mussel attachment is the action of filtration provided by stratified levels of media.

Practical challenges remain with regard to the need for UWCD to develop staffing that will operate this new treatment system effectively and conduct the necessary seasonal O&M requirements. Pilot-scale testing is recommended to verify the effectiveness of this treatment alternative as it is not a standard technique that has been used elsewhere. Furthermore, O&M treatment for veligers/mussels would be required throughout the unprotected UWCD system.

### 7.3.4 Increased Pumping from Recharge Basins

This is Alternative No. 4 (illustrated in **Figure 7-5**), involving the construction of new groundwater pumping facilities to increase the recharge basin pumping capacity to meet flow requirements for downstream stakeholders. It is assumed that there would not be any need for land acquisition or environmental mitigation measures from construction due to already existing UWCD land ownership and/or right-of-way access. An additional benefit of this alternative is the potential that operation of the Moss Screen could possibly be discontinued as all treated water would now be filtered through underground recharge basins.

Similar to previous alternatives, the pumping station(s) would need to be constructed to meet the flow requirements of the downstream stakeholders (75 cfs) and is not expected to require the use of treatment chemicals. It is likely that new facilities required for this alternative would not need to have a capacity of 75 cfs as they would complement existing pumping capacity of the Saticoy wellfield.

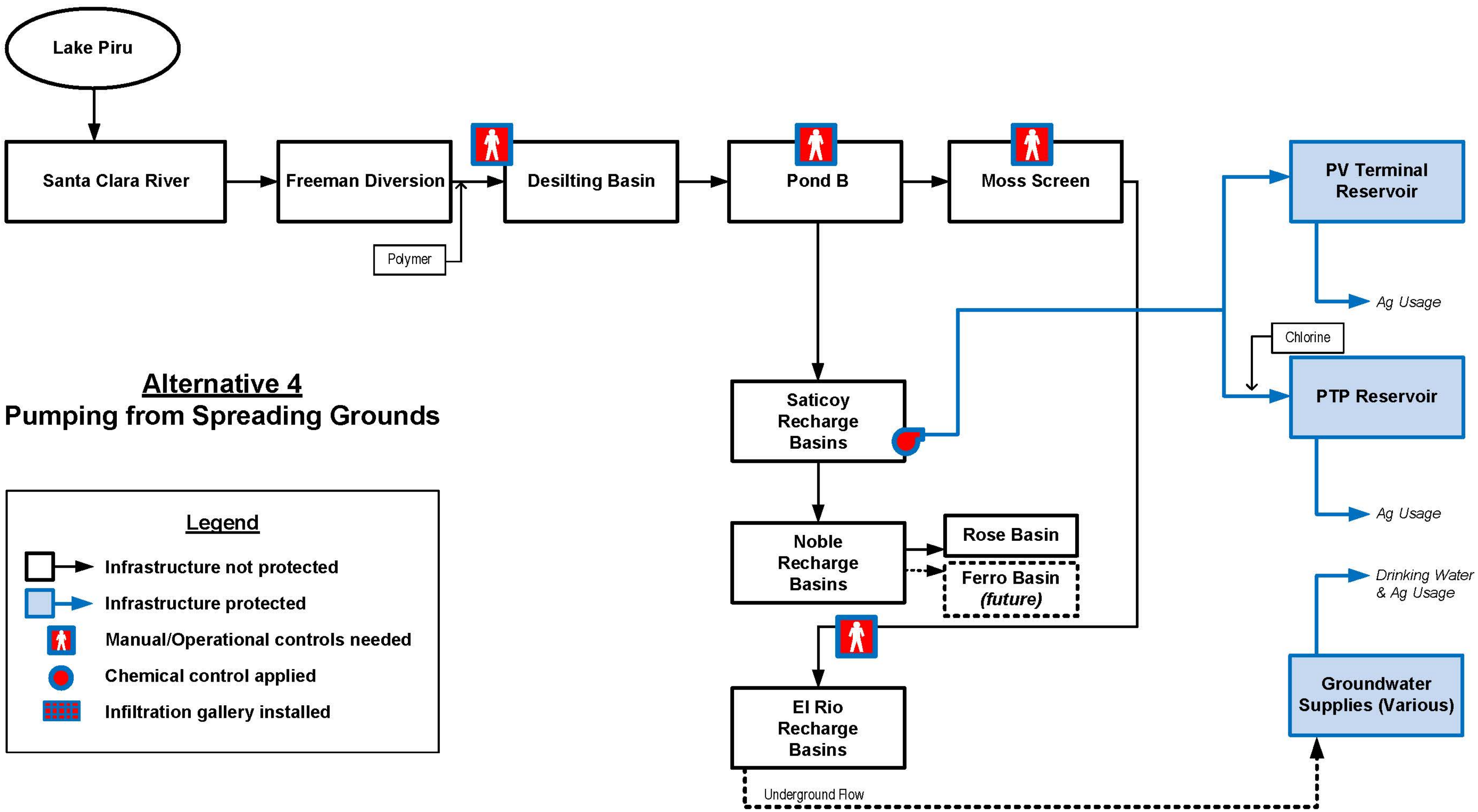


**Figure 7-5. Alternative 4: Increased Pumping from Recharge Basin**

#### 7.3.4.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B.** As a summary, these include the following:

- Flow of 75 cfs (48.5 MGD) to be the constructed capacity as a conservative assumption,
- Flow equalization tank storage ranging from 40,000 to 70,000 gallons,
- Power costs for providing up to 150 feet of lift to treated water, and
- Conveyance pipeline of up to 1,000 feet.
- Only operate when there are surface water diversions or mounding in the Saticoy Basins.

#### 7.3.4.2 Mode of Action and Challenges

Similar to the infiltration galleries, the control method used to protect against veliger passage and subsequent mussel attachment is the action of filtration. However, this filtration is achieved through the deep groundwater aquifer system rather than a constructed media filter.

The practical challenges for this alternative would be finding proper locations for installation of the additional wells in addition to completing proper alignment for any additional required conveyance pipelines. Likely, the complexity of operating this type of system would not be any different than the existing UWCD facility operations. Furthermore, there would not be a need for bench- or pilot-scale testing.

This alternative does require the need, however, for UWCD to implement proper O&M treatment for veligers/mussels throughout the unprotected UWCD system.

This alternative would likely require approval and conditioning from the Fox Canyon Groundwater Management Agency.

### 7.3.5 Lower-System Chemical Feed

This alternative involves the addition of chemicals at two different sub-alternative locations: immediately before or after the Moss Screen. These sub-alternatives (5a and 5b) are illustrated in **Figure 7-6** and **Figure 7-7**, respectively. These alternatives are based upon adding chemical to the full flow at these locations, 225 cfs (145 MGD). Chemical treatment at the two different locations was considered because of benefits compared to the upstream chemical feed alternatives as follows:

- Treatment at prior to the Moss Screen (5a) would protect the Moss Screen facility and would treat a flow significantly reduced (with possibly improved water quality) from the upper system chemical treatment alternatives while protecting the Moss Screen from mussel attachment,
- Treatment following the Moss Screen (5b) may require less chemical feed than chemical feed prior to the Moss Screen, but require O&M treatment within the Moss Screen.

Differences in infrastructure protection are illustrated by the denoted blue process designations in **Figure 7-6** and **Figure 7-7**. All stakeholders would be protected under either sub alternative.

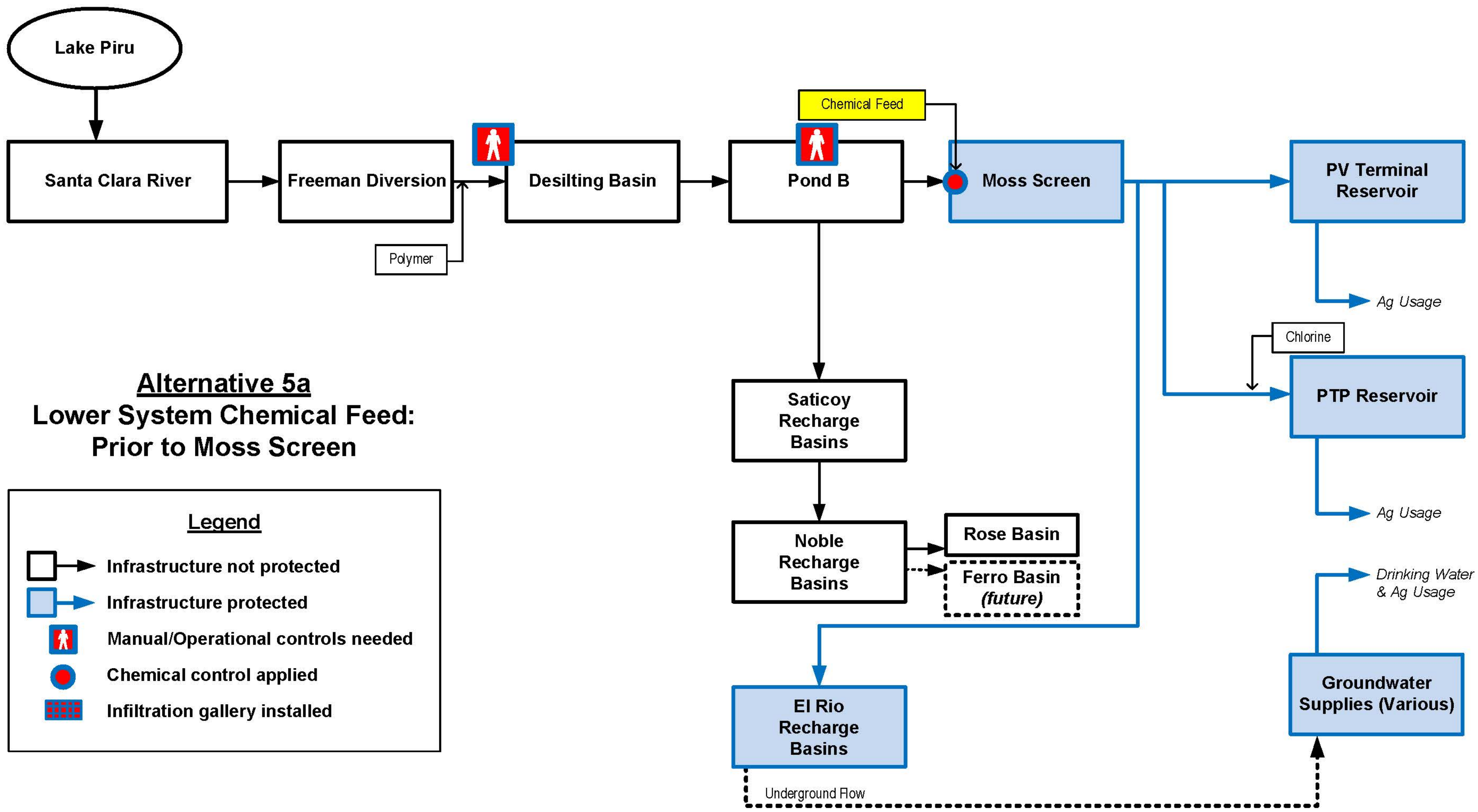


**Figure 7-6. Alternative 5a: Lower System Chemical Feed Prior to the Moss Screen**

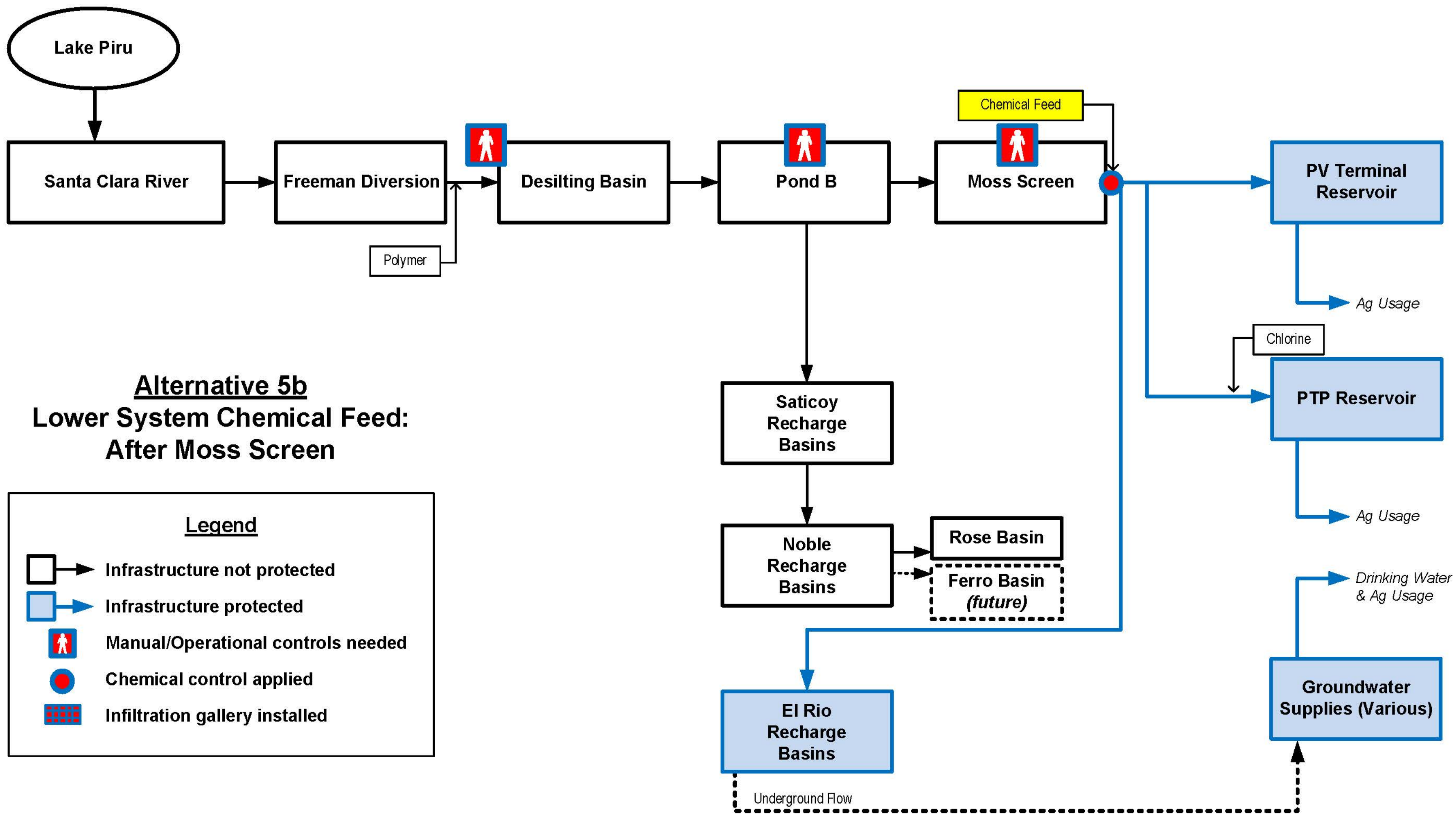


**Figure 7-7. Alternative 5b: Lower System Chemical Feed Immediately Following the Moss Screen**

#### 7.3.5.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B**. As a summary, these include the following:

- Flow of 225 cfs (145 MGD) at either location,
- Estimated chlorine addition between 5-8 mg/L before or 3-5 mg/L after the Moss Screen, or potassium permanganate between 2-3 mg/L before or 1-2 mg/L after the Moss Screen;
- Design redundancy factor of 1.25,
- Use of gas-fed systems for the chlorine facilities due to anticipated lower lifecycle cost and easier operations expected when compared to bulk liquid, and
- Conveyance piping ranging from 200 to 500 feet.

#### 7.3.5.2 Mode of Action and Challenges

Mode of action (oxidation) and challenges (testing confirmation needs, residual disinfection, start/stop operations, operating needs, and DBP formation) are similar to those for Alternative 2a and 2b. In addition, it is possible that addition of chlorine immediately prior to the Moss Screen may cause corrosion of Moss Screen equipment which will require mitigation.

### 7.3.6 Chemical Feed Prior to Reservoirs

As shown in **Figure 7-8**, this alternative involves the addition of chemicals downstream of all significant UWCD infrastructure and immediately prior to the two stakeholder water storage reservoirs. When compared against previous alternatives, this alternative allows for chemical addition to the lowest anticipated flow rate (75 cfs). Treatment at this general location is expected to be the least expensive chemical option because of the reduced flow and best expected water quality. Operating chemical feed facilities at this location would likely be less complicated than previously-described upstream locations while still offering the same level of stakeholder protection against mussel infestation. Furthermore, because chemical feed would be downstream of flow which travels to El Rio, there would not be any concerns about DBP production for drinking water.

#### 7.3.6.1 Design Considerations

A detail of the design considerations for this alternative is included in the process and cost estimate calculations sheets provided in **Appendix B**. As a summary, these include the following:

- Flow of 75 cfs (49 MGD),
- Estimated addition of either 3-5 mg/L chlorine or 1-2 mg/L potassium permanganate,
- Design redundancy factor of 1.25,
- Use of gas-fed systems for the chlorine facilities due to anticipated lower lifecycle cost and easier operations expected when compared to bulk liquid, and
- Conveyance piping ranging from 500 to 1,000 feet.

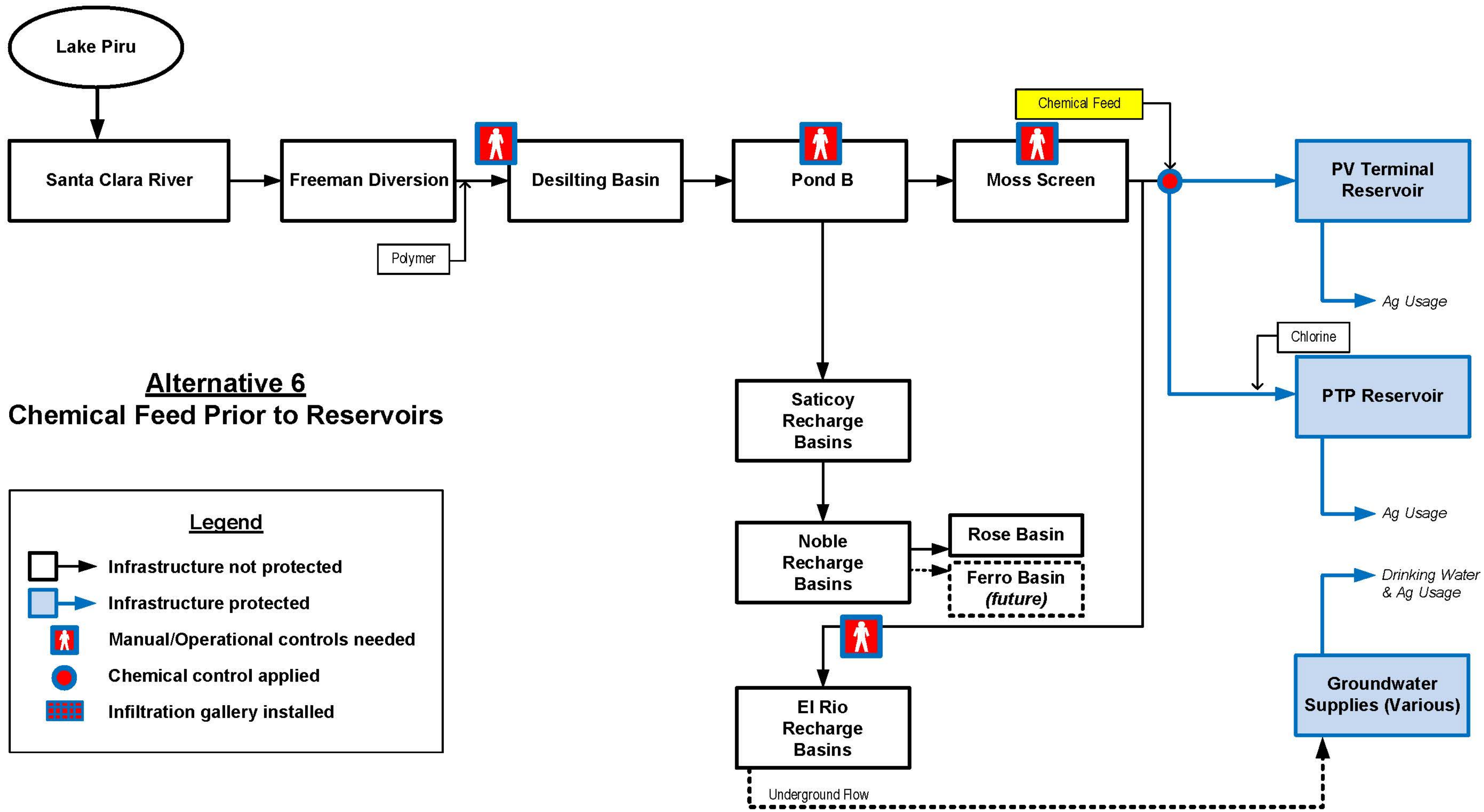


**Figure 7-8. Alternative 6: Chemical Feed Prior to Reservoirs**

#### 7.3.6.2 Mode of Action and Challenges

Mode of action (oxidation) and challenges (testing confirmation needs, residual disinfection, start/stop operations, and operating needs) are similar to those for the previous chemical feed alternatives. Formation of DBPs is not expected to be a concern for this issue as there are is no downstream drinking water use. Note that depending on where chemical is fed, secondary maintenance will be required upstream with regard to periodic cleaning and/or disinfection of the El Rio Pipeline.

### 7.3.7 O&M-Based Control Alternative

The seventh alternative was considered which involves withholding the installation of any capital facilities. The reason for considering this alternative is that no veligers or mussels have yet been discovered within the UWCD conveyance system or in any of the downstream stakeholder facilities. This alternative would involve the following actions:

1. Hiring of sufficient staff to sustain proper monitoring, analysis, and O&M responses to veliger/mussel control as needed;

2. Development of sufficient monitoring plans which allow for early detection of veligers;

3. Establishment of effective emergency response protocols such that detected organisms can be treated within the UWCD system without threat of infesting downstream stakeholder facilities;

4. Implementation of effective communications within UWCD and with downstream stakeholders such that monitoring, reporting, and treatment protocols are understood and supportive of rapid changes to system operations (such as stop flow and procurement/operation of subcontractor/leased chemical dosing systems) if organisms enter the UWCD system.

## 7.4 Assessment of Alternatives

The developed alternatives all have benefits and cost- and non-cost-based challenges. Based upon the design criteria presented for each alternative, all were assessed for their anticipated estimated cost as well as for select non-cost benefits and challenges.

### 7.4.1 Order-of-Magnitude Cost

Planning-level capital and O&M costs were developed for each alternative described above based upon available operating information provided by UWCD and the planning-level design assumptions and considerations described in this report. In several instances, assumptions were made where insufficient information was available (such as for the estimated level of chemical dosing or the estimated level of staffing required).

#### 7.4.1.1 Land Acquisition

The cost associated with land acquisition is not included in the cost estimate, but should be included in subsequent phases of the project.

#### 7.4.1.2 Cost Estimate Calculations

The cost estimates herein are based on the limited, high-level project information described in this report that was developed at the time of preparing this report. These estimates should only be used in order to determine indicative order-of-magnitude cost values for comparison of scope or delivery method options and for initial evaluation of project economic viability and/or long-range planning and project screening. It is expected that cost estimates for these alternatives will change in the future as the following factors change: normal site conditions, equipment, buildings, installation, site work, electrical work, instrumentation and controls, piping, land acquisition needs, construction costs, treatment viability (as confirmed with bench- and/or pilot-scale testing as needed), and conveyance requirements. These costs will be influenced by final design, bidding environment, and inflation and are subject to change. The estimates of cost provided are only provided as a desktop feasibility study / planning-level suggestion and should be considered to be a rough order of magnitude estimate.

The detail that was considered for estimating cost for each alternative is provided in **Appendix B**. For each alternative, the following capital cost items were considered:

- Unit process construction;
- Yard piping, site work, and electrical & controls;
- Permitting and environmental;
- Engineering, legal and administrative;
- In-river access fees/costs as needed;
- Water surge tanks and/or pipeline conveyance as needed; and
- For the O&M-based Alternative 7, estimates for increased full-time-equivalent (FTE) staffing were included.

**Figure 7-9** summarizes the planning-level estimated capital costs by graphing the cost values for each of the alternatives. Alternatives are described by name (including their sub-alternative names) in order from left to right along the horizontal axis. Shading is provided to help distinguish between each of the bar-graph groupings for the alternatives. The vertical axis for the graph is set to a logarithmic scale, showing $100,000,000 ($100M) estimated cost at the top while the bottom of the scale shows values estimated to be below $1,000,000 ($1M).

Each of the cost estimates were calculated based upon ranges of design values. These ranges of design values included such things such as lower and upper preliminary design limit considerations for chemical feed, media permeability, surge tank sizing, pipeline length, and other items. As a result of this approach, each cost bar actually represents an average estimate of the range of these values. The tick marks provided above and below each bar represent calculated upper- and lower-bound ranges of variability. For the purposes of this report, the cost estimate for the alternatives should be considered to potentially exist anywhere between the upper- or lower-bound marks.

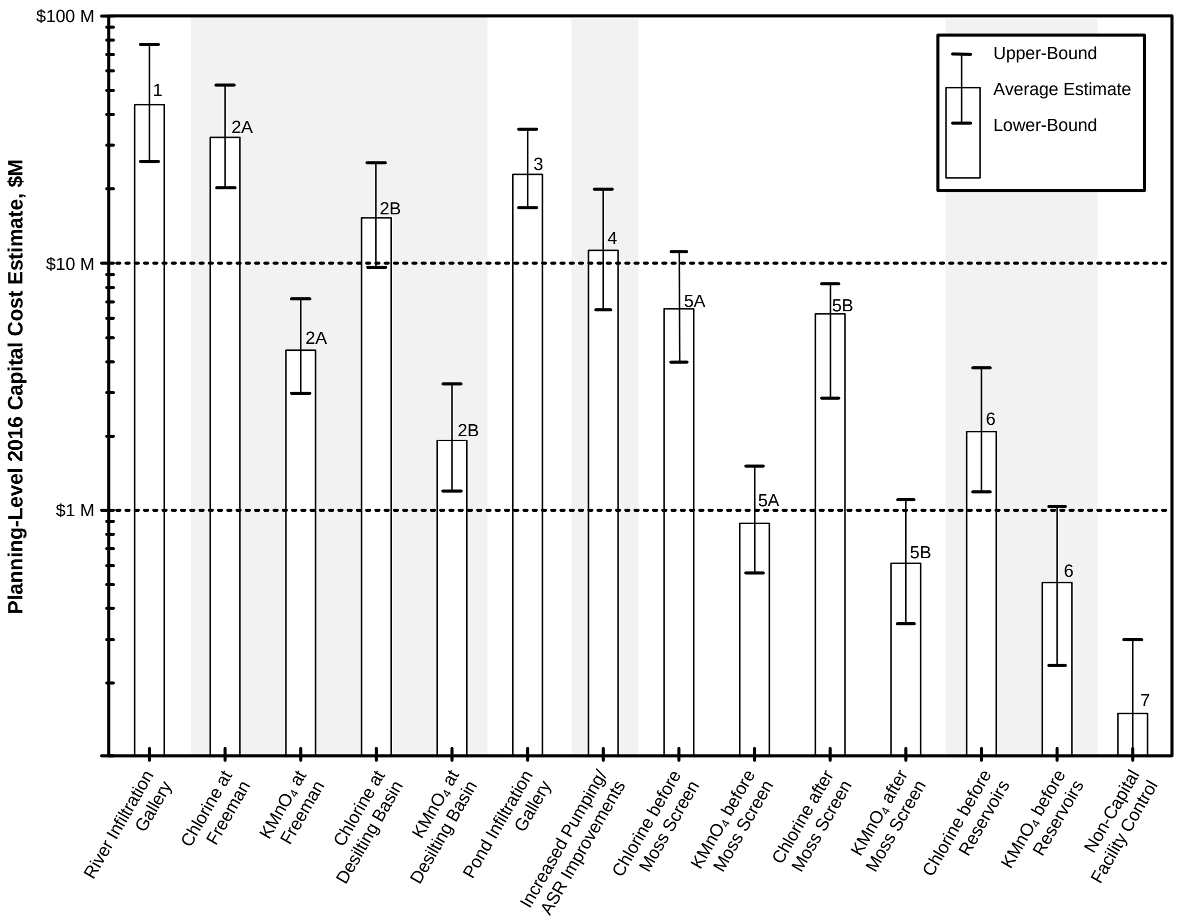


**Figure 7-9. Planning-Level Capital Cost Estimates for Alternatives**

The summary of estimated capital costs produced the following observations:

- The most expensive capital-cost alternatives are the river infiltration gallery (No. 1), chlorination at the Freeman Diversion (No. 2a), and the pond infiltration gallery (No. 3);
- Alternatives with mid-level potential cost (potentially ranging between an estimated $1M and $10M include upper-system potassium permanganate systems, chlorination before or after the Moss Screen, pumping / aquifer storage and recovery (ASR) improvements, and chlorination before the reservoirs; and,
- The least expensive cost alternatives (below an estimated $1M cost) include the non-capital / O&M alternative and the potassium permanganate feed systems at the Moss Screen or prior to the reservoirs.

Estimates for O&M costs for each alternative were also completed using the same order-of-magnitude approach as described above for the capital cost estimates. Estimated O&M costs include the following:

- O&M applies to caring for the constructed facility (full-time-equivalent [FTE] assignments, power, maintenance);
- O&M needs for UWCD facilities to perform secondary spot-treatment for veligers and mussel removal as needed (depending on each alternative); and
- For the O&M-based Alternative 7, estimates for analytical services and veliger/mussel monitoring were included (although this should likely be conducted for any of the selected alternatives, it was not included in the cost estimates for alternatives 1-6).

**Figure 7-10** illustrates the a summary of lifecycle costs that were calculated by including both the previously illustrated capital costs and the calculated O&M costs for each alternative.

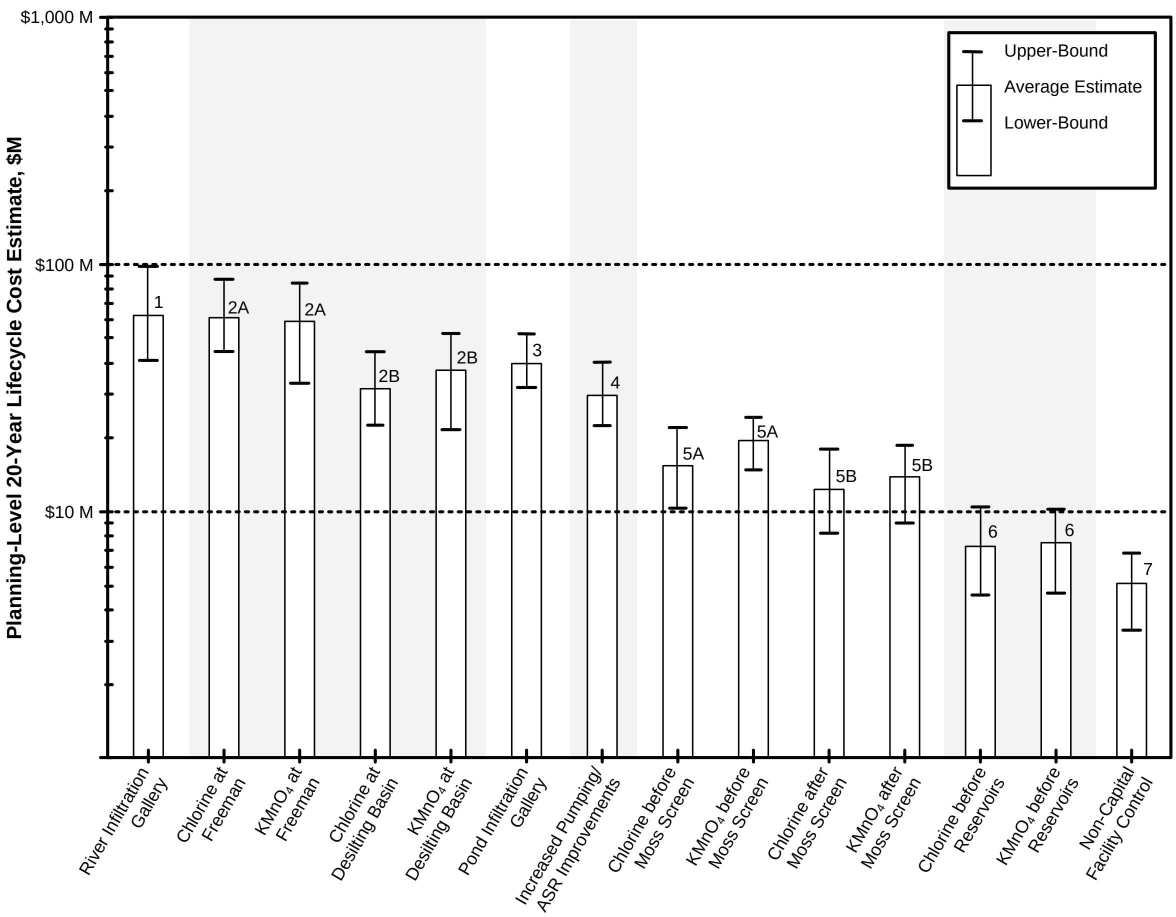


**Figure 7-10. Planning-Level Lifecycle Cost Estimates (including Capital and O&M costs) for Alternatives**

Lifecycle costs were determined by incorporating the following assumptions and value conditions:

- Capital costs are expended in 2016;

- Yearly O&M costs are calculated over a period of 20 years facility life and converted to a 2016 value using a 4 %/year discount rate;
- Full-time equivalent (FTE) rates are $90,000/year/FTE and were not considered to escalate over time; and,
- The resulting lifecycle cost is the summation of the 2016 capital expenditure and the 2016-valued 20-year O&M cost.

The summary of estimated lifecycle costs produced the following observations:

- The magnitude of lifecycle cost decreases as treatment/control is moved downstream through the UWCD system (i.e., it is more costly to put treatment near the UWCD intake than it is to place it further downstream, closer to the reservoirs);
- The pumping/ASR alternative lifecycle cost range is
    - Approximately mid-range for all alternatives, and
    - Statistically similar (the upper/lower estimate bounds overlap) in cost to either chemical feed at the desilting basin, the pond infiltration gallery, or chemical treatment prior to the Moss Screen; and
    - Could eliminate need to inject chlorine at the PTP Reservoir.
- Chemical treatment at the reservoirs is statistically similar in cost to the O&M-based alternative.

### 7.4.2 Alternatives Analysis by Multi-Criteria Analysis

In addition to cost estimating, a multi-criteria analysis (MCA) was performed on the alternatives in order to perform a high-level qualitative ranking. MCA was used in order to structure and solve some of the decision and planning for alternative selection using multiple criteria. The reason for employing such an analysis is because there isn’t a unique optimal solution for alternative selection and it is necessary to use decision-maker’s preferences to provide a logical method for differentiating between alternatives. The result of the MCA can be interpreted as choosing the most preferred alternative from the set of all available alternatives.

The categories used for performing the MCA include both cost and non-cost items that were chosen to represent key issues of concern for implementing a control alternative. The categories include the following items which are listed below (with MCA weightings that sum total to 100):

- <u>Lifecycle Cost (MCA Weight = 30)</u>
  Overall lifecycle costs, although already quantified, are valuable to be considered within the qualitative assessment of the MCA. Alternatives with relatively lower cost are scored greater.
- <u>Permitting (MCA Weight = 5)</u>
  Each alternative has a certain degree of difficulty (or ease) in its ability to be permitted. Alternatives anticipated to have less difficult permitting are scored greater than others.

- Constructability (MCA Weight = 5)
  Each alternative has a certain degree of difficulty (or ease) in its ability to be constructed. Increased difficulty will make it more likely the alternative will experience challenges in the construction process and possibly result in abandonment or escalation of cost. Alternatives that are anticipated to have relatively less difficulty in constructability are scored greater.

- Need for Secondary O&M (MCA Weight = 10)
  Some alternatives are able to protect more facilities than others. Alternatives which do not provide protection for all UWCD facilities will require implementation of secondary O&M practices to manage mussel infestation. Alternatives with relatively less need for UWCD to implement secondary O&M practices are scored greater than other alternatives.

- Estimated Footprint (MCA Weight = 5)
  Each alternative will require a certain amount of space. As an example, very large chemical feed systems will require much more space than pump stations. Alternatives with a smaller relative footprint are provided greater scoring.

- Operating Complexity (MCA Weight = 10)
  Each alternative has a certain amount of operational complexity. Chemical feed systems will be significantly more complex to operate than pump stations. Alternatives with lower anticipated operating complexity than other alternatives are provided greater scoring.

- Additional Testing Required (MCA Weight = 10)
  Prior to final selection and implementation, several of the alternatives must be assessed with bench- and/or pilot-scale performance testing in order to confirm their capability for risk protection. Alternatives that do not require testing are scored greater than alternatives that require performance testing.

- Overall Risk Protection & Reduced Secondary Risks (MCA Weight = 25)
  No alternative can provide a 100-percent guarantee against passage of veligers and/or mussels. After any of the alternatives are selected, developed/constructed, and then finally operated, there is a certain level of relative risk protection that it may provide. Furthermore, an alternative may also have secondary risks (such as the formation of DBPs that may impact a downstream drinking water source). Alternatives that have relatively greater risk protection and lower secondary risks are scored greater than other alternatives.

**Table 7-2** summarizes the matrix of each alternative and the scoring provided for each alternative based upon each of the MCA categories described above. Each of the scores provided range from a ranking of 1 to 5 based upon the following:

1 = Lowest ranking possible / is not expected to perform well in this category;

2 = Low ranking / performance will be less than desired;

3 = Moderate ranking / performance will be acceptable;

4 = High ranking / expected to perform well; and

5 = Greatest ranking possible / expected to perform exceptionally.

**Table 7-2. Multi-Criteria Analysis Categories and Resulting Rankings for Mussel Control Alternatives**

| Alternative | MCA Category Scoring From 1 to 5 (5 is Best) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Life-cycle Cost | Permitting | Constructability | Need for Secondary O&M | Footprint | Complexity | Additional Testing Required | Overall Risk Protection |
| 1. River Infiltration Gallery | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 5 |
| 2a. Chemical Feed at Freeman | 1 | 2 | 2 | 5 | 1 | 1 | 1 | 2 |
| 2b. Chemical Feed After Desilting Basin | 1 | 2 | 2 | 5 | 1 | 1 | 1 | 2 |
| 3. Pond Infiltration Gallery | 2 | 5 | 4 | 2 | 2 | 2 | 1 | 5 |
| 4. Increased Pumping at Recharge Basin | 3 | 4 | 4 | 2 | 5 | 1 | 5 | 5 |
| 5a. Chemical Feed Before Moss Screen | 4 | 4 | 4 | 3 | 2 | 2 | 2 | 2 |
| 5b. Chemical Feed After Moss Screen | 4 | 4 | 4 | 2 | 2 | 2 | 2 | 2 |
| 6. Pre-Reservoir Chemical Feed | 4 | 3 | 3 | 1 | 3 | 2 | 2 | 3 |
| 7. Non-Capital Facility Control | 5 | 5 | 5 | 1 | 5 | 3 | 5 | 2 |
| ***MCA Category Weightings:*** | ***30%*** | ***5%*** | ***5%*** | ***10%*** | ***5%*** | ***10%*** | ***10%*** | ***25%*** |

Based upon the categories and scoring shown above, each of the alternatives were ranked based upon the equation: Total Score = (MCA Score) x (Weighting). Compared against each other after receiving their Total Score, alternatives were given a relative performance value and overall beneficial ranking as shown below in **Table 7-3**.

**Table 7-3. Multi-Criteria Analysis Relative Performance Ratings and Resulting Final Alternative Ranks**

| Alternative | Relative Performance | Rank |
|---|---|---|
| 1. River Infiltration Gallery | 0.55 | 5 |
| 2a. Chemical Feed at Freeman | 0.48 | 6 (Tie) |
| 2b. Chemical Feed After Desilting Basin | 0.48 | 6 (Tie) |
| 3. Pond Infiltration Gallery | 0.80 | 3 (Tie) |
| 4. Increased Pumping at Recharge Basin | 0.99 | 2 |
| 5a. Chemical Feed Before Moss Screen | 0.80 | 3 (Tie) |
| 5b. Chemical Feed After Moss Screen | 0.77 | 4 |
| 6. Pre-Reservoir Chemical Feed | 0.80 | 3 (Tie) |
| 7. Non-Capital Facility Control | 1.0 | 1 |

The result of the MCA analysis indicates that Alternatives are ranked from best to worst as follows:

1. Alternative 7: Non-Capital Facility Control;
2. Alternative 4: Increased Pumping at Recharge Basin;
3. Alternatives 3, 5a, and 6 (Tie Scores): Pond Infiltration Gallery, Chemical Feed Before Moss Screen, and Pre-Reservoir Chemical Feed;
4. Alternatives 5b: Chemical Feed After Moss Screen;
5. Alternative 1: River Infiltration Gallery;
6. Alternatives 2a and 2b (Tie scores): Chemical Feed at Freeman Diversion and Chemical Feed After the Desilting Basin.

# 8.0 Recommendations and Next Steps

Although no control alternative is perfect, a mixture of selecting an alternative – and implementing lower-cost O&M measures – can be expected to provide the risk protection required against invasive mussels entering UWCD's stakeholders' water systems. Based upon the system engineering and operating knowledge provided, available control options, potential negative impacts from some options, and planning-level cost estimates for mussel control alternatives, the following recommendations are made:

**1. Implement one or more of the following control alternatives**

a. Increased Pumping / ASR Improvements (this is recommended as the best-case alternative as it is estimated to have a mid-range cost, no chemical use, and offers an excellent barrier against veliger passage and downstream mussel infestation), or

b. Chemical Feed Immediately Before Stakeholder Reservoirs (this is considered a next-best alternative as it is low cost, but requires the construction and operation of chemical addition facilities).

**2 After selecting one of the above alternatives, complete the following next-steps**

a. Implement monitoring for veligers and mussels throughout the UWCD system,

b. Finalize sizing, operating conditions, and location/siting for facilities and conveyance systems that need to be constructed, and

c. Determine if there are any right-of-way or permitting issues that require resolution in order to successfully implement the selected alternative, and

d. Refine engineering and operations cost estimates for the selected alternative such that the increased cost of delivered water can be quantified, and

e. Conduct bench- and/or pilot-scale testing of chemical dosing options necessary for O&M control of veligers in UWCD's system (e.g., chlorine, $KMnO_4$, or a proprietary chemical and/or biological molluskicides).

Regardless of implementation of the above, UWCD should implement elevated levels of monitoring and O&M-based controls throughout the UWCD system (from the Freeman Diversion through the Moss Screen and all Recharge Basins) which may include several of the following:

1. Continuous monitoring for veligers throughout the UWCD system, and

2. Intermittent application of chemical oxidants (i.e., chlorine), when necessary to kill veligers that have entered the system and at levels which do not produce negative water quality impacts to downstream drinking water purveyors, and

3. Intermittent application of chemical or biological molluskicides in ponded areas such as in the Desilting Basin if mussels have been able to grow (if they meet drinking water application requirements and are NSF certified).

The above recommendations are based upon the following needs and assumptions:

1. Ability to provide consistent, continuous protection in UWCD's stakeholders' water systems against passage of veligers and colonization by mussels;

2. Minimization of negative secondary impacts from treatment (e.g., production of regulated DBPs that may enter a downstream drinking water system);

3. Selection of an alternative with a reasonable planning-level estimated cost (relative to other alternatives);

4. Selection of an alternative that does not require excessive pre-implementation bench- and/or pilot-scale process testing; and

5. Selection of an alternative characterized as having no significant difficulty in permitting, construction, or operation.

# 9.0 References

De Leon, R. (2008) Testimony before the U.S. House of Representatives Committee on Natural Resources, Subcommittee on Water and Power, Hearing on “The Silent Invasion: Finding Solutions to Minimize the Impacts of Invasive Quagga Mussels on Water Rates, Water Infrastructure and the Environment”. June 24.

Mackie, G.L & Claudi, R. (2010) “Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems,” Second Edition, CRC Press.

McMahon, R.F, T. A. Ussery, and M. Clarke (1993) “Use of Emersion as a Zebra Mussel Control Method.” Prepared for US Army Corps of Engineers; monitored by Environmental Laboratory, US Army Engineer Waterways Experimental Station. 33 p.: ill. : 28 cm. – (Contract report: EL-93-1)

Schwaebe, L. (2013) “Spawning, Veliger Growth and Desiccation of Dressena bulgensis” UNLV Theses/Dissertations/Professional Papers/ Capstones. Paper 1625.

United Water Conservation District (UWCD) (2016) Quagga Mussel Monitoring and Control Plan Lake Piru, California. October.

# Appendix A

# Meeting Notes

1. Discussion, Q & A
    a. Quaggas were discovered in the Great Lakes in the 1980s, and I'm just surprised there has been no technological advances to eradicate them? Also surprised there has been no new taxes to take care of the problem. - Dan Naumann
    b. What is the red dot (Zebra mussel) in central California? San Justo Reservoir. The infestation started with Federal project. The lake was infested before Lake Piru. - Dan Naumann
    c. Reproduction:
        i. How long can veligers last? How is this associated with risk levels? Response: Varies by other environmental conditions, unlikely to last more than 3-4 weeks under favorable conditions, much less under non-favorable conditions. Chemical treatments or physical treatments such as heat stress would need to persist long enough to ensure mortality of veligers, especially if using a treatment such as heat but the environmental conditions reduce the effectiveness of that treatment.
        ii. Females can spawn 1,000,000 eggs - John Broome. Response: Up to ~1 million eggs/female/year – Keller et al 2007.
    d. 100 vertical feet of sand should work as a barrier to quagga (ASR alternative).
    e. Chemical upstream of the desilting basin, wouldn't silt be problematic?
    f. Need to change location of existing chlorine addition at PTP Reservoir on all diagrams. It is currently shown downstream of the PTP reservoir, but the injector is at the inlet of the PTP reservoir.
    g. River infiltration - We're not doing that one! - Dan Naumann
    h. Did the costs consider the average deliveries?
    i. How much did Metropolitan's Facilities costs?
        i. Could also include San Diego Water Auth. Facilities
    j. Wouldn't ASR include groundwater pumping fees?
        i. 30 day storage SWRCB allowance @ Saticoy.
        ii. Need to confirm how this would all work.
    k. What if chemical "super-duper X" comes out that works on quaggas, can we use the same facility?
    l. What about human or technological errors? If one veliger slips through, it's over - John Broome. Response: Need at least 2, male and female.
        i. Secondary systems?
        ii. Monitoring/immediate response plan
    m. Most labs are focused on new infestations. UWCD plans to work with a UC San Diego Lab and we'll be setting up our own equipment in Lake Piru and the River. We'll be meeting with NMFS in a few weeks to discuss options and will provide an update at the next stakeholder meeting. - Tony Emmert
    n. Alternative Number 4 (ASR Pumping) is the answer - Dan Naumann
    o. How far away can we extract from the Saticoy Well Field considering the SWRCB 30-day storage water right?

2. Additional notes #1
    a. Many bio/lifecycle questions. Please see above.
    b. General questions about how options are selected.
    c. Change the name of “Do Nothing” to “O&M Only” since it is more reflective of the alternatives actions.
    d. What are the operational challenges for dosing of the chemicals?
    e. What are the possible chemical impacts to agriculture?

f. “Don’t want any quagga!”

3. Additional notes #2

a. Goals from customers: listen, history of quagga infestation, closure, “quagga free” water

b. What’s the difference between quagga and zebra mussels? Response: Different species but same genus. Zebras arrived first, quaggas later. Zebras are somewhat larger, somewhat less tolerant of deeper water or soft substrate, and have a slightly different shape. Where they co-occur, quaggas have begun to replace zebras. http://fl.biology.usgs.gov/Nonindigenous_Species/Zebra_mussel_FAQs/Dreissena_FAQs/dreissena_faqs.html

c. Why haven’t invasive mussels been controlled?

d. Why isn’t there State or Federal money available?

e. How long can veligers survive? Can they make it to PV/PT? Response: Veligers take 3-4 weeks to develop into juveniles that will settle and attach by their byssal threads.

f. What are the limiting environmental conditions for quagga survival: turbidity, pH, phosphorus, etc.? Response: Varies but presented in isolation in table in report. Caveat is that stressors can act synergistically, i.e. if at the upper end of their thermal tolerance range other stressors may be more effective, e.g. it may take a shorter period of exposure to a given chlorine level to kill the animals.

g. Is flow variability a reason for removing some alternatives from consideration in the first round of alternative analysis? No, but it will be possible reason in subsequent rounds.

# Appendix B

# Process Cost Calculations

| UWCD Quagga Control Cost Item (All costs in $Million) | 1 River Infiltration Gallery | | 2a Chlorine at Freeman Diversion | | 2a KMnO4 at Freeman Diversion | | 2b Chlorine at Desilting Basin | | 2b KMnO4 at Desilting Basin | | 3 Pond Infiltration Gallery | | 4 Pumping Improvements | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper |
| **Capital Costs** | | | | | | | | | | | | | | |
| Unit process cost ($M) | $ 11.80 | $ 15.45 | $ 11.62 | $ 15.20 | $ 1.20 | $ 1.48 | $ 5.81 | $ 7.60 | $ 0.70 | $ 0.87 | $ 9.94 | $ 9.94 | $ 3.88 | $ 5.82 |
| Yard piping ($M) | $ 1.18 | $ 1.55 | $ 1.16 | $ 1.52 | $ 0.12 | $ 0.15 | $ 0.58 | $ 0.76 | $ 0.07 | $ 0.09 | $ 0.99 | $ 0.99 | $ 0.39 | $ 0.58 |
| Sitework ($M) | $ 0.59 | $ 0.77 | $ 0.58 | $ 0.76 | $ 0.06 | $ 0.07 | $ 0.29 | $ 0.38 | $ 0.04 | $ 0.04 | $ 0.50 | $ 0.50 | $ 0.19 | $ 0.29 |
| Electrical and controls ($M) | $ 2.36 | $ 3.09 | $ 2.32 | $ 3.04 | $ 0.24 | $ 0.30 | $ 1.16 | $ 1.52 | $ 0.14 | $ 0.17 | $ 1.99 | $ 1.99 | $ 0.78 | $ 1.16 |
| Permitting, environmental | $ 1.00 | $ 1.00 | $ 1.00 | $ 1.00 | $ 1.00 | $ 1.00 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Subtotal cost ($M) | $ 16.93 | $ 21.86 | $ 16.69 | $ 21.52 | $ 2.62 | $ 3.00 | $ 7.84 | $ 10.26 | $ 0.95 | $ 1.18 | $ 13.42 | $ 13.42 | $ 5.23 | $ 7.85 |
| Engineering, legal, admin ($M) | $ 5.57 | $ 7.30 | $ 5.49 | $ 7.18 | $ 0.57 | $ 0.70 | $ 2.75 | $ 3.59 | $ 0.33 | $ 0.41 | $ 4.70 | $ 4.70 | $ 1.74 | $ 2.62 |
| Added in-river access ($M) | $ 2.00 | $ 2.00 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Water surge tank cost ($M) | $ 0.07 | $ 0.20 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.07 | $ 0.20 | $ 0.04 | $ 0.08 |
| Pipeline cost ($M) | $ 3.96 | $ 10.56 | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.13 | $ 0.40 | $ 0.13 | $ 0.40 |
| 30% Contingency ($M) | $ 6.29 | $ 9.79 | $ 5.02 | $ 6.52 | $ 0.80 | $ 0.96 | $ 2.37 | $ 3.14 | $ 0.30 | $ 0.41 | $ 4.08 | $ 4.21 | $ 1.62 | $ 2.50 |
| Grand total | $ 34.82 | $ 51.71 | $ 27.25 | $ 35.42 | $ 4.04 | $ 4.86 | $ 13.01 | $ 17.19 | $ 1.63 | $ 2.20 | $ 22.39 | $ 22.92 | $ 8.76 | $ 13.45 |
| Average | $ | 43.26 | $ | 31.33 | $ | 4.45 | $ | 15.10 | $ | 1.91 | $ | 22.66 | $ | 11.11 |
| 50 Upper bound estimate | $ 52.23 | $ 77.56 | $ 40.88 | $ 53.13 | $ 6.06 | $ 7.29 | $ 19.52 | $ 25.78 | $ 2.44 | $ 3.30 | $ 33.59 | $ 34.39 | $ 13.15 | $ 20.18 |
| -25 Lower bound estimate | $ 26.11 | $ 38.78 | $ 20.44 | $ 26.56 | $ 3.03 | $ 3.64 | $ 9.76 | $ 12.89 | $ 1.22 | $ 1.65 | $ 16.79 | $ 17.19 | $ 6.57 | $ 10.09 |
| **O&M Costs (per annum)** | | | | | | | | | | | | | | |
| Primary Capital Facility O&M | | | | | | | | | | | | | | |
| FTE staffing amount | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 0.5 | 1 |
| FTE staffing cost | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.05 | $ 0.09 |
| Added power cost | $ 0.07 | $ 0.07 | | | | | | | | | $ 0.25 | $ 0.25 | $ 0.74 | $ 0.74 |
| 4 Mo/Season/Year Chem Use | $ - | $ - | $ 0.906 | $ 1.358 | $ 2.037 | $ 5.433 | $ 0.453 | $ 0.679 | $ 1.358 | $ 3.396 | $ - | $ - | $ - | $ - |
| 5 %/Yr Maintenance Costs | $ 0.847 | $ 1.093 | $ 0.834 | $ 1.076 | $ 0.131 | $ 0.150 | $ 0.392 | $ 0.513 | $ 0.047 | $ 0.059 | $ 0.671 | $ 0.671 | $ 0.262 | $ 0.393 |
| Secondary Control Efforts O&M | | | | | | | | | | | | | | |
| - O&M at Freeman Diversion | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 |
| FTE staffing amount | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 |
| - O&M at Desilting Basin | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 |
| FTE staffing amount | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 |
| - O&M at Ponds | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 |
| FTE staffing amount | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 |
| - O&M at Moss Screen | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 |
| FTE staffing amount | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 |
| - O&M at Spreading Grounds | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 |
| FTE staffing amount | 0.2 | 0.4 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 |
| Analytical / monitoring cost | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Total O&M cost | $ 1.15 | $ 1.65 | $ 1.83 | $ 2.61 | $ 2.26 | $ 5.76 | $ 0.96 | $ 1.43 | $ 1.52 | $ 3.70 | $ 1.15 | $ 1.40 | $ 1.19 | $ 1.53 |
| 20 Year present value Lifecycle cost | | | | | | | | | | | | | | |
| Maximum | $ 67.9 | $ 100.0 | $ 65.7 | $ 88.7 | $ 36.8 | $ 85.6 | $ 32.6 | $ 45.3 | $ 23.1 | $ 53.5 | $ 49.2 | $ 53.5 | $ 29.3 | $ 41.0 |
| Cost | $ 50.5 | $ 74.2 | $ 52.1 | $ 70.9 | $ 34.7 | $ 83.2 | $ 26.1 | $ 36.7 | $ 22.3 | $ 52.4 | $ 38.0 | $ 42.0 | $ 25.0 | $ 34.3 |
| Average Cost | $ | 62.3 | $ | 61.5 | $ | 59.0 | $ | 31.4 | $ | 37.4 | $ | 40.0 | $ | 29.6 |
| Minimum | $ 41.8 | $ 61.2 | $ 45.3 | $ 62.1 | $ 33.7 | $ 82.0 | $ 22.8 | $ 32.4 | $ 21.9 | $ 51.9 | $ 32.4 | $ 36.3 | $ 22.8 | $ 30.9 |

| UWCD Quagga Control Cost Item (All costs in $Million) | 5a Chlorine Before Moss Screen | | 5a KMnO4 Before Moss Screen | | 5b Chlorine After Moss Screen | | 5b KMnO4 After Moss Screen | | 6 Chlorine For Reservoirs | | 6 KMnO4 For Reservoirs | | 7 Primarily O&M | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper |
| **Capital Costs** | | | | | | | | | | | | | | |
| Unit process cost ($M) | $ 2.39 | $ 3.26 | $ 0.31 | $ 0.34 | $ 1.70 | $ 2.39 | $ 0.18 | $ 0.22 | $ 0.65 | $ 0.91 | $ 0.07 | $ 0.08 | $ - | $ - |
| Yard piping ($M) | $ 0.24 | $ 0.33 | $ 0.03 | $ 0.03 | $ 0.17 | $ 0.24 | $ 0.02 | $ 0.02 | $ 0.07 | $ 0.09 | $ 0.01 | $ 0.01 | $ - | $ - |
| Sitework ($M) | $ 0.12 | $ 0.16 | $ 0.02 | $ 0.02 | $ 0.09 | $ 0.12 | $ 0.01 | $ 0.01 | $ 0.03 | $ 0.05 | $ 0.00 | $ 0.00 | $ - | $ - |
| Electrical and controls ($M) | $ 0.48 | $ 0.65 | $ 0.06 | $ 0.07 | $ 0.34 | $ 0.48 | $ 0.04 | $ 0.04 | $ 0.13 | $ 0.18 | $ 0.01 | $ 0.02 | $ - | $ - |
| Permitting, environmental | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Subtotal cost ($M) | $ 3.23 | $ 4.40 | $ 0.42 | $ 0.46 | $ 2.30 | $ 3.23 | $ 0.25 | $ 0.30 | $ 0.88 | $ 1.23 | $ 0.10 | $ 0.11 | $ - | $ - |
| Engineering, legal, admin ($M) | $ 1.13 | $ 1.54 | $ 0.15 | $ 0.16 | $ 0.81 | $ 1.13 | $ 0.09 | $ 0.10 | $ 0.31 | $ 0.43 | $ 0.03 | $ 0.04 | $ 0.10 | $ 0.20 |
| Added in-river access ($M) | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Water surge tank cost ($M) | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - |
| Pipeline cost ($M) | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.05 | $ 0.20 | $ 0.13 | $ 0.40 | $ 0.13 | $ 0.40 | $ - | $ - |
| 30% Contingency ($M) | $ 0.98 | $ 1.38 | $ 0.14 | $ 0.20 | $ 0.70 | $ 1.03 | $ 0.09 | $ 0.15 | $ 0.30 | $ 0.49 | $ 0.07 | $ 0.15 | $ - | $ - |
| Grand total | $ 5.39 | $ 7.52 | $ 0.76 | $ 1.03 | $ 3.85 | $ 5.58 | $ 0.47 | $ 0.75 | $ 1.61 | $ 2.55 | $ 0.32 | $ 0.70 | $ 0.10 | $ 0.20 |
| Average | $ | 6.46 | $ | 0.89 | $ | 4.72 | $ | 0.61 | $ | 2.08 | $ | 0.51 | $ | 0.15 |
| 50 Upper bound estimate | $ 8.08 | $ 11.28 | $ 1.14 | $ 1.54 | $ 5.78 | $ 8.38 | $ 0.71 | $ 1.13 | $ 2.42 | $ 3.83 | $ 0.48 | $ 1.06 | $ 0.15 | $ 0.30 |
| -25 Lower bound estimate | $ 4.04 | $ 5.64 | $ 0.57 | $ 0.77 | $ 2.89 | $ 4.19 | $ 0.36 | $ 0.56 | $ 1.21 | $ 1.92 | $ 0.24 | $ 0.53 | $ 0.08 | $ 0.15 |
| **O&M Costs (per annum)** | | | | | | | | | | | | | | |
| Primary Capital Facility O&M | | | | | | | | | | | | | | |
| FTE staffing amount | 1 | 2 | 1 | 2 | 1 | 2 | 1 | 2 | 0.5 | 1 | 0.5 | 1 | 0.5 | 1 |
| FTE staffing cost | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.09 | $ 0.18 | $ 0.05 | $ 0.09 | $ 0.05 | $ 0.09 | $ 0.05 | $ 0.09 |
| Added power cost | | | | | | | | | | | | | | |
| 4 Mo/Season/Year Chem Use | $ 0.146 | $ 0.233 | $ 0.873 | $ 1.310 | $ 0.087 | $ 0.146 | $ 0.437 | $ 0.873 | $ 0.029 | $ 0.049 | $ 0.146 | $ 0.291 | $ - | $ - |
| 5 %/Yr Maintenance Costs | $ 0.161 | $ 0.220 | $ 0.021 | $ 0.023 | $ 0.115 | $ 0.161 | $ 0.012 | $ 0.015 | $ 0.044 | $ 0.062 | $ 0.005 | $ 0.006 | $ - | $ - |
| Secondary Control Efforts O&M | | | | | | | | | | | | | | |
| - O&M at Freeman Diversion | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ - | $ - |
| FTE staffing amount | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ - | $ - |
| - O&M at Desilting Basin | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ - | $ - |
| FTE staffing amount | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ - | $ - |
| - O&M at Ponds | | | | | | | | | | | | | | |
| Equipment & chemical | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ - | $ - |
| FTE staffing amount | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| FTE staffing cost | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ - | $ - |
| - O&M at Moss Screen | | | | | | | | | | | | | | |
| Equipment & chemical | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ - | $ - |
| FTE staffing amount | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| FTE staffing cost | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ - | $ - |
| - O&M at Spreading Grounds | | | | | | | | | | | | | | |
| Equipment & chemical | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.01 | $ 0.03 | $ 0.01 | $ 0.03 | $ - | $ - |
| FTE staffing amount | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.2 | 0.4 | 0.2 | 0.4 | 0 | 0 |
| FTE staffing cost | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.02 | $ 0.04 | $ 0.02 | $ 0.04 | $ - | $ - |
| Analytical / monitoring cost | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ - | $ 0.200 | $ 0.400 |
| Total O&M cost | $ 0.48 | $ 0.82 | $ 1.07 | $ 1.70 | $ 0.40 | $ 0.73 | $ 0.65 | $ 1.31 | $ 0.26 | $ 0.51 | $ 0.34 | $ 0.69 | $ 0.25 | $ 0.49 |
| 20 Year present value Lifecycle cost | | | | | | | | | | | | | | |
| Maximum | $ 14.6 | $ 22.4 | $ 15.7 | $ 24.6 | $ 11.3 | $ 18.3 | $ 9.6 | $ 19.0 | $ 5.9 | $ 10.7 | $ 5.0 | $ 10.5 | $ 3.5 | $ 7.0 |
| Cost | $ 11.9 | $ 18.6 | $ 15.3 | $ 24.1 | $ 9.3 | $ 15.5 | $ 9.3 | $ 18.6 | $ 5.1 | $ 9.4 | $ 4.9 | $ 10.1 | $ 3.4 | $ 6.9 |
| Average Cost | $ | 15.3 | $ | 19.7 | $ | 12.4 | $ | 14.0 | $ | 7.3 | $ | 7.5 | $ | 5.1 |
| Minimum | $ 10.6 | $ 16.7 | $ 15.1 | $ 23.8 | $ 8.4 | $ 14.1 | $ 9.2 | $ 18.4 | $ 4.7 | $ 8.8 | $ 4.8 | $ 9.9 | $ 3.4 | $ 6.8 |

Notes

$90,000 per year / FTE
All chlorine options assume chlorine gas (1-ton cylinders)
Lifecycle cost estimate settings
4.0 % / year interest
20 Year lifecycle estimate

$ 0.20 $/lb chlorine gas cost
$ 3.00 $/lb KMnO4 cost
$ 0.19 $/kWh power cost

Date last updated: April 27, 2016

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

1-In-River Infiltration Gallery

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 75 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 33660 | GPM | 48.5 | MGD | | |

| Infiltration gallery permeability (GPM/sf) | |
|---|---|
| Minimum | 1.5 |
| Maximum | 3 |

| Infiltration gallery area requirement (sf) | |
|---|---|
| Minimum | 11220 |
| Maximum | 22440 |

| Preliminary design considerations | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum area w/ redundancy | 14025 | |
| Maximum area w/ redundancy | 28050 | |
| individual galleries per layout | 3 | each |
| Preliminary design area / gallery (min) | 4675 | |
| Preliminary design area / gallery (max) | 7480 | |

| Surge tank sizing | | |
|---|---|---|
| Minimum flow capture | 2 | min |
| Maximum flow capture | 5 | min |
| Minimum volume | 67320 | Gal |
| Maximum volume | 168300 | Gal |
| Minimum roundup sizing | 70,000 | Gal |
| Maximum roundup sizing | 170,000 | Gal |

| Gallery dimensions | | |
|---|---|---|
| Assumed gallery length | 100 | ft |
| Minimum width | 46.75 | |
| Minimum width, rounded | 50 | |
| Maximum width | 74.8 | |
| Maximum width, rounded | 70 | |

| Revised design conditions | | |
|---|---|---|
| Minimum dimensions | 100 | ft long |
| | 50 | ft wide |
| | 5000 | sf per gallery |
| | 3 | gallery layout, each |
| | 15000 | square feet total |
| Maximum dimensions | 100 | ft long |
| | 70 | ft wide |
| | 7000 | sf per gallery |
| | 3 | gallery layout, each |
| | 21000 | square feet total |

| Power cost estimate | |
|---|---|
| 404.5 | M lb/day |
| 100 | % of flow |
| 15 | ft lift |
| 6067.3 | M ft-lb/day |
| 0.0023 | M kWh/day |
| 2285.0 | kWh/day |
| 0.19 | $/kWh |
| 70 | % Efficiency |
| 620.2 | $/day |
| 4 | Mo/year |
| 74427.00 | $/year |

Cost estimates based on revised design conditions

| Lower limit design and costs | | | | Upper limit design and costs | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | Total gallery units (EA) | | | 3 | Total gallery units (EA) |
| | | 5,000 | Individual gallery area (SF) | | | 7,000 | Individual gallery area (SF) |
| | | 15,000 | Total gallery area all units (SF) | | | 21,000 | Total gallery area all units (SF) |
| | $ | 11.80 | Unit process cost ($M) | | $ | 15.45 | Unit process cost ($M) |
| | $ | 1.18 | Yard piping ($M) | | $ | 1.55 | Yard piping ($M) |
| | $ | 0.59 | Sitework ($M) | | $ | 0.77 | Sitework ($M) |
| | $ | 2.36 | Electrical and controls ($M) | | $ | 3.09 | Electrical and controls ($M) |
| | $ | 1.00 | Permitting, environmental | | $ | 1.00 | Permitting, environmental |
| | $ | 16.93 | Subtotal cost ($M) | | $ | 21.86 | Subtotal cost ($M) |
| | $ | 5.57 | Engineering, legal, admin ($M) | | $ | 7.30 | Engineering, legal, admin ($M) |
| | $ | 2.00 | Added in-river access ($M) | | $ | 2.00 | Added in-river access ($M) |
| 1.0 $/Gal | $ | 0.07 | Water surge tank cost ($M) | 1.2 $/Gal | $ | 0.20 | Water surge tank cost ($M) |
| | | 15,840 | Pipeline length (FT) | | | 26,400 | Pipeline length (FT) |
| 250 $/ft | $ | 3.96 | Pipeline cost ($M) | 400 $/ft | $ | 10.56 | Pipeline cost ($M) |
| 30% | $ | 6.29 | Contingency ($M) | 30% | $ | 9.79 | Contingency ($M) |
| | $ | 34.82 | Grand total | | $ | 51.71 | Grand total |
| 50% | $ | 52.23 | Upper bound estimate | 50% | $ | 77.56 | Upper bound estimate |
| -25% | $ | 26.11 | Lower bound estimate | -25% | $ | 38.78 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

2a-Chlorine addition at the Freeman Diversion

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 350 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 157080 | GPM | 226.2 | MGD | | |

**Chlorine dose estimate**

| | | |
|---|---|---|
| Minimum | 20 | mg/L |
| Maximum | 30 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum chlorine storage design w/ redundancy | 37729 | #/day |
| Maximum chlorine storage design w/ redundancy | 56594 | #/day |
| Number of storage/dosing facilities per layout | 6 | each |
| Preliminary capacity per facility MIN | 6288 | #/day |
| Preliminary capacity per facility MAX | 9432 | #/day |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 4527523 | #/season |
| Maximum usage per year | 6791285 | #/season |
| Chemical cost | $ 0.20 | $/# |
| Min cost | $ 0.906 | $M/season |
| Max cost | $ 1.358 | $M/season |

Cost estimates based on revised design conditions

| Lower limit design and costs | | | | Upper limit design and costs | | | |
|---|---|---|---|---|---|---|---|
| | | 20 | Chlorine dose (mg/L) | | | 30 | Chlorine dose (mg/L) |
| | | 37,729 | Total Chlorine capacity (#/D) | | | 56,594 | Total Chlorine capacity (#/D) |
| | | 6 | Number of facilities (EA) | | | 6 | Number of facilities (EA) |
| | | 6,288 | Capacity per facility (#/D) | | | 9,432 | Capacity per facility (#/D) |
| | $ | 11.62 | Unit process cost ($M) | | $ | 15.20 | Unit process cost ($M) |
| | $ | 1.16 | Yard piping ($M) | | $ | 1.52 | Yard piping ($M) |
| | $ | 0.58 | Sitework ($M) | | $ | 0.76 | Sitework ($M) |
| | $ | 2.32 | Electrical and controls ($M) | | $ | 3.04 | Electrical and controls ($M) |
| | $ | 1.00 | Permitting, environmental | | $ | 1.00 | Permitting, environmental |
| | $ | 16.69 | Subtotal cost ($M) | | $ | 21.52 | Subtotal cost ($M) |
| | $ | 5.49 | Engineering, legal, admin ($M) | | $ | 7.18 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) | | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) | 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) | | | 500 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) | 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 5.02 | Contingency ($M) | 30% | $ | 6.52 | Contingency ($M) |
| | $ | 27.25 | Grand total | | $ | 35.42 | Grand total |
| 50% | $ | 40.88 | Upper bound estimate | 50% | $ | 53.13 | Upper bound estimate |
| -25% | $ | 20.44 | Lower bound estimate | -25% | $ | 26.56 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

2a-KMnO4 addition at the Freeman Diversion

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 350 | CF / s | 7.48 | gal / CF | 60 | s / min |
| | 157080 | GPM | 226.2 | MGD | | |

**KMnO4 dose estimate**

| | | |
|---|---|---|
| Minimum | 3 | mg/L |
| Maximum | 8 | mg/L |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum KMnO4 storage design w/ redundancy | 5659 | #/day |
| Maximum KMnO4 storage design w/ redundancy | 15092 | #/day |
| Number of storage/dosing facilities per layout | 35 | each |
| Preliminary capacity per facility MIN | 162 | #/day |
| Preliminary capacity per facility MAX | 431 | #/day |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 679128 | #/season |
| Maximum usage per year | 1811009 | #/season |
| Chemical cost | $ 3.00 | $/# |
| Min cost | $ 2.037 | $M/season |
| Max cost | $ 5.433 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 3 | KMnO4 dose (mg/L) |
| | | 5,659 | Total KMnO4 capacity (#/D) |
| | | 35 | Number of facilities (EA) |
| | | 162 | Capacity per facility (#/D) |
| | $ | 1.20 | Unit process cost ($M) |
| | $ | 0.12 | Yard piping ($M) |
| | $ | 0.06 | Sitework ($M) |
| | $ | 0.24 | Electrical and controls ($M) |
| | $ | 1.00 | Permitting, environmental |
| | $ | 2.62 | Subtotal cost ($M) |
| | $ | 0.57 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 0.80 | Contingency ($M) |
| | $ | 4.04 | Grand total |
| 50% | $ | 6.06 | Upper bound estimate |
| -25% | $ | 3.03 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 8 | KMnO4 dose (mg/L) |
| | | 15,092 | Total KMnO4 capacity (#/D) |
| | | 35 | Number of facilities (EA) |
| | | 431 | Capacity per facility (#/D) |
| | $ | 1.48 | Unit process cost ($M) |
| | $ | 0.15 | Yard piping ($M) |
| | $ | 0.07 | Sitework ($M) |
| | $ | 0.30 | Electrical and controls ($M) |
| | $ | 1.00 | Permitting, environmental |
| | $ | 3.0 | Subtotal cost ($M) |
| | $ | 0.70 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 0.96 | Contingency ($M) |
| | $ | 4.86 | Grand total |
| 50% | $ | 7.29 | Upper bound estimate |
| -25% | $ | 3.64 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

2b-Chlorine addition after the desilting basin

| | | | | | |
|---|---|---|---|---|---|
| Flow | 350 | CF / s | 7.48 | gal / CF | 60 s / min |
| | 157080 | GPM | 226.2 | MGD | |

**Chlorine dose estimate**

| | | |
|---|---|---|
| Minimum | 10 | mg/L |
| Maximum | 15 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum chlorine storage design w/ redundancy | 18865 | #/day |
| Maximum chlorine storage design w/ redundancy | 28297 | #/day |
| Number of storage/dosing facilities per layout | 3 | each |
| Preliminary capacity per facility MIN | 6288 | #/day |
| Preliminary capacity per facility MAX | 9432 | #/day |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 2263762 | #/season |
| Maximum usage per year | 3395642 | #/season |
| Chemical cost | $ 0.20 | $/# |
| Min cost | $ 0.453 | $M/season |
| Max cost | $ 0.679 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 10 | Chlorine dose (mg/L) |
| | | 18,865 | Total Chlorine capacity (#/D) |
| | | 3 | Number of facilities (EA) |
| | | 6,288 | Capacity per facility (#/D) |
| | $ | 5.81 | Unit process cost ($M) |
| | $ | 0.58 | Yard piping ($M) |
| | $ | 0.29 | Sitework ($M) |
| | $ | 1.16 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 7.84 | Subtotal cost ($M) |
| | $ | 2.75 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 2.37 | Contingency ($M) |
| | $ | 13.01 | Grand total |
| 50% | $ | 19.52 | Upper bound estimate |
| -25% | $ | 9.76 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 15 | Chlorine dose (mg/L) |
| | | 28,297 | Total Chlorine capacity (#/D) |
| | | 3 | Number of facilities (EA) |
| | | 9,432 | Capacity per facility (#/D) |
| | $ | 7.60 | Unit process cost ($M) |
| | $ | 0.76 | Yard piping ($M) |
| | $ | 0.38 | Sitework ($M) |
| | $ | 1.52 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 10.3 | Subtotal cost ($M) |
| | $ | 3.59 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 3.14 | Contingency ($M) |
| | $ | 17.19 | Grand total |
| 50% | $ | 25.78 | Upper bound estimate |
| -25% | $ | 12.89 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

2b-KMnO4 addition after the desilting basin

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 350 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 157080 | GPM | 226.2 | MGD | | |

**KMnO4 dose estimate**

| | | |
|---|---|---|
| Minimum | 2 | mg/L |
| Maximum | 5 | mg/L |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum KMnO4 storage design w/ redundancy | 3773 | #/day |
| Maximum KMnO4 storage design w/ redundancy | 9432 | #/day |
| Number of storage/dosing facilities per layout | 20 | each |
| Preliminary capacity per facility MIN | 189 | #/day |
| Preliminary capacity per facility MAX | 472 | #/day |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

| | | | |
|---|---|---|---|
| Number of months/year operating | | 4 | Months / season / year |
| Minimum usage per year | | 452752 | #/season |
| Maximum usage per year | | 1131881 | #/season |
| Chemical cost | $ | 3.00 | $/# |
| Min cost | $ | 1.358 | $M/season |
| Max cost | $ | 3.396 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 2 | Chlorine dose (mg/L) |
| | | 3,773 | Total Chlorine capacity (#/D) |
| | | 20 | Number of facilities (EA) |
| | | 189 | Capacity per facility (#/D) |
| | $ | 0.70 | Unit process cost ($M) |
| | $ | 0.07 | Yard piping ($M) |
| | $ | 0.04 | Sitework ($M) |
| | $ | 0.14 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.95 | Subtotal cost ($M) |
| | $ | 0.33 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 0.30 | Contingency ($M) |
| | $ | 1.63 | Grand total |
| 50% | $ | 2.44 | Upper bound estimate |
| -25% | $ | 1.22 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 5 | Chlorine dose (mg/L) |
| | | 9,432 | Total Chlorine capacity (#/D) |
| | | 20 | Number of facilities (EA) |
| | | 472 | Capacity per facility (#/D) |
| | $ | 0.87 | Unit process cost ($M) |
| | $ | 0.09 | Yard piping ($M) |
| | $ | 0.04 | Sitework ($M) |
| | $ | 0.17 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 1.2 | Subtotal cost ($M) |
| | $ | 0.4 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 0.41 | Contingency ($M) |
| | $ | 2.20 | Grand total |
| 50% | $ | 3.30 | Upper bound estimate |
| -25% | $ | 1.65 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

3-In-Pond Infiltration Gallery

| | | | |
|---|---|---|---|
| Flow | 75 CF/s | 7.48 gal/CF | 60 s/min |
| | 33660 GPM | 48.5 MGD | |

| Infiltration gallery permeability (GPM/sf) | |
|---|---|
| Minimum | 3 |
| Maximum | 3 |

| Infiltration gallery area requirement (sf) | |
|---|---|
| Minimum | 11220 |
| Maximum | 11220 |

| Preliminary design considerations | | |
|---|---|---|
| Design redundancy | 1.1 | |
| Minimum area w/ redundancy | 12342 | |
| Maximum area w/ redundancy | 12342 | |
| individual galleries per layout | 3 | each |
| Preliminary design area / gallery (min) | 4114 | |
| Preliminary design area / gallery (max) | 3740 | |

| Surge tank sizing | | |
|---|---|---|
| Minimum flow capture | 2 | min |
| Maximum flow capture | 5 | min |
| Minimum volume | 67320 | Gal |
| Maximum volume | 168300 | Gal |
| Minimum roundup sizing | 70,000 | Gal |
| Maximum roundup sizing | 170,000 | Gal |

| Gallery dimensions | | |
|---|---|---|
| Assumed gallery length | 80 | ft |
| Minimum width | 51.425 | |
| Minimum width, rounded | 50 | |
| Maximum width | 46.75 | |
| Maximum width, rounded | 50 | |

| Revised design conditions | | |
|---|---|---|
| Minimum dimensions | 80 | ft long |
| | 50 | ft wide |
| | 4000 | sf per gallery |
| | 3 | gallery layout, each |
| | 12000 | square feet total |
| Maximum dimensions | 80 | ft long |
| | 50 | ft wide |
| | 4000 | sf per gallery |
| | 3 | gallery layout, each |
| | 12000 | square feet total |

| Power cost estimate | |
|---|---|
| 404.5 | M lb/day |
| 100 | % of flow |
| 50 | ft lift |
| 20224.3 | M ft-lb/day |
| 0.0076 | M kWh/day |
| 7616.8 | kWh/day |
| 0.19 | $/kWh |
| 70 | % Efficiency |
| 2067.4 | $/day |
| 4 | Mo/year |
| 248089.99 | $/year |

Cost estimates based on revised design conditions

| Lower limit design and costs | | | | Upper limit design and costs | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | Total gallery units (EA) | | | 3 | Total gallery units (EA) |
| | | 4,000 | Individual gallery area (SF) | | | 4,000 | Individual gallery area (SF) |
| | | 12,000 | Total gallery area all units (SF) | | | 12,000 | Total gallery area all units (SF) |
| | $ | 9.94 | Unit process cost ($M) | | $ | 9.94 | Unit process cost ($M) |
| | $ | 0.99 | Yard piping ($M) | | $ | 0.99 | Yard piping ($M) |
| | $ | 0.50 | Sitework ($M) | | $ | 0.50 | Sitework ($M) |
| | $ | 1.99 | Electrical and controls ($M) | | $ | 1.99 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental | | $ | - | Permitting, environmental |
| | $ | 13.42 | Subtotal cost ($M) | | $ | 13.42 | Subtotal cost ($M) |
| | $ | 4.70 | Engineering, legal, admin ($M) | | $ | 4.70 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) | | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | 0.07 | Water surge tank cost ($M) | 1.2 $/Gal | $ | 0.20 | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) | | | 1,000 | Pipeline length (FT) |
| 250 $/ft | $ | 0.13 | Pipeline cost ($M) | 400 $/ft | $ | 0.40 | Pipeline cost ($M) |
| 30% | $ | 4.08 | Contingency ($M) | 30% | $ | 4.21 | Contingency ($M) |
| | $ | 22.39 | Grand total | | $ | 22.92 | Grand total |
| 50% | $ | 33.59 | Upper bound estimate | 50% | $ | 34.39 | Upper bound estimate |
| -25% | $ | 16.79 | Lower bound estimate | -25% | $ | 17.19 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

4-Pumping Improvements

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 75 | CF<br>s | 7.48 | gal<br>CF | 60 | s<br>min |
| | 33660 | GPM | 48.5 | MGD | | |

Pumping facility cost estimate

| | | |
|---|---|---|
| | 0.08 | $M per MGD |
| | 3.9 | $M low range cost |
| x1.5 = | 5.8 | $M high range cost |

Surge tank sizing

| | | |
|---|---|---|
| Minimum flow capture | 1 | min |
| Maximum flow capture | 2 | min |
| Minimum volume | 33660 | Gal |
| Maximum volume | 67320 | Gal |
| Minimum roundup sizing | 40,000 | Gal |
| Maximum roundup sizing | 70,000 | Gal |

Power cost estimate

| | |
|---|---|
| 404.5 | M lb/day |
| 100 | % of flow |
| 150 | ft lift |
| 60672.8 | M ft-lb/day |
| 0.0229 | M kWh/day |
| 22850.4 | kWh/day |
| 0.19 | $/kWh |
| 70 | % Efficiency |
| 6202.2 | $/day |
| 4 | Mo/year |
| 744269.98 | $/year |

Cost estimates based on revised design conditions

Lower limit design and costs

| | | | |
|---|---|---|---|
| | | 0 | Total gallery units (EA) |
| | | - | Individual gallery area (SF) |
| | | - | Total gallery area all units (SF) |
| | $ | 3.88 | Unit process cost ($M) |
| | $ | 0.39 | Yard piping ($M) |
| | $ | 0.19 | Sitework ($M) |
| | $ | 0.78 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 5.23 | Subtotal cost ($M) |
| | $ | 1.74 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | 0.04 | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 250 $/ft | $ | 0.13 | Pipeline cost ($M) |
| 30% | $ | 1.62 | Contingency ($M) |
| | $ | 8.76 | Grand total |
| 50% | $ | 13.15 | Upper bound estimate |
| -25% | $ | 6.57 | Lower bound estimate |

Upper limit design and costs

| | | | |
|---|---|---|---|
| | | 0 | Total gallery units (EA) |
| | | - | Individual gallery area (SF) |
| | | - | Total gallery area all units (SF) |
| | $ | 5.82 | Unit process cost ($M) |
| | $ | 0.58 | Yard piping ($M) |
| | $ | 0.29 | Sitework ($M) |
| | $ | 1.16 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 7.85 | Subtotal cost ($M) |
| | $ | 2.62 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | 0.08 | Water surge tank cost ($M) |
| | | 1,000 | Pipeline length (FT) |
| 400 $/ft | $ | 0.40 | Pipeline cost ($M) |
| 30% | $ | 2.50 | Contingency ($M) |
| | $ | 13.45 | Grand total |
| 50% | $ | 20.18 | Upper bound estimate |
| -25% | $ | 10.09 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

5a-Chlorine addition before the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 225 | CF<br>s | 7.48 | gal<br>CF | 60 | s<br>min |
| | 100980 | GPM | 145.4 | MGD | | |

**Chlorine dose estimate**

| | | |
|---|---|---|
| Minimum | 5 | mg/L |
| Maximum | 8 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum chlorine storage design w/ redundancy | 6064 | #/day |
| Maximum chlorine storage design w/ redundancy | 9702 | #/day |
| Number of storage/dosing facilities per layout | 2 | each |
| Preliminary capacity per facility MIN | 3032 | #/day |
| Preliminary capacity per facility MAX | 4851 | #/day |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 727638 | #/season |
| Maximum usage per year | 1164220 | #/season |
| Chemical cost | $ 0.20 | $/# |
| Min cost | $ 0.146 | $M/season |
| Max cost | $ 0.233 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 5 | Chlorine dose (mg/L) |
| | | 6,064 | Total Chlorine capacity (#/D) |
| | | 2 | Number of facilities (EA) |
| | | 3,032 | Capacity per facility (#/D) |
| | $ | 2.39 | Unit process cost ($M) |
| | $ | 0.24 | Yard piping ($M) |
| | $ | 0.12 | Sitework ($M) |
| | $ | 0.48 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 3.23 | Subtotal cost ($M) |
| | $ | 1.13 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 0.98 | Contingency ($M) |
| | $ | 5.39 | Grand total |
| 50% | $ | 8.08 | Upper bound estimate |
| -25% | $ | 4.04 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 8 | Chlorine dose (mg/L) |
| | | 9,702 | Total Chlorine capacity (#/D) |
| | | 2 | Number of facilities (EA) |
| | | 4,851 | Capacity per facility (#/D) |
| | $ | 3.26 | Unit process cost ($M) |
| | $ | 0.33 | Yard piping ($M) |
| | $ | 0.16 | Sitework ($M) |
| | $ | 0.65 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 4.40 | Subtotal cost ($M) |
| | $ | 1.54 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 1.38 | Contingency ($M) |
| | $ | 7.52 | Grand total |
| 50% | $ | 11.28 | Upper bound estimate |
| -25% | $ | 5.64 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

5a-KMnO4 addition before the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 225 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 100980 | GPM | 145.4 | MGD | | |

**KMnO4 dose estimate**

| | | |
|---|---|---|
| Minimum | 2 | mg/L |
| Maximum | 3 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum KMnO4 storage design w/ redundancy | 2425 | #/day |
| Maximum KMnO4 storage design w/ redundancy | 3638 | #/day |
| Number of storage/dosing facilities per layout | 8 | each |
| Preliminary capacity per facility MIN | 303 | #/day |
| Preliminary capacity per facility MAX | 455 | #/day |

| | | | |
|---|---|---|---|
| Number of months/year operating | | 4 | Months / season / year |
| Minimum usage per year | | 291055 | #/season |
| Maximum usage per year | | 436583 | #/season |
| Chemical cost | $ | 3.00 | $/# |
| Min cost | $ | 0.873 | $M/season |
| Max cost | $ | 1.310 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 2 | Chlorine dose (mg/L) |
| | | 2,425 | Total Chlorine capacity (#/D) |
| | | 8 | Number of facilities (EA) |
| | | 303 | Capacity per facility (#/D) |
| | $ | 0.31 | Unit process cost ($M) |
| | $ | 0.03 | Yard piping ($M) |
| | $ | 0.02 | Sitework ($M) |
| | $ | 0.06 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.42 | Subtotal cost ($M) |
| | $ | 0.15 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 0.14 | Contingency ($M) |
| | $ | 0.76 | Grand total |
| 50% | $ | 1.14 | Upper bound estimate |
| -25% | $ | 0.57 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 3 | Chlorine dose (mg/L) |
| | | 3,638 | Total Chlorine capacity (#/D) |
| | | 8 | Number of facilities (EA) |
| | | 455 | Capacity per facility (#/D) |
| | $ | 0.34 | Unit process cost ($M) |
| | $ | 0.03 | Yard piping ($M) |
| | $ | 0.02 | Sitework ($M) |
| | $ | 0.07 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.46 | Subtotal cost ($M) |
| | $ | 0.16 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 0.20 | Contingency ($M) |
| | $ | 1.03 | Grand total |
| 50% | $ | 1.54 | Upper bound estimate |
| -25% | $ | 0.77 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

5b-Chlorine addition after the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 225 | CF<br>s | 7.48 | gal<br>CF | 60 | s<br>min |
| | 100980 | GPM | 145.4 | MGD | | |

**Chlorine dose estimate**

| | | |
|---|---|---|
| Minimum | 3 | mg/L |
| Maximum | 5 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum chlorine storage design w/ redundancy | 3638 | #/day |
| Maximum chlorine storage design w/ redundancy | 6064 | #/day |
| Number of storage/dosing facilities per layout | 2 | each |
| Preliminary capacity per facility MIN | 1819 | #/day |
| Preliminary capacity per facility MAX | 3032 | #/day |

| | | | |
|---|---|---|---|
| Number of months/year operating | | 4 | Months / season / year |
| Minimum usage per year | | 436583 | #/season |
| Maximum usage per year | | 727638 | #/season |
| Chemical cost | $ | 0.20 | $/# |
| Min cost | $ | 0.087 | $M/season |
| Max cost | $ | 0.146 | $M/season |

Cost estimates based on revised design conditions

| Lower limit design and costs | | | | Upper limit design and costs | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | Chlorine dose (mg/L) | | | 5 | Chlorine dose (mg/L) |
| | | 3,638 | Total Chlorine capacity (#/D) | | | 6,064 | Total Chlorine capacity (#/D) |
| | | 2 | Number of facilities (EA) | | | 2 | Number of facilities (EA) |
| | | 1,819 | Capacity per facility (#/D) | | | 3,032 | Capacity per facility (#/D) |
| | $ | 1.70 | Unit process cost ($M) | | $ | 2.39 | Unit process cost ($M) |
| | $ | 0.17 | Yard piping ($M) | | $ | 0.24 | Yard piping ($M) |
| | $ | 0.09 | Sitework ($M) | | $ | 0.12 | Sitework ($M) |
| | $ | 0.34 | Electrical and controls ($M) | | $ | 0.48 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental | | $ | - | Permitting, environmental |
| | $ | 2.30 | Subtotal cost ($M) | | $ | 3.23 | Subtotal cost ($M) |
| | $ | 0.81 | Engineering, legal, admin ($M) | | $ | 1.13 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) | | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) | 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) | | | 500 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) | 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 0.70 | Contingency ($M) | 30% | $ | 1.03 | Contingency ($M) |
| | $ | 3.85 | Grand total | | $ | 5.58 | Grand total |
| 50% | $ | 5.78 | Upper bound estimate | 50% | $ | 8.38 | Upper bound estimate |
| -25% | $ | 2.89 | Lower bound estimate | -25% | $ | 4.19 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

5b-KMnO4 addition after the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 225 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 100980 | GPM | 145.4 | MGD | | |

KMnO4 dose estimate

| | | |
|---|---|---|
| Minimum | 1 | mg/L |
| Maximum | 2 | mg/L |

Preliminary design considerations

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum KMnO4 storage design w/ redundancy | 1213 | #/day |
| Maximum KMnO4 storage design w/ redundancy | 2425 | #/day |
| Number of storage/dosing facilities per layout | 5 | each |
| Preliminary capacity per facility MIN | 243 | #/day |
| Preliminary capacity per facility MAX | 485 | #/day |

Surge tank sizing

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 145528 | #/season |
| Maximum usage per year | 291055 | #/season |
| Chemical cost | $ 3.00 | $/# |
| Min cost | $ 0.437 | $M/season |
| Max cost | $ 0.873 | $M/season |

Cost estimates based on revised design conditions

Lower limit design and costs

| | | | |
|---|---|---|---|
| | | 1 | Chlorine dose (mg/L) |
| | | 1,213 | Total Chlorine capacity (#/D) |
| | | 5 | Number of facilities (EA) |
| | | 243 | Capacity per facility (#/D) |
| | $ | 0.18 | Unit process cost ($M) |
| | $ | 0.02 | Yard piping ($M) |
| | $ | 0.01 | Sitework ($M) |
| | $ | 0.04 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.25 | Subtotal cost ($M) |
| | $ | 0.09 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 200 | Pipeline length (FT) |
| 250 $/ft | $ | 0.05 | Pipeline cost ($M) |
| 30% | $ | 0.09 | Contingency ($M) |
| | $ | 0.47 | Grand total |
| 50% | $ | 0.71 | Upper bound estimate |
| -25% | $ | 0.36 | Lower bound estimate |

Upper limit design and costs

| | | | |
|---|---|---|---|
| | | 2 | Chlorine dose (mg/L) |
| | | 2,425 | Total Chlorine capacity (#/D) |
| | | 5 | Number of facilities (EA) |
| | | 485 | Capacity per facility (#/D) |
| | $ | 0.22 | Unit process cost ($M) |
| | $ | 0.02 | Yard piping ($M) |
| | $ | 0.01 | Sitework ($M) |
| | $ | 0.04 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.30 | Subtotal cost ($M) |
| | $ | 0.10 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 400 $/ft | $ | 0.20 | Pipeline cost ($M) |
| 30% | $ | 0.15 | Contingency ($M) |
| | $ | 0.75 | Grand total |
| 50% | $ | 1.13 | Upper bound estimate |
| -25% | $ | 0.56 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

6-Chlorine addition after the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 75 | CF/s | 7.48 | gal/CF | 60 | s/min |
| | 33660 | GPM | 48.5 | MGD | | |

**Chlorine dose estimate**

| | | |
|---|---|---|
| Minimum | 3 | mg/L |
| Maximum | 5 | mg/L |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum chlorine storage design w/ redundancy | 1213 | #/day |
| Maximum chlorine storage design w/ redundancy | 2021 | #/day |
| Number of storage/dosing facilities per layout | 1 | each |
| Preliminary capacity per facility MIN | 1213 | #/day |
| Preliminary capacity per facility MAX | 2021 | #/day |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

| | | |
|---|---|---|
| Number of months/year operating | 4 | Months / season / year |
| Minimum usage per year | 145528 | #/season |
| Maximum usage per year | 242546 | #/season |
| Chemical cost | $ 0.20 | $/# |
| Min cost | $ 0.029 | $M/season |
| Max cost | $ 0.049 | $M/season |

Cost estimates based on revised design conditions

| Lower limit design and costs | | | | Upper limit design and costs | | | |
|---|---|---|---|---|---|---|---|
| | | 3 | Chlorine dose (mg/L) | | | 5 | Chlorine dose (mg/L) |
| | | 1,213 | Total Chlorine capacity (#/D) | | | 2,021 | Total Chlorine capacity (#/D) |
| | | 1 | Number of facilities (EA) | | | 1 | Number of facilities (EA) |
| | | 1,213 | Capacity per facility (#/D) | | | 2,021 | Capacity per facility (#/D) |
| | $ | 0.65 | Unit process cost ($M) | | $ | 0.91 | Unit process cost ($M) |
| | $ | 0.07 | Yard piping ($M) | | $ | 0.09 | Yard piping ($M) |
| | $ | 0.03 | Sitework ($M) | | $ | 0.05 | Sitework ($M) |
| | $ | 0.13 | Electrical and controls ($M) | | $ | 0.18 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental | | $ | - | Permitting, environmental |
| | $ | 0.88 | Subtotal cost ($M) | | $ | 1.23 | Subtotal cost ($M) |
| | $ | 0.31 | Engineering, legal, admin ($M) | | $ | 0.43 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) | | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) | 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) | | | 1,000 | Pipeline length (FT) |
| 250 $/ft | $ | 0.13 | Pipeline cost ($M) | 400 $/ft | $ | 0.40 | Pipeline cost ($M) |
| 30% | $ | 0.30 | Contingency ($M) | 30% | $ | 0.49 | Contingency ($M) |
| | $ | 1.61 | Grand total | | $ | 2.55 | Grand total |
| 50% | $ | 2.42 | Upper bound estimate | 50% | $ | 3.83 | Upper bound estimate |
| -25% | $ | 1.21 | Lower bound estimate | -25% | $ | 1.92 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.

AECOM

# Process and cost estimate calculations

Engineer: A. Mofidi
Date April 27, 2016

United Water Conservation District
Quagga Control Treatment alternatives

6-KMnO4 addition after the Moss Screen

| | | | | | | |
|---|---|---|---|---|---|---|
| Flow | 75 | CF / s | 7.48 | gal / CF | 60 | s / min |
| | 33660 | GPM | 48.5 | MGD | | |

**KMnO4 dose estimate**

| | | |
|---|---|---|
| Minimum | 1 | mg/L |
| Maximum | 2 | mg/L |

**Surge tank sizing**

| | | |
|---|---|---|
| Minimum flow capture | 0 | min |
| Maximum flow capture | 0 | min |
| Minimum volume | 0 | Gal |
| Maximum volume | 0 | Gal |
| Minimum roundup sizing | - | Gal |
| Maximum roundup sizing | - | Gal |

**Preliminary design considerations**

| | | |
|---|---|---|
| Design redundancy | 1.25 | |
| Minimum KMnO4 storage design w/ redundancy | 404 | #/day |
| Maximum KMnO4 storage design w/ redundancy | 808 | #/day |
| Number of storage/dosing facilities per layout | 2 | each |
| Preliminary capacity per facility MIN | 202 | #/day |
| Preliminary capacity per facility MAX | 404 | #/day |

| | | | |
|---|---|---|---|
| Number of months/year operating | | 4 | Months / season / year |
| Minimum usage per year | | 48509 | #/season |
| Maximum usage per year | | 97018 | #/season |
| Chemical cost | $ | 3.00 | $/# |
| Min cost | $ | 0.146 | $M/season |
| Max cost | $ | 0.291 | $M/season |

Cost estimates based on revised design conditions

**Lower limit design and costs**

| | | | |
|---|---|---|---|
| | | 1 | Chlorine dose (mg/L) |
| | | 404 | Total Chlorine capacity (#/D) |
| | | 2 | Number of facilities (EA) |
| | | 202 | Capacity per facility (#/D) |
| | $ | 0.07 | Unit process cost ($M) |
| | $ | 0.01 | Yard piping ($M) |
| | $ | 0.004 | Sitework ($M) |
| | $ | 0.01 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.10 | Subtotal cost ($M) |
| | $ | 0.03 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.0 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 500 | Pipeline length (FT) |
| 250 $/ft | $ | 0.13 | Pipeline cost ($M) |
| 30% | $ | 0.07 | Contingency ($M) |
| | $ | 0.32 | Grand total |
| 50% | $ | 0.48 | Upper bound estimate |
| -25% | $ | 0.24 | Lower bound estimate |

**Upper limit design and costs**

| | | | |
|---|---|---|---|
| | | 2 | Chlorine dose (mg/L) |
| | | 808 | Total Chlorine capacity (#/D) |
| | | 2 | Number of facilities (EA) |
| | | 404 | Capacity per facility (#/D) |
| | $ | 0.08 | Unit process cost ($M) |
| | $ | 0.01 | Yard piping ($M) |
| | $ | 0.004 | Sitework ($M) |
| | $ | 0.02 | Electrical and controls ($M) |
| | $ | - | Permitting, environmental |
| | $ | 0.11 | Subtotal cost ($M) |
| | $ | 0.04 | Engineering, legal, admin ($M) |
| | $ | - | Added in-river access ($M) |
| 1.2 $/Gal | $ | - | Water surge tank cost ($M) |
| | | 1,000 | Pipeline length (FT) |
| 400 $/ft | $ | 0.40 | Pipeline cost ($M) |
| 30% | $ | 0.15 | Contingency ($M) |
| | $ | 0.70 | Grand total |
| 50% | $ | 1.06 | Upper bound estimate |
| -25% | $ | 0.53 | Lower bound estimate |

AAM 4/27

Notes: Cost estimates based upon USEPA treatment cost estimating procedures, using December 2015 updated Engineering News Record Construction Cost Index numbers.