DRAFT FOR FINAL REVIEW

Manual for the Control, Operation and Maintenance of Zebra Mussels

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Manual for the Control, Operation, and Maintenance of Zebra Mussels

FINAL

Prepared for:
City of Denton

Prepared by:
Arcadis US, Inc.
12400 Coit Road
Suite 1200
Dallas
Texas 75251
Tel 972 934 3711
Fax 972 934 3662

In coordination with:
Robert McMahon, PhD
Barry Payne, PhD

Our Ref.:

05673009.0000

Date:

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ARCADIS Design & Consultancy for natural and built assets

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Purpose and Background

The City of Denton (COD) has two raw water systems supplying the Lake Lewisville Water Treatment Plant (LLWTP) and the Ray Roberts Water Treatment Plant (RRWTP) raw water systems that are at risk for zebra mussel fouling. Zebra mussels (*Dreissena polymorpha*) are an invasive species that can cause fouling of water handling facilities (e.g., intake, racks, screens, pipelines, pumps, dam releases, gates, etc.) that are located in or transmit water from potentially infested water sources as well as contribute to changes in source water quality that can affect operations. This fouling is caused by the accumulation of adult mussels that attach to the surface of structures and to each other. The Asian clam is another invasive species that was observed during this project that can collect and grow in water facilities. With continuous flows to provide a constant food and oxygen source, intake structures, piping and other raw water appurtenances are an ideal habitat for mussel proliferation. Once an infestation has occurred, zebra mussels can build a layer up to six inches thick, severely constricting flows and clogging pumps, screens and filters. In addition, zebra mussel infestations may adversely affect the ecosystem and water quality.

The RRWTP raw water system has already been impacted by zebra mussels. In early 2014, the COD discovered that the 60" raw water pipeline downstream of Ray Roberts Lake was 70% clogged with mussels at a low point. Although the COD LLWTP Intake is not currently infested, the Upper Trinity Regional Water District has observed a sustainably reproducing zebra mussel population at their intake near the Lake Lewisville Dam, a heavy settlement of mussels was observed in the Elm Fork arm of Lake Lewisville following the 2015 flooding, and zebra mussels have been observed downstream in the Elm Fork of the Trinity River. To prepare for the likely spread of mussels to the LLWTP raw water system and develop methods to ease future cleaning events in COD raw water systems, the COD commissioned the development of a Manual for the Control, Operation and Maintenance of Zebra Mussels (Manual).

Goal

The *overarching* goal of this Manual is to develop zebra mussel management approaches that balance the risk of future infestations with capital spending and potential unintended downstream consequences.

Introduction

The management, operation and maintenance approaches recommended in the Manual consider the following:

- **Source water quality** including seasonal water quality changes and the variability of water quality at each structure
- **Physical characteristics** of each structure to assess the susceptibility to fouling and the potential impact of fouling on individual components, accessibility, level of security, proximity to the public, the floodplain elevation and the potential to reuse existing equipment and facilities
- **Hydraulics** including pipeline velocities, capacities and detention times, potential hydraulic capacity reductions due to an infestation and the potential to alternate pipeline or source water use to optimize zebra mussel management
- **Operational impacts** including consideration of required labor hours, current daily operational activities and annual operations and maintenance costs
- **Capital Costs and O&M Costs** were evaluated and compared to understand the true costs of various options and alternatives identified
- **Public perception** including the selection of publically accepted technologies and avoidance of adverse environmental and/or ecological impacts
- **Operation of downstream water treatment plants** including water quality goals, seasonal trends in customer demands, seasonal operating practices, planned process changes, unintended consequences, and the potential for management approaches to provide pre-treatment
- **Zebra mussel biology and ecology** including local growth and progression rates, water conditions favorable to zebra mussel settlement, and equipment and materials especially susceptible to fouling
- **Planned future improvements** to raw water handling facilities including opportunities for optimization of future projects for zebra mussel management
- **Current and potential future regulations** at the local, state and national level
- **Risk reduction** strategies that balance capital spending with minimizing future risks (e.g., capacity reductions due to fouling) such as selection of proven technologies and monitoring.

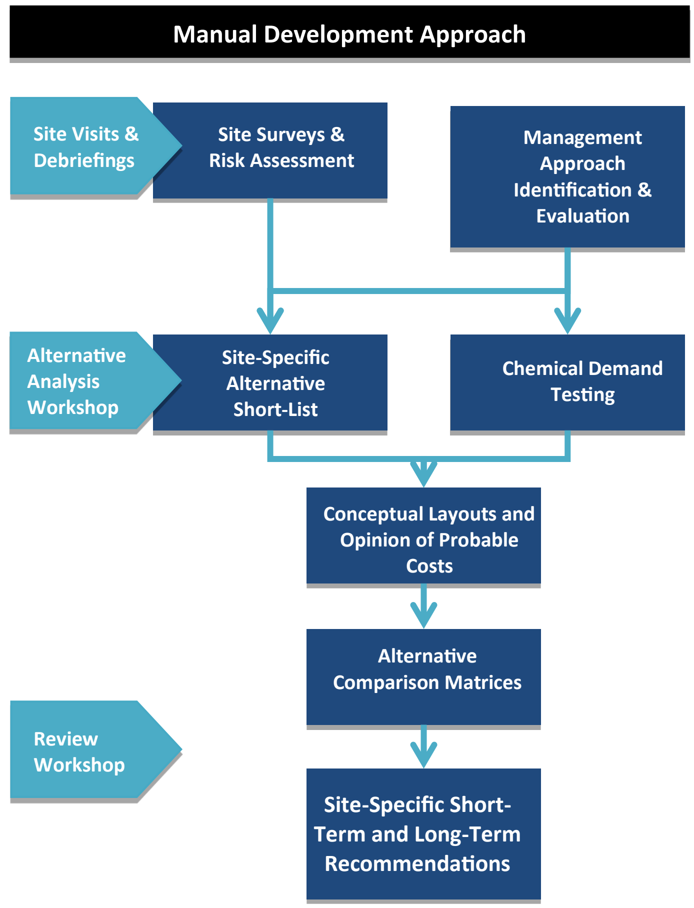
Forming the Right Team

To address the multi-dimensional O&M considerations, a multi-disciplinary team including an academic professor and a retired USACE expert brought a unique perspective to this evaluation – an understanding of the synergy of zebra mussel biology, potential unintended consequences, institutional knowledge of management approaches, and the engineering aspects of the system to be protected. The team also included a technical advisor with years of experience evaluating, designing and managing zebra mussels in the Great Lakes region. Additionally, numerous COD staff were involved throughout this project by participating in site visits and workshops and reviewing the Manual.

Manual Development Approach

Site surveys were conducted for both of the COD's two raw water systems. Site surveys included both desktop design document review and field visits, during which the team gained a greater understanding of what components are at most risk for fouling. Through site surveys, the team gained an understanding of how the systems are operated seasonally to meet customer demands and water quality goals, unique water quality and operational challenges of each intake, and what the potential impact of a mussel infestation at either intake would be on the system as a whole. A **risk assessment** was conducted to rank the overall relative risk to the raw water facilities and to provide information/notification of potential impacts. Lastly, a list of **potential future improvements**, including a summary of benefits and risks to future zebra mussel management, was developed .

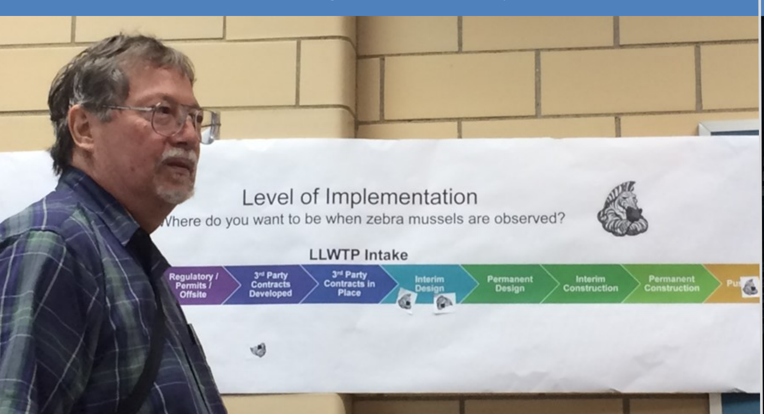
In parallel, a review of zebra mussel **management approaches** was conducted, including both innovative and conventional technologies. Evaluations of alternatives were conducted for each site on a component-by-component basis while maintaining a system-wide approach that considered operational impacts to the downstream treatment plants and distributions system. During the **Alternatives Analysis Workshop**, COD staff ranked evaluation criteria and selected alternatives for further evaluation. **Chemical demand testing** was conducted to increase the accuracy of cost estimates and better understand the feasibility of implementation of the selected chemicals in the COD raw water systems.



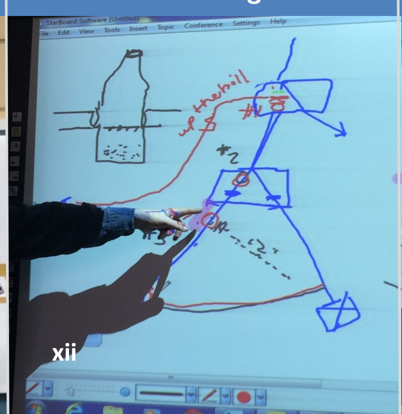
Conceptual layouts and costs were then developed for the top two preventative alternatives in addition to a reactive approach (i.e., physical removal and disposal), and **comparison matrices** were developed to compare the top alternatives. **Recommendations** for multi-barrier management approaches within both raw water systems were developed including the following:

- Short and long-term capital improvements,
- Monitoring and inspection guidelines,
- Operations and maintenance guidelines, and
- Risk management approaches.

Alternatives Analysis Workshop



Debriefings



Chemical Demand Testing

Risk Considerations

Key **risk review** considerations included:

- **Likelihood of infestation** - based on current water quality data (temperature, pH, Ca and DO) and location of current zebra mussel infestations
- **Potential impact to the COD** - considered both the susceptibility to fouling and risk to COD operations in the case of fouling

Risk Analysis Results

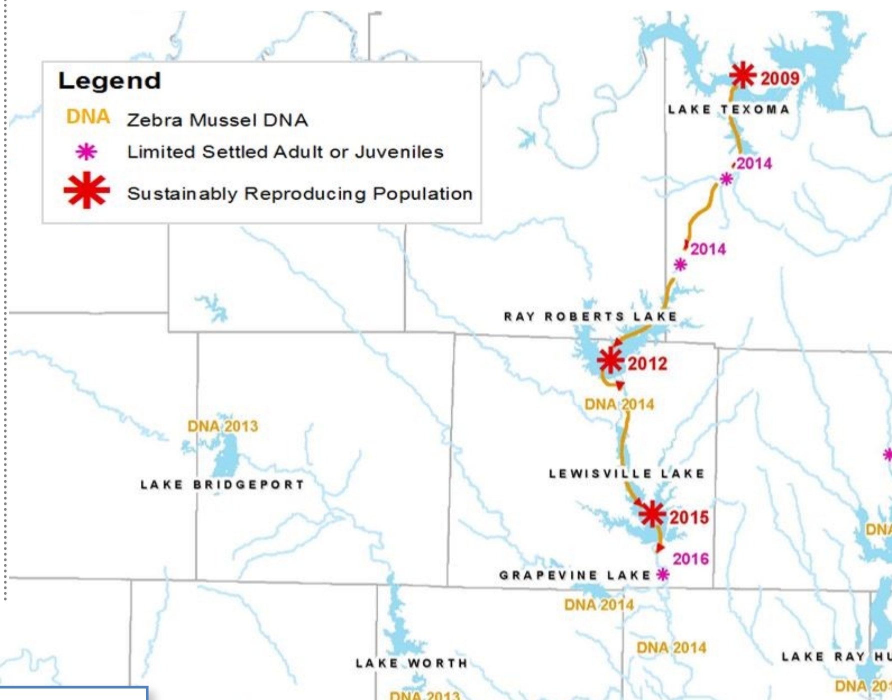
Site	Likelihood of Infestation	Potential Impact to COD	Overall Risk
LWLTP Intake	HIGH	HIGH	HIGH
RRWTP Intake	INFESTED	HIGH	EXTREMELY HIGH

Components with the Greatest Risk

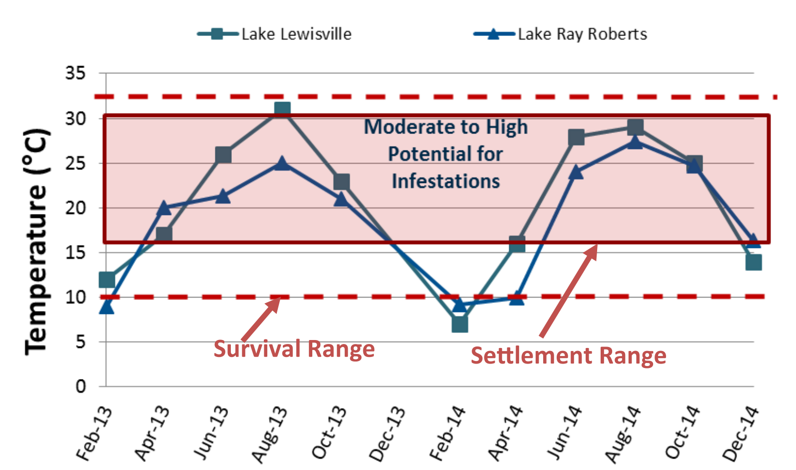
The following components were classified as the greatest risk for infestation:

Site	Component	Primary Reason
RRWTP Intake	Low point in 60-inch line	Shell accumulation
	Lagoon recycle line	Small diameter; potential headloss
	Fish strainer	Small openings; potential headloss
	Valves	Very susceptible to fouling
LLWTP Intake	Upper intake	No redundancy; only 36" diameter; favorable environment within the lake for settlement
	Bar screens	Small openings; potential headloss
	Solution water line for $KMnO_4$	Small diameter (1.5-inches); potential headloss
	Valves	Very susceptible to fouling
	Wet well	Shell accumulation; pump clogging

The team classified both of COD's raw water systems as high potential impact, meaning they are susceptible to fouling due to the presence of many hard surfaces with small openings (i.e. trash racks, gates, screens, pipelines) and would pose a significant risk to COD operations if flow was constricted. Both of COD's source waters were also classified as having a high likelihood of infestation due to water quality generally conducive to settlement. Thus, the LLWTP Intake was classified as high overall risk and the RRWTP Intake was classified as extremely high overall risk due to the prior infestation.

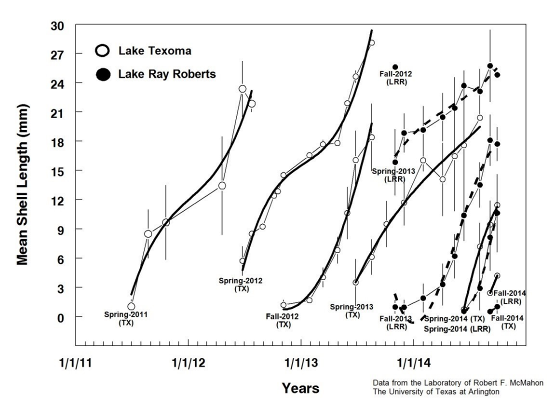


Temperature in COD Source Waters from 2013-2014



March – July and August–December are the most likely seasons, locally, for zebra mussel propagation.

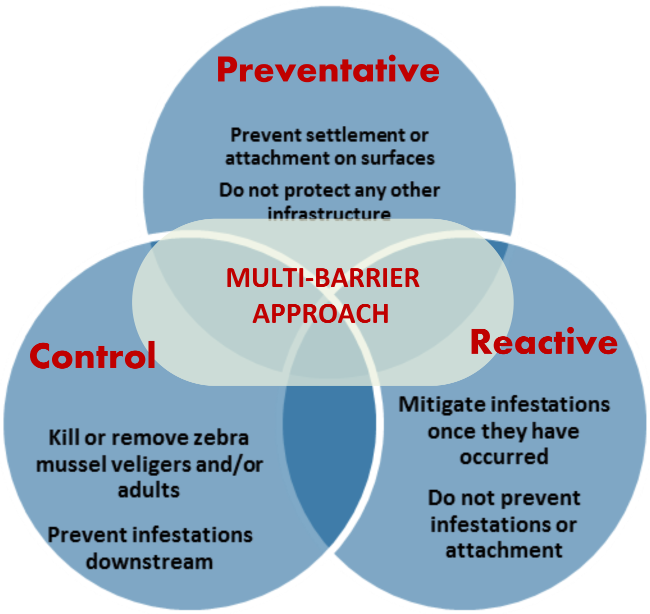
Based on ongoing research conducted by project team member Dr. Bob McMahon, zebra mussel populations in North Texas exhibit more rapid growth, earlier maturity and shorter life spans compared to those in the Great Lakes region.



See Manual Section 2 for more information.

Management Approaches

A review was conducted to identify and evaluate zebra mussel management approaches, which would also be effective at controlling Asian clams. Mussel management approaches can be classified as preventative, control, reactive strategies, or a combination thereof. For example, a management approach might include an oxidant which can prevent settlement of veligers when low doses are maintained through the system (i.e. a preventative strategy) and kill adult mussels at a higher dose (i.e. a control strategy), as well as provisions for physical removal and disposal (i.e. a reactive strategy).



During the Alternatives Analysis Workshop, preventative, control and reactive strategies were discussed. Considerations related to feasibility of each potential management approach for COD, such as effectiveness and operational impacts, were derived from discussions with the technical advisors for this project, discussions with vendors, and a review of available literature, as well as the results of site visits and reviews to understand the design and operation of the COD facilities at risk for zebra mussel fouling. COD staff then scored each strategy based on the level of feasibility for implementation in the COD system.

Upon completion of chemical demand testing (conducted in April and June of 2015) and further evaluation of copper alternatives, COD staff further narrowed the short-list of chemical alternatives by selecting the top two most feasible chemicals for further evaluation. The short-list of alternatives included metal alloys, sodium permanganate, copper ion generation systems and physical removal using divers or by dewatering pipelines. An evaluation of disposal methods was also completed and landfilling was recommended.

Preventative Strategies	Control Strategies	Reactive Strategies
• Molluscicides (see below) • Metal Alloy Materials of Construction or Coatings • Foul-Release Coatings • Anti-Fouling Coatings • Maintenance of High Velocities	• Molluscicides (see below) • Strainers and Screens • Biological Treatment • Bank or Sand Filtration • UV Light • Acoustics • Electric Shock / High Voltage • Electric / Low Voltage Electric Magnetism • Copper Ion Generation Systems	• Physical Removal: ✓ Physical Scraping and Power Washing with Divers ✓ Pipe Pigging ✓ Physical Scraping and Power Washing of Dewatered Pipes • Oxygen Deprivation • Dewatering / Desiccation • Thermal Exposure

Molluscicides Evaluated as Preventative & Control Strategies		Disposal
Oxidants: • Chlorine (Hypochlorite and Chlorine gas) • Chloramines • Chlorine Dioxide • Sodium Permanganate • Potassium Permanganate • Hydrogen Peroxide • Ozone • Bromine • Peracetic Acid	**Non-Oxidants:** • Cationic Polymer • Quaternary & Polyquaternary Ammonium Compounds (e.g. Bulab 6002, Calgon, Veligon) • Aromatic Hydrocarbons (e.g. Mexel 432, Bulab 6009) • Endothall (e.g. EVAC) • Potassium Compounds (e.g. potash, potassium chloride) • Copper Sulfate	• Landfill • On-Site Burial • Leave-in-Place • Composting • Other Beneficial Uses

Key:
- Alternatives Selected for Further Evaluation
- Alternatives Selected for Detailed Comparison with Quantitative and Qualitative Evaluation Criteria

Evaluation Criteria:

- Life Cycle Cost (Capital &Operations & Maintenance)
- Effectiveness for Zebra Mussel Control
- Ease of Operation & Maintenance & Operational Flexibility
- Impact to Downstream Water Quality & Water Treatment Plant
- Impact to Environment / Ecology
- Implementability
- Health & Safety
- Status in the Industry / Record of Performance
- Public acceptability

See Manual Section 3.1 for more information.

Operations & Maintenance Guidelines

A multi-barrier zebra mussel management approach should include enhancing daily operational activities, improving designs to ease maintenance activities, optimizing chemical dosing strategies, and initiating programs to manage future risks.

See Manual Section 3.2 for more information.

Operational and Maintenance Enhancements

O&M enhancements that will optimize zebra mussel management are outlined below. These are not intended to be stand-alone approaches to managing zebra mussels. However, they are good practices that give operators a second level of management. For example, if a trash rack were being reconstructed in stainless steel to allow for application of a metal alloy coating, the reconstruction could include increased opening sizes to prevent clogging with mussels and a means for removing the trash racks for cleaning and coating replacement.

Operational Enhancements

- Operate all moving equipment frequently
- Clean trash racks and screens frequently
- Isolate and dewater components during shutdowns or maintenance to desiccate any attached mussels
- Clean silt away from gates and screens to allow operation and rakes to fully clean components
- Alternate pipeline use when parallel pipelines are available to allow for oxygen deprivation (may require flushing anoxic water)

Maintenance Enhancements

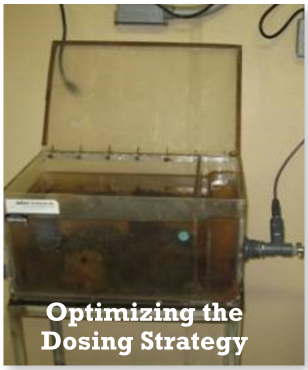
- Include redundant or oversized pipelines
- Replace stationary screens with travelling screens
- Design trash racks with 6 inch or greater openings
- Design removable bar screens and trash racks to ease cleaning
- Include pressure washing or pigging stations
- Allow for isolation of components (e.g. replace any leaky or non-functioning gates)

Chemical Dosing Strategies

Dosing strategies to manage zebra mussels using chemicals in raw water systems include prevention (i.e. continuous or semi-continuous treatment) and control / reaction approaches (end-of-settlement season or periodic treatment). Determining which approach to use depends on specifics of the facility's raw water system, the level of management required and the management approach selected. Regardless of the dosing strategy, a **biological monitoring program** should be implemented as a feedback mechanism to allow for adjustments in timing and dosing of the chemical. Specific chemical dosing recommendations for the copper ion generation system and sodium permanganate are provided.

Copper Ion Generation Dosing Strategy

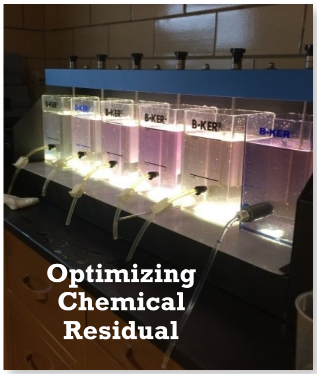
Copper ion generation technology produces positively charged copper ions which are toxic to mussels and aluminum hydroxide floc which coat pipe surfaces and immobilize veligers. The following dosing strategies should be implemented.



- **Optimize the Dose –** The manufacturers recommend copper and aluminum doses of approximately 5 and 0.05 ppb (during settlement) and 2 and 0.02 ppb (during non-settlement seasons), respectively. Conductivity, temperature and total suspended solids data should be provided to the system PLC to improve accuracy of the calculated dose, and mussel settlement should be evaluated at the farthest point in the system requiring protection to optimize the dose.
- **Optimize the Dosing Frequency –** The manufacturer recommends a continuous dosing strategy; idling of the cells without flow is not recommended.
- **Monitor for Settlement –** Application of the higher chemical dose to prevent mussel settlement need only occur during months when mussel veliger larvae are present in the water column, which is approximately 4-5 months of the year compared to the 8 months of the year when the temperature is favorable for settlement.

Sodium Permanganate Dosing Strategy

The molluscicidal properties of sodium permanganate centers on its capacity to oxidize biological organic compounds in living cells, leading to loss of function and eventually death. The following dosing strategies should be implemented.



- **Optimize the Dose –** A target permanganate residual of approximately 0.25 mg/L must be maintained throughout the entire system to effectively protect against zebra mussel fouling. Demand of the local water quality was considered in order to determine approximate chemical doses required for COD source waters. However, the required dose will change throughout the year as the water quality changes and should be monitored by measuring the chemical residual and monitoring for mussel settlement at the farthest point in the system requiring protection.
- **Optimize the Dosing Frequency –** It is recommended, based on previous project experience, that COD begin by applying a semi-continuous dosing strategy (e.g. 30 minutes on and 90 minutes off) to balance mitigation of zebra mussel veliger settlement with minimizing chemical costs. Continuous dosing may have added value if a consistent influent water quality to the plant or pre-oxidation is desired. The dosing strategy should be optimized after start-up by monitoring the chemical residual and using biological monitoring techniques.
- **Monitor for Settlement –** Application of the higher chemical dose to prevent mussel settlement need only occur during months when mussel veliger larvae are present in the water column, which is approximately 4-5 months of the year, compared to the 8 months of the year when the temperature is favorable for settlement.

Risk Management Strategies

Both of the COD's raw water intakes are currently at risk for future zebra mussel infestations if preventative measures are not in place as the RRWTP has already experienced a zebra mussel infestation and a heavy settlement of zebra mussels was identified this year in the Elm Fork arm of Lake Lewisville. However, considering that the long-term density of zebra mussels in either of these source waters is unknown combined with the short zebra mussel life spans (approximately one year), fast growth rates and two settlement seasons per year observed in North Texas, it may be difficult to get a permanent chemical feed system designed, bid and constructed before another severe infestation in one of the COD raw water systems. Other utilities in the past have balanced capital investment with risk of reduced hydraulic capacity or public confidence by developing a number of risk management strategies.

1. **Implement a robust monitoring program –** Expanding upon the current COD raw water monitoring program is recommended to allow for more accurate estimates of how quickly and frequently management measures are required (i.e. to act as an early warning system in optimizing the selected management approach). Monitoring methods used by other utilities include: information gathering / collaboration, water quality monitoring (e.g. pH, temperature and calcium), veliger monitoring with plankton nets, substrate samplers, direct site inspections and control validation with sidestream bioboxes.

2. **Design permanent chemical systems but do not construct –** "Pre-designing" systems reduces the implementation time by six months to a year, which is critical given that zebra mussel infestations have been noted to occur in less than 1.5 years. The frequently cited downside of this approach is the risk that the designs will lose viability over time if changes are made to the facilities. However, pre-designing the systems in advance allows for thoughtful input by operations personnel in a non-emergency situation, while designing after an infestation will naturally prioritize response speed over operational input.

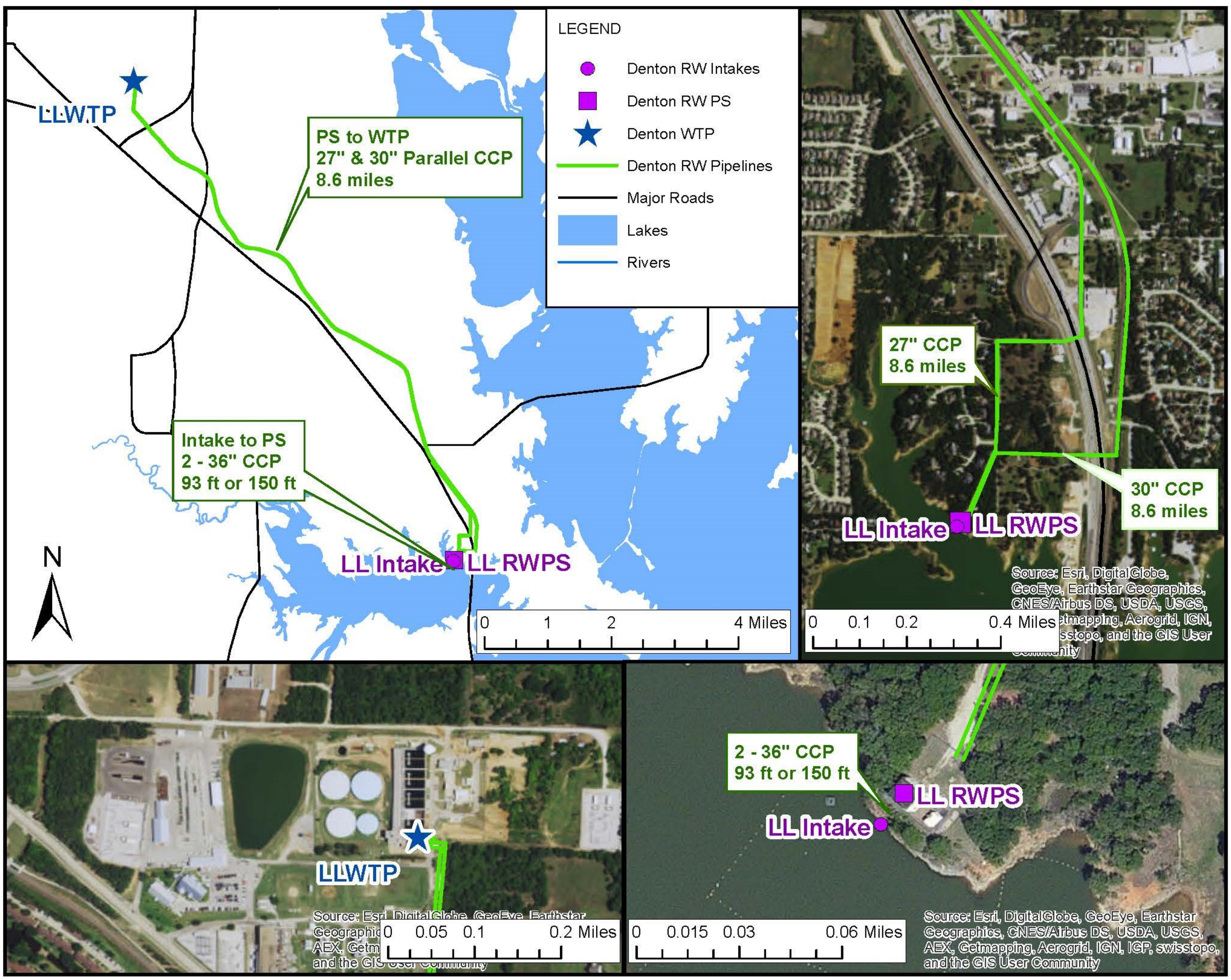
3. **Interim chemical systems –** Temporary chemical feed systems might include piping routed overland with temporary secondary containment from the back of the container on a truck or from rented tanks and could include temporary diffuser systems. Temporary systems can be installed quickly to provide some degree of protection during the design and construction of permanent facilities. Pre-designing these systems along-side permanent designs would allow for optimization of capital expenditures (i.e. identification of equipment which could be reused in permanent systems). An interim chemical system, as discussed here, would also provide the opportunity to implement demonstration testing (additional data on oxidant demand and the effectiveness of the chemical dosed in this source water).

4. **On-call contracts –** On-call contracts allow for rapid mobilization of contractor forces and can be bid ahead of a zebra mussel infestation on an annual or multi-year basis. On-call contracts can be prepared separately, or in combination, for monitoring, inspection and cleaning services. On-call contracts should provide the detail necessary to allow lump sum bidding of the services listed above at a subset of or at all of the facilities and would put the winning contractor on standby to perform those services within a predetermined period of time after being notified of the need for the services.

LLWTP Overview

The LLWTP is the largest of the two COD water treatment plants. The plant was originally constructed in 1957 but has been upgraded several times in 1964, 1972 and 1988 to the current capacity of 30 MGD. Average flows are approximately 8.4 MGD while minimum flows are approximately 5 MGD. A major improvements project just finished construction in 2015 that included addition of ozone and biologically active filtration to the treatment plant.

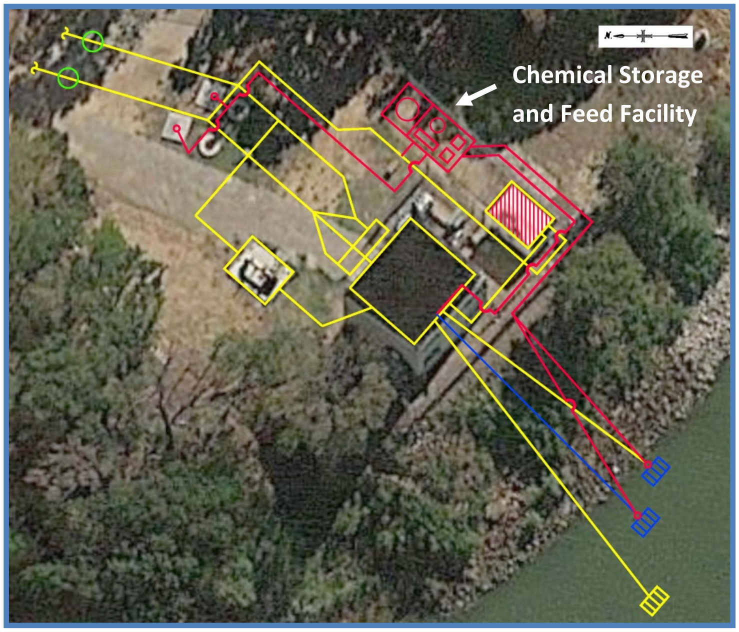
The LLWTP Intake provides water from Lake Lewisville to the wet well through two 36” prestressed concrete cylinder pipe (PCCP) raw water lines with bar screens, also referred to as the lower and upper intakes, located at elevations of 480 ft and 505 ft, respectively. From the RWPS, which includes an existing potassium permanganate storage and feed system and four vertical enclosed-line pumps, water is pumped to the LLWTP through two parallel concrete raw water lines (one 27-inch and one 30-inch). The total distance from Lake Lewisville to the LLWTP is approximately 8.6 miles.

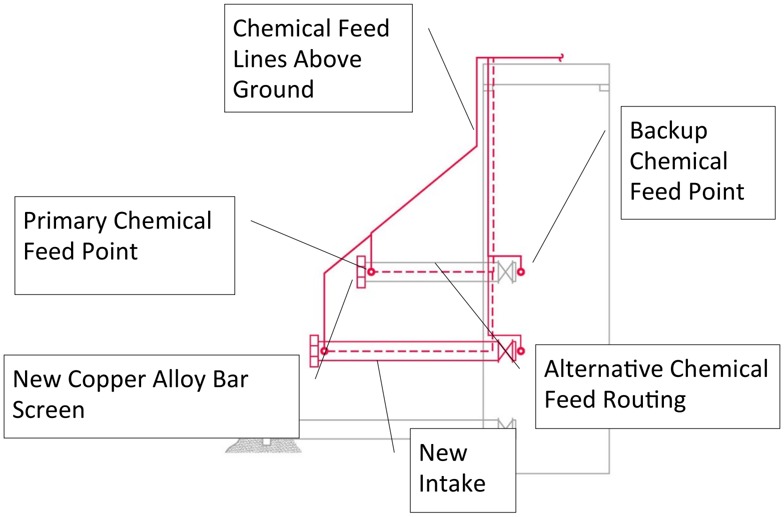


LLWTP Capital, Operations and Maintenance Recommendations

Primary recommendations include rebuilding the upper intake bar screen in copper alloy along with a redesign to make the screen removable, and adding chemical immediately after the bar screen to protect all downstream components including the RWPS. Chemical facilities will be located to the north-east of the existing permanganate building. Two-chemical systems using common piping and feed system components provide redundancy without a significant increase in cost, and are common in zebra mussel management strategies employed in the Great Lakes region. The ability to utilize an alternate system to reduce the impact of system limitations or when the primary system is not operating due to maintenance, will provide the LLWTP with a robust preventative zebra mussel management strategy. Additional commendations include manway installations, operating pumps and valves frequently, and risk management strategies (e.g. monitoring and inspections).

Probable Costs	Recommendations
Probable **Capital Improvement** Cost: $ 2,360,000 Probable **Engineering and Construction Administration** Fee: $ 480,000	• Rebuild bar screen in copper alloy • Install a copper ion system (based upon plant flow) • Install a sodium permanganate storage and feed system (based on design dose of 5.5 mg/L) • Minor manway improvements for physical removal and disposal access especially at pipeline low points
Probable Annual **Operations & Maintenance** Cost: $ 99,000—$ 147,000	• Light physical removal and disposal, as required (e.g. bar screen power washing) • During settlement season, feed copper ions at a dose of 5 ppb copper (2 ppb year-round) or sodium permanganate at an average dose of 3.5 mg/L (range of 1.5-5.5 mg/L) • Operate pumps and valves frequently • Isolate and dewater structures (e.g. wet well) during plant shutdowns (lower water level if dewatering not possible) • Alternate pipeline use, when possible
Risk Management Recommendations	• Increase monitoring to include additional water quality, substrate sampler and veliger monitoring at minimum • Visually inspect debris from the bar screen(s). Also visually inspect any dewatered surfaces during maintenance activities • Develop a plan for interim chemical feed using the existing potassium permanganate system • Implement on-call contracts, begin regulatory coordination and develop new SOPs





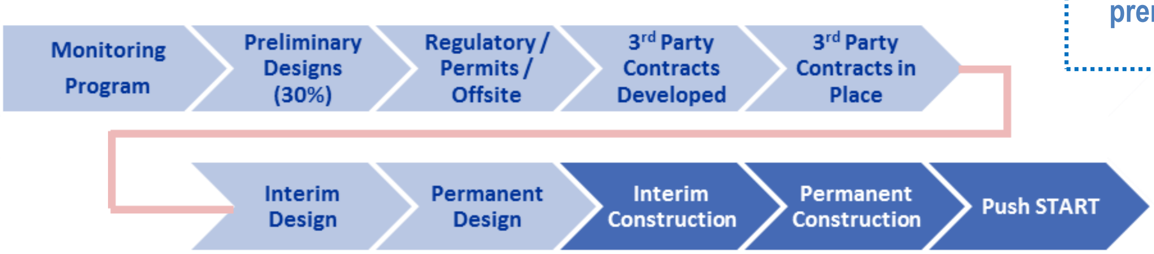
LLWTP Recommended Next Steps

The previous RRWTP raw water system zebra mussel infestation and recent heavy juvenile zebra mussel settlement in Lake Lewisville lead to the recommendation that the COD proceed proactively with actions to better prepare for future zebra mussel infestations of the LLWTP raw water system. As the LLWTP raw water facilities are susceptible to fouling, and zebra mussel infestations would pose significant risk to COD operations, a proactive program to manage risk is recommended for immediate implementation. Key recommendations include:

- Applying monitoring and inspection techniques to input information into the decision-making process;
- Developing a multi-barrier approach to zebra mussel management; and
- Optimizing O&M activities, which can significantly reduce future impacts with minimal capital investment.

However, the recommended capital improvements do not need to be constructed immediately. There are a number of proactive actions COD can initiate to prepare for potential future infestations of the LLWTP Intake without spending capital funds prematurely. Develop a response plan to initiate further steps to provide zebra mussel protection (e.g. confirm the trigger for constructing interim and permanent improvements).

There are a number of proactive actions the COD can initiate to prepare for potential future infestations without spending excessive capital prematurely.



Key:
- Short-Term Action Items
- Initiate Upon Mussel Observance

Group activities during workshops highlighted the need to balance future risks by sufficiently preparing but not over-preparing for a mussel infestation. The timeline above summarizes recommendations for the timing of completion of each preparation stage.

Develop and Initiate a Response or Strategic Plan:

Develop a Zebra Mussel Monitoring SOP

Increased biological monitoring should begin immediately to maximize the amount of time to respond and prevent future potential infestations. Consider hiring and/or training staff members to perform zebra mussel monitoring (i.e. veliger, settlement and adult identification) at both intake locations. Update the monitoring plan annually based upon a review of trended data collected through the monitoring effort. Following implementation of any molluscicides, the SOP should provide procedures for modifying the site's monitoring program for chemical feed optimization including the use of chemical residual monitors and bioboxes in the intake and at the point farthest downstream in the system where protection is required.

[See Manual Sections 4.3.1.1 & 4.3.2.1]

Begin Regulatory Coordination

Zebra mussel management will require coordination with multiple regulatory agencies throughout the planning, design, and construction phases of the project. Which agencies are involved depends on the selected zebra mussel management approach and the application, but the following regulatory focus items should be addressed in the near term:

- Send design documents for new chemical improvements to TCEQ for review and approval
- Make arrangements with TPWD and US FWS for native mussel surveys, if required
- Coordinate with USACE on required permits and follow up on the new easement agreement

[See Manual Sections 2.6 & 4.3.2.2]

LLWTP Recommended Next Steps

Develop On-Call Contracts for Physical Removal and Disposal

It is recommended that COD proactively develop an on-call contract for cleaning and disposal of mussels. On-call contracts generally require the contractor to coordinate disposal in accordance with all regulations. Develop on-call contracts (or price agreements) for inspecting facilities for zebra mussels and cleaning mussel infestations from facilities. On-call contracts should include detailed drawings and specifications that consider the lessons learned from the RRWTP zebra mussel cleaning event .

[See Manual Sections 2.4, 3.2.3.4 & 4.3.2.3]

Assess Acceptable Impacts and Evaluate Access

Consider potential hydraulic losses due to zebra mussels and/or Asian clams, potential disposal efforts associated with disposal of shells and evaluate access points for physical removal of shells.

- Determine the level of allowable reduced hydraulic capacity before cleaning is necessary
- Consider the maximum volume of mussels that should be allowed to accumulate before removal
- Consider executing inspection on-call contracts including CCTV assessments
- Evaluate locations for maintenance access points for zebra mussel and/or Asian clam removal, especially at low points

[See Manual Section 4.3.2.4]

Coordinate Disposal

Based on a review of the alternatives, landfilling is recommended to minimize capital costs and future risks associated with alternative disposal approaches. It is assumed that the COD landfill, which was used to dispose of mussels from the RRWTP raw water system, will be used for the LLWTP. If a different landfill will be used, there may be additional testing and regulatory requirements. Verify that testing completed previously with mussel samples from Lake Ray Roberts is sufficient for approval of future mussels removed from the LLWTP raw water system, and review easement and access agreements to ensure ability to access all raw water lines in the case that physical removal is required.

[See Manual Sections 2.4, 3.2.3.4 & 4.3.2.5]

Develop an Interim Chemical Feed Plan

Develop a plan for using the existing potassium permanganate system to provide some level of zebra mussel management in the case that an infestation occurs before a permanent system is constructed. Detailed recommendations for increasing the permanganate feed are provided in section 4.3.1.2 and recommendations for increased monitoring and inspections are provided in section 4.3.1.1. The interim design should include the necessary monitoring equipment (e.g. residual monitors and bioboxes) to optimize the chemical dose and frequency required. Consider completing additional testing of a higher chemical dose in coordination with the recommended increased monitoring (i.e. manganese, ORP and pH profiles) prior to an infestation to troubleshoot any downstream consequences (e.g. increased turbidity or colored water).

[See Manual Sections 4.3.1.1, 4.3.1.2 & 4.3.2.6]

Develop New Chemical System Design Documents

As settled zebra mussels have been identified in Lake Lewisville, begin development of design documents for the selected alternative. If construction will be completed immediately, complete 100% design documents. Otherwise, 60 or 90% design documents could be developed to minimize the time to complete design prior to future construction without sacrificing the value of designs decreasing as they sit on the shelf. The design should balance dual-water quality benefits with downstream treatment challenges and include developing chemical dosing SOPs, protection of all small diameter pipelines, and redundancy of equipment.

[See Manual Sections 4.2.1, 4.3.1 & 4.3.2.7]

Develop a Manganese SOP

With sodium permanganate (or potassium permanganate for interim feed) implementation, a manganese standard operating procedure (SOP) should be developed. If not properly monitored and managed, permanganate can result in increased manganese concentrations (potentially above the 0.05 mg/L MCL) in the treatment stream, which in turn can lead to colored water events. It should be noted that although development of a manganese management procedure is recommended, many utilities (e.g. City of Oregon, OH, City of Toledo, OH and City of Raleigh, NC) have used permanganate doses of 2-4 mg/L without any noticeable resulting manganese water quality impacts.

[See Manual Sections 4.3.1.1 & 4.3.2.8]

Monitor Copper and Aluminum

Copper removal via downstream processes should be verified to ensure compliance with regulations and assess impacts on distribution system copper and lead control, understanding that regulations generally become more stringent over time. Aluminum should also be monitored and assessed. Due to the limited information available and limited full-scale municipal installations for zebra mussel control, a sidestream biobox pilot study could be performed prior to installation of a copper ion alternative to verify efficacy in COD source waters. Additionally a performance guarantee of zebra mussel settlement prevention could be requested from the manufacturer.

[See Manual Section 4.3.2.9]

RRWTP Overview

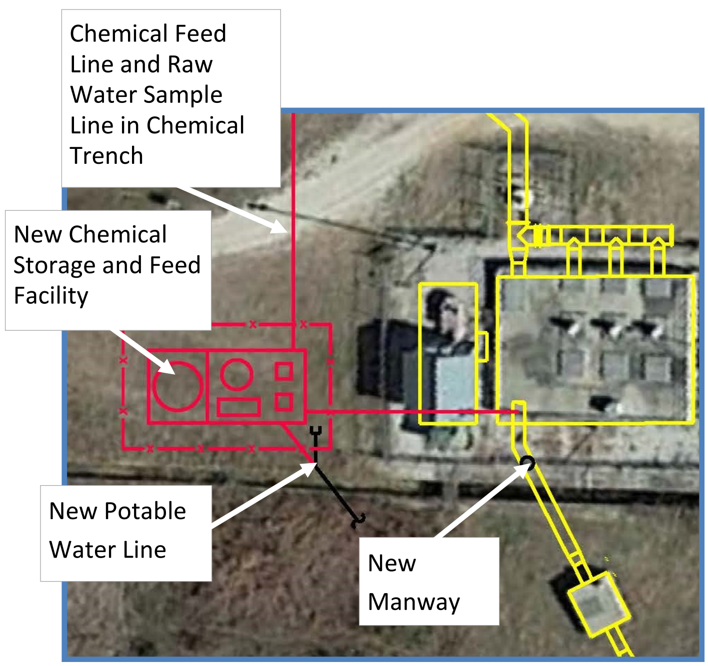
The RRWTP is the smaller of the two COD water treatment plants. The plant was constructed in 2002 while the raw water infrastructure was completed in 1983 and the second valve vault added in 1997. Most recently, in 2014, manways were installed in the raw water line to allow access for cleaning and disposal of zebra mussels. The plant has a current capacity of 20 MGD, average flows of approximately 9.9 MGD and minimum flows of approximately 5 MGD. If future demands increase, the capacity of the RRWTP will be increased to 50 and ultimately 100 MGD.

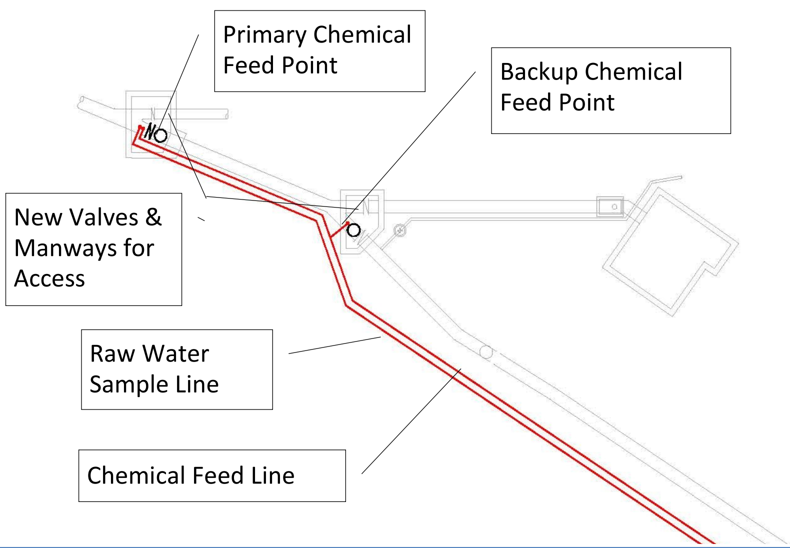
The raw water system consists of the USACE-owned dam outlet structure (i.e. the RRWTP Intake), a 60-inch raw water pipeline to the raw water pump station (RWPS) that is currently bypassed, and a 42-inch pipeline to the plant. The COD also owns a hydroelectric power plant that is connected to the raw water system but is no longer functioning. The total distance from Lake Ray Roberts to the RRWTP is approximately 1 mile.

RRWTP Capital, Operations and Maintenance Recommendations

Primary recommendations include improvements to the raw water pipelines to provide additional access and adding a chemical feed point in valve vault 1 to protect all downstream components including the RWPS. Due to environmental releases through the USACE structure into the Elm Fork of the Trinity River, chemical cannot be applied any farther upstream. Chemical facilities will be located to the north-west of the RWPS. Two-chemical systems using common piping and feed system components provide redundancy without a significant increase in cost. The ability to utilize an alternate system will serve as a key aspect of the RRWTP's zebra mussel management strategy. Additional recommendations include operating pumps and valves frequently and risk management strategies (e.g. monitoring and inspections at USACE pipe outlet).

Probable Costs	Recommendations
Probable **Capital Improvement** Cost: $ 2,180,000	• Improve the raw water pipelines with additional access points and valves • Install a copper ion system based upon plant flow
Probable **Engineering and Construction Administration** Fee: $ 440,000	• Install a sodium permanganate storage and feed system (based on a design dose of 2.5 mg/L) • Minor manway improvements for physical removal and disposal access especially at pipeline low points
Probable Annual **Operations & Maintenance** Cost: $ 98,000—$ 119,000	• Light physical removal and disposal, as required (e.g. low point downstream of USACE outlet) • During settlement season, feed copper ions at a 5 ppb dose (2 ppb during non-settlement season) or feed sodium permanganate at an average dose of 1.5 mg/L (range of 0.5-2.5 mg/L) • Operate pumps (if operational) and valves frequently • Isolate and dewater structures (e.g. pipelines) during plant shutdowns (lower water level if dewatering not possible)
Risk Management Recommendations	• Increase monitoring to include additional water quality, substrate sampler and veliger monitoring at minimum • Visually inspect debris from the pipelines or USACE Outlet. Also visually inspect any dewatered surfaces during maintenance activities • Continue developing the plan for interim chemical feed using sodium permanganate totes • Implement on-call contracts, begin regulatory coordination and develop new SOPs





RRWTP Recommended Next Steps

Lessons learned from the previous RRWTP raw water system zebra mussel infestation lead to the recommendation that the COD proceed proactively with actions to better prepare for future zebra mussel infestations of the RRWTP raw water system. As the RRWTP raw water facilities are susceptible to fouling, and zebra mussel infestations would pose significant risk to COD operations, a proactive program to manage risk is recommended for immediate implementation. Key recommendations include:

- Applying monitoring and inspection techniques to input information into the decision-making process;
- Developing a multi-barrier approach to zebra mussel management; and
- Optimizing O&M activities, which can significantly reduce future impacts with minimal capital investment.

In addition to designing and constructing the selected capital improvements ASAP, there are a number of proactive actions COD can initiate to prepare for potential future infestations of the RRWTP Intake. Develop a response plan to initiate further steps to provide zebra mussel protection (e.g. confirm the trigger for constructing interim and permanent improvements). The response plan should include:

- Implement the next steps recommended in this section,
- Revise budgets in the Capital Improvements Plan (CIP) to account for increased annual costs to manage zebra mussels,
- Begin designs and subsequent construction of permanent systems,
- Begin implementation of the interim sodium permanganate system to minimize future infestation of 42” pipeline,
- Make plans for physical removal and disposal at least every two years,
- During future projects, include zebra mussel management approaches during design and construction, and
- Update the response or strategic plan annually based upon updated data from monitoring.

Develop and Initiate a Response or Strategic Plan:

Develop a Zebra Mussel Monitoring SOP

Increased biological monitoring should begin immediately to maximize the amount of time to respond and prevent future potential infestations. Consider hiring and/or training staff members to perform zebra mussel monitoring (i.e. veliger, settlement and adult identification) at both intake locations. Update the monitoring plan annually based upon a review of trended data collected through the monitoring effort. Following implementation of any molluscicides, the SOP should provide procedures for modifying the site’s monitoring program for chemical feed optimization including the use of chemical residual monitors and bioboxes in the intake and at the point farthest downstream in the system where protection is required.

[See Manual Sections 5.3.1.1 & 5.3.3.1]

Begin Regulatory Coordination

Zebra mussel management will require coordination with multiple regulatory agencies throughout the planning, design, and construction phases of the project. Which agencies are involved depends on the selected zebra mussel management approach and the application, but the following regulatory focus items should be addressed in the near term:

- Send design documents for new chemical improvements to TCEQ for review and approval
- Make arrangements with TPWD and US FWS for native mussel surveys, if required
- Coordinate with USACE on required permits and follow up on the new easement agreement

[See Manual Sections 2.6 & 5.3.3.2]

RRWTP Recommended Next Steps

Develop On-Call Contracts for Physical Removal and Disposal	It is recommended that COD proactively develop an on-call contract for cleaning and disposal of mussels. On-call contracts generally require the contractor to coordinate disposal in accordance with all regulations. Develop on-call contracts (or price agreements) for inspecting facilities for zebra mussels and cleaning mussel infestations from facilities. On-call contracts should include detailed drawings and specifications that consider the lessons learned from the RRWTP zebra mussel cleaning event . **[See Manual Sections 2.4, 3.2.3.4 & 5.3.3.3]**
Assess Acceptable Impacts and Evaluate Access	Consider potential hydraulic losses due to zebra mussels and/or Asian clams, potential disposal efforts associated with and evaluate access points for physical removal of shells. • Determine the level of allowable reduced hydraulic capacity before cleaning is necessary • Consider the maximum volume of mussels that should be allowed to accumulate before removal • Consider executing inspection on-call contracts including CCTV assessments **[See Manual Section 5.3.3.4]**
Implement the Interim Chemical Feed Plan	Implement the interim chemical feed system as described in section 5.3.1.2. Concurrently, implement the recommendations for increased monitoring and inspections provided in section 5.3.1.1. The interim design should include the necessary monitoring equipment (e.g. residual monitors and bioboxes) to optimize the chemical dose and frequency required. **[See Manual Sections 5.3.1.1, 5.3.1.2 & 5.3.3.5]**
Develop New Chemical System Design Documents	Complete development of design documents for the selected alternative. The design should balance dual-water quality benefits with downstream treatment challenges and include developing chemical dosing SOPs, protection of all small diameter pipelines, and redundancy of equipment. **[See Manual Sections 5.2.1, 5.3.1 & 5.3.3.6]**
Develop a Manganese SOP	If sodium permanganate is implemented, a manganese standard operating procedure (SOP) should be developed. If not properly monitored and managed, permanganate can result in increased manganese concentrations (potentially above the 0.05 mg/L MCL) in the treatment stream, which in turn can lead to colored water events. It should be noted that although development of a manganese management procedure is recommended, many utilities (e.g. City of Oregon, OH, City of Toledo, OH and City of Raleigh, NC) have used permanganate doses of 2-4 mg/L without any noticeable resulting manganese water quality impacts. **[See Manual Sections 5.3.1.1 & 5.3.3.7]**
Monitor Copper and Aluminum	Copper removal via downstream processes should be verified to ensure compliance with regulations and assess impacts on distribution system copper and lead control, understanding that regulations generally become more stringent over time. Aluminum should also be monitored and assessed. Due to the limited information available and limited full-scale municipal installations for zebra mussel control, a sidestream biobox pilot study could be performed prior to installation of a copper ion alternative to verify efficacy in COD source waters. Additionally a performance guarantee of zebra mussel settlement prevention could be requested from the manufacturer. **[See Manual Section 5.3.3.8]**

12400 Coit Road, Suite 1200 | Dallas, Texas 75251

Tel. 972.934.3711 | Fax 972.934.3662

1. INTRODUCTION

The City of Denton (COD) has two raw water systems that are at risk for zebra mussel fouling - the Lake Lewisville Water Treatment Plant (LLWTP) and the Ray Roberts Water Treatment Plant (RRWTP) raw water systems, as shown in Figure 1-1. Zebra mussels (*Dreissena polymorpha*) are an invasive species that can cause fouling of water handling facilities (e.g., intake, racks, screens, pipelines, pumps, dam releases, gates, etc.) that are located in or transmit water from potentially infested water sources as well as contribute to changes in source water quality that can affect operations. This fouling is caused by the accumulation of adult mussels that attach to the surface of structures and to each other. The Asian clam is another invasive species that was observed during this project that can collect and grow in water facilities. With continuous flows to provide a constant food and oxygen source, intake structures, piping and other raw water appurtenances are an ideal habitat for mussel proliferation. Once an infestation has occurred, zebra mussels can build a layer greater than 6 inches thick, severely constricting flows and clogging pumps, screens and filters. In addition, zebra mussel infestations may adversely affect the ecosystem and water quality.

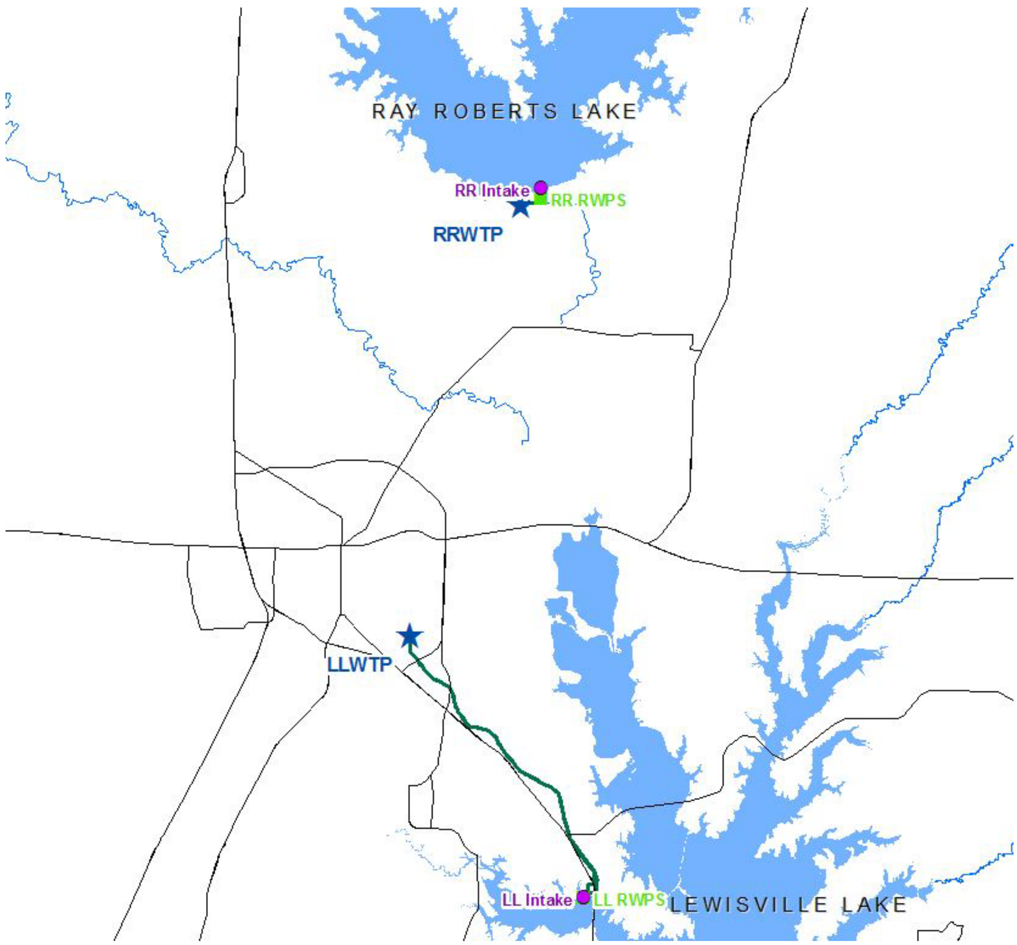


Figure 1-1: COD Raw Water System

The RRWTP raw water system has already been impacted by zebra mussels. Early in 2014 the COD discovered the 60-inch raw water pipeline downstream of Ray Roberts Lake was 70% clogged with mussels at a low point, although recent data suggests the population density in Ray Roberts Lake may be decreased this year. The Upper Trinity Regional Water District has also observed a sustainably reproducing zebra mussel population at their intake near the Lewisville Lake Dam and a heavy settlement of juvenile mussels was observed in the Elm Fork arm of Lewisville Lake following flooding this year. Most recently, DWU discovered zebra mussels in the Bachman WTP raw water line originating in Fishing Hole Lake along the Elm Fork of the Trinity River downstream of Lewisville Lake. To prepare for the likely spread of mussels to the LLWTP raw water system and develop methods to ease future cleaning events in the RRWTP raw water system, the COD commissioned the development of a Manual for the Control, Operation and Maintenance of Zebra Mussels (Manual).

The overarching goal of this Manual is to develop zebra mussel management approaches that balance the risk of future infestations with capital spending and potential unintended downstream consequences.

1.1. MANUAL ORGANIZATION

The Executive Summary, included at the opening of the report, provides a concise summary of the study's principle findings, conclusions and recommendations. The Manual chapters are as follows:

Chapter 1. Introduction – Describes the purpose of the Manual, the approach for developing the recommendations in the Manual, and the contents of the Manual.

Chapter 2. Background – Provides background information on risk considerations including an overview of relevant zebra mussel biology and ecology, a summary of the progression and growth rates of zebra mussels in North Texas including discussion of the recent zebra mussel cleaning effort by the COD, an analysis of COD source water quality in relation to water quality ranges favorable to zebra mussel settlement and propagation, a discussion of the potential impacts of zebra mussels on potable water facilities and a summary of related regulations.

Chapter 3. Zebra Mussel Management, Operation and Maintenance Approaches – Presents a review of various preventative, control and reactive strategies for zebra mussel management including a discussion of chemical demand testing performed as part of this study. Evaluation criteria selected by COD and alternatives selected for further consideration by COD are summarized. Lastly, operation and maintenance (O&M) strategies to improve zebra mussel management are provided, including a discussion of various chemical dosing strategies, a review of risk management strategies that have been used by other utilities (including monitoring), and a summary of regulatory considerations.

Chapter 4. LLWTP – Summarizes the results of the site surveys, zebra mussel management alternative identification and evaluation conducted for the LLWTP raw water system and recommendations for short-term improvements, long-term improvements and immediate action items at this site.

Chapter 5. RRWTP – Summarizes the results of the site surveys, zebra mussel management alternative identification and evaluation conducted for the RRWTP raw water system and recommendations for short-term improvements, long-term improvements and immediate action items at this site.

Appendices – The Manual contains appendices including water quality data, chemical demand testing results, workshop activity results, supplemental information for sites including the opinion of probable cost estimates, additional information on copper ion generation systems, and the results of manganese profiling at the LLWTP.

1.2. MANUAL DEVELOPMENT APPROACH

The multifaceted approach to developing this Manual considered local raw water quality, local zebra mussel biology and ecology, downstream water quality goals, potential operational impacts, current and potential future regulations, and future changes to raw water system and downstream treatment plants in determining the best system-wide solution to zebra mussel control and prevention. The source-to-tap approach considered potential dual benefits, such as manganese oxidation, and identified unintended consequences of each control alternative. COD and the project team involved operational staff from both water treatment plants throughout the evaluation of alternatives. Operational staff led tours of each site discussing the current operational strategies and site-specific physical and operational limitations. Throughout the evaluation process, operational staff participated in ranking alternatives and providing feedback on how each alternative would impact, either positively or negatively, their daily workload and the operation of the treatment systems. Including operational staff ensured the recommendations could be implemented and operated effectively. The Manual considered the following:

- **Source water quality** including seasonal water quality changes and the variability of water quality at each structure
- **Physical characteristics** of each structure to assess the susceptibility to fouling and the potential impact of fouling on individual components, accessibility, level of security, proximity to the public, the floodplain elevation and the potential to reuse existing equipment and facilities
- **Hydraulics** including pipeline velocities, capacities and detention times, potential hydraulic capacity reductions due to an infestation and consideration of the potential to alternate pipeline use to optimize zebra mussel management
- **Operational impacts** including consideration of required labor hours, current daily operational activities and annual O&M costs
- **Capital Costs and O&M Costs** were evaluated and compared to understand the true costs of various options and alternatives identified
- **Public perception** including the selection of publically accepted technologies and avoidance of adverse environmental and/or ecological impacts
- **Operation of downstream water treatment plants** including water quality goals, seasonal trends in customer demands, seasonal operating practices, planned process changes,

unintended consequences, and the potential for management approaches to provide pre-treatment

- **Zebra mussel biology and ecology** including local growth and progression rates, water conditions favorable to zebra mussel settlement, and equipment and materials especially susceptible to fouling
- **Planned future improvements** to the raw water system including opportunities for optimization of future projects for zebra mussel management
- **Current and future potential regulations** at the local, state and national level
- **Risk reduction** strategies that balance capital spending with minimizing future risks (e.g., capacity reductions due to fouling) such as selection of proven technologies and monitoring

Figure 1-2 summarizes the key development phases that were completed. **Site surveys** were conducted for both of the COD's two raw water systems for the RRWTP and LLWTP. Site surveys included both desktop design document review and field visits, during which the team gained a greater understanding of what components are at most risk for fouling. A **risk assessment** was conducted to rank the overall relative risk to the raw water system and to provide information/notification of potential impacts. Lastly, a list of **potential future improvements**, including a summary of benefits and risks to future zebra mussel management, was developed.

In parallel, a review of zebra mussel **management approaches** was conducted, including both new and old technologies. During the **Alternatives Analysis Workshop**, COD staff ranked evaluation criteria and selected alternatives for further evaluation. **Chemical demand testing** was conducted to increase the accuracy of cost estimates and better understand the feasibility of implementation of the selected chemicals in the COD raw water systems.

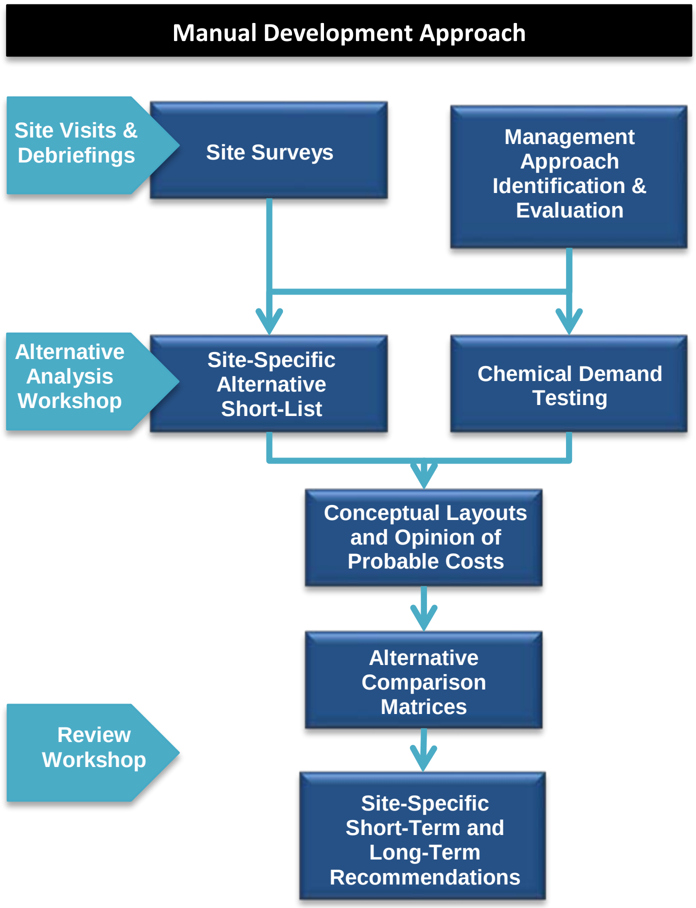


Figure 1-2: Manual Development Approach

Conceptual layouts and costs were then developed for the top two preventative alternatives in addition to a reactive approach (i.e. physical removal and disposal), and **comparison matrices** were developed to compare the top alternatives. **Recommendations** for multi-barrier management approaches within both raw water systems were developed including the following:

- Short and long-term capital improvements
- Monitoring and inspection guidelines
- Operations and maintenance guidelines
- Risk management approaches

1.2.1. Project Team

To address the multi-dimensional O&M considerations, a **multi-disciplinary team** (Table 1-1) including an academic professor and a retired U.S. Army Corps of Engineers (USACE) expert was formed. Each team member brought a unique perspective to this evaluation – an understanding of the synergy of zebra mussel biology, potential unintended consequences, institutional knowledge of management approaches, and the engineering aspects of the system to be protected. The team also included a technical advisor with years of experience evaluating, designing and managing zebra mussels in the Great Lakes region. Additionally, numerous COD staff were involved throughout this project by participating in site visits and workshops and reviewing the Manual.

Table 1-1: Project Team

Project Team	Role
Arcadis Project Lead Team:	
Gail Charles, PE	Project Manager
Ashley Evans, EIT	Risk Assessment & Management Approach Task Leader
Ben Kuhnel, PE	Conceptual Design & Cost Estimate Task Leader
Randy McIntyre, PE	Quality Assurance / Quality Control
Technical Advisor Team:	
John Amend, PE (NY) – Arcadis	Engineering Design*
Bree Carrico, PE – Arcadis	Process / Water Quality
Caroline Russell, PE – Arcadis	Process / Water Quality
Dr. Robert McMahon – Professor Emeritus, UT Arlington	Zebra Mussel Biology, Ecology and Control*
Dr. Barry Payne – Retired USACE	Zebra Mussel Biology and Control
COD Staff:	
Mamun Yusuf, Project Manager	
Randy Markham	
Tim Fisher	Data collection, participation in workshops and site visits, and review of the Manual
Brian Smith	
David Clark	
Ken Hurley	
Kathy Gault	

*Previous experience managing zebra mussels in the Great Lakes Region

1.2.2. Site Surveys

Site surveys were conducted for both of the COD's two raw water systems, the RRWTP system including the RRWTP Intake and RWPS. Site surveys included desktop design document review and site visits (conducted March 23, 2015) with operational staff (Figure 1-3) from both water treatment plants. In addition to touring the facilities, operations staff provided insight into how the facilities are currently operated and any operational constraints that may exist. A list of planned **future improvements** to each facility was also developed. Following each site visit, a debriefing workshop was held with COD staff to review the risk assessment for each facility, discuss key challenges for each raw water system and identify feasible alternatives for each site. The **risk assessment** reviewed design drawings, photographs, reports and local team knowledge of COD facilities to rank the overall relative risk to each raw water system. The review considered local water quality, the most recent data on occurrence of zebra mussels, and the level of potential impact on COD's water supply if a zebra mussel infestation were to occur (Figure 1-4). Results of the site surveys include:

- An overview of each facility including photos from site visits and schematics based on design drawings
- Major physical and operational considerations
- Major components at risk for zebra mussel fouling and the associated impacts from fouling to each component
- Potential future improvements at each site
- The risk assessment for each site

Figure 1-3: Site Visits

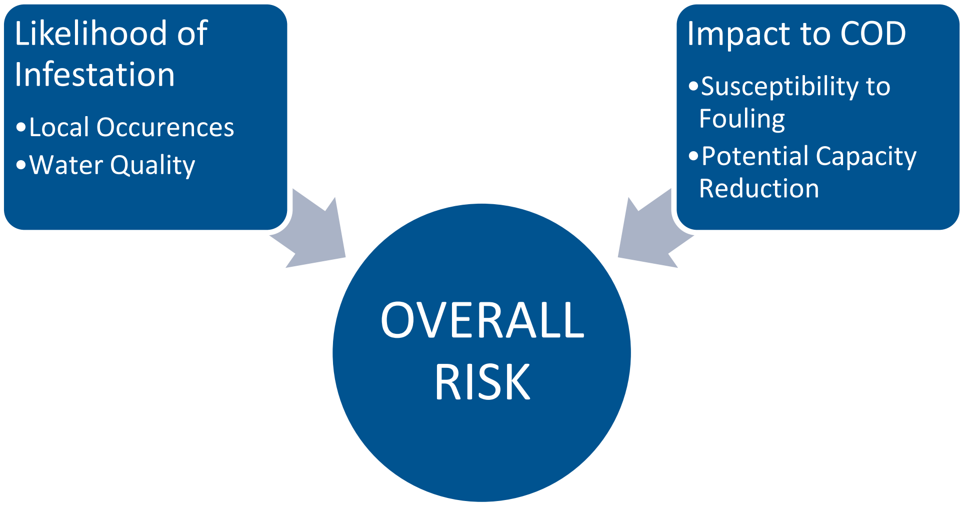


Figure 1-4: Risk Assessment Considerations

1.2.3. Management Approach Identification and Evaluation

A review was conducted to identify and evaluate **zebra mussel management approaches** (i.e., a combination of preventative, control, and reactive strategies). Both innovative and conventional technologies were vetted through this process including chemicals ranging from chlorine to non-oxidizing molluscicides (e.g. Bulab 6002), and newer technologies including but not limited to Zequanox, the Jacquelyn™ Coating, and copper ion generation systems. Key considerations for each preventative, control and reactive strategy were derived from discussions with the technical advisors for this project, discussions with vendors, and a review of available literature (e.g. Nalepa and Schloesser, 2014; Mocek, 2013; McMahon, 2013; and others presented in Appendix A).

O&M strategies for managing zebra mussels were evaluated for each site. Some examples of operational strategies include more frequent operation of equipment, more frequent cleaning of trash racks and alternating the use of pipelines. Maintenance strategies might include silt removal, redesigning bar screens to ease physical removal or improving access for future physical removal and disposal efforts. O&M strategies are a complimentary part of any multi-barrier management approach.

Additionally, based upon the number of unknowns that still exist (e.g. whether Lewisville Lake will support a sustainably reproducing zebra mussel population throughout the Lake and especially during drought conditions), **risk management approaches** were discussed including:

1. **Implementing a robust monitoring program** – Various monitoring techniques were discussed, and recommendations for additional monitoring prior to and following an infestation were outlined.

2. **Designing permanent control systems but not constructing them** – A common practice other utilities facing similar uncertain risks have implemented to balance preparedness with minimizing the risk of constructing systems that may not be required is completing 60% or 90% construction documents and then shelving the documents until an infestation is imminent. The advantages and risks of this practice were discussed including the need for a clearly defined trigger for completion of design documents.

3. **Feasibility of Temporary Control Systems (including modification of existing equipment)** – Potential temporary control measures to prevent zebra mussel infestation during the time required to design, construct, and start up permanent facilities were discussed including potential locations for interim chemical feed facilities.

4. **Use of On-call contracts** – On-call contract development for site inspections and physical removal of mussels was also discussed, including the type of information that would be required and the advantages of developing on-call contracts.

1.2.3.1. Alternatives Analysis Workshop

During the Alternatives Workshop held May 13, 2015, the results of the site surveys were reviewed, evaluation criteria were established and a short-list of alternatives for further evaluation was developed. **Evaluation criteria** (including quantitative and qualitative factors) were established and ranked by COD in order from most to least important. An overall weight for each criterion was then assigned based upon the average ranking of all COD staff. Considering the established evaluation criteria, COD staff then scored each zebra mussel management strategy based on the level of feasibility for implementation in the COD system. Scoring was completed on a scale from A – D (or 1 – 4) where:

- A (1.0) – Very feasible
- B (2.0) – Feasible but some limitations
- C (3.0) – Feasible but many limitations
- D (4.0) – Not feasible / not interested

A short-list of alternatives for further evaluation was developed by selecting alternatives that were scored, on average, as the most feasible (2.0 or below) by the COD team. Results of the workshop activities are presented in Appendix D. The workshop also included discussion of risk management strategies, potential related regulations, and recommended additional monitoring. COD staff were asked to participate in a team exercise where they noted how prepared they wanted to be when a zebra mussel infestation occurs.

Figure 1-5: Alternatives Analysis Workshop Activity

1.2.4. Chemical Demand Testing

One apparent limitation to the information available from literature reviews, vendors and previous project experiences was accurate estimations of the chemical doses that would be required in COD raw water systems. Previous data on required doses for effective prevention of zebra mussel veliger settlement were based on laboratory studies or projects in the Great Lakes Region where the annual water temperature and organic concentrations are much lower. Although some data was available for review from City of Dallas source waters, the closest data was from samples collected in a river downstream of the COD's intakes located on lakes. Thus, **chemical demand testing** was performed using four chemicals (chlorine dioxide, chloramines, permanganate and a polyquaternary ammonium compound (Bulab 6002) on both COD source waters with the following goals:

- Improve the accuracy of estimated chemical facility design doses
- Improve the accuracy of annual average chemical doses
- Better estimate the magnitude of potential unintended downstream consequences associated with each chemical alternative
- Select the most viable chemical alternatives for application in the COD raw water systems

Chemical demand testing was scheduled in two phases for both COD source waters (i.e., the LLWTP Intake and the RRWTP Intake) based upon raw water pipeline detention times calculated using the average annual flow. Source water samples for Phase I were collected during the spring season (i.e., on April 21st, 2015) and for Phase II were collected during the early summer (i.e., June 10th, 2015). The complete testing plan, data and results are provided in Appendix C. Based upon the results of demand testing and the Alternatives Analysis Workshop, two chemicals (i.e., sodium permanganate and copper ion solution) were selected for opinion of probable cost and conceptual layout development. Site-specific demand, recommended chemical facility design doses, and annual average doses are presented with the design criteria for each site.

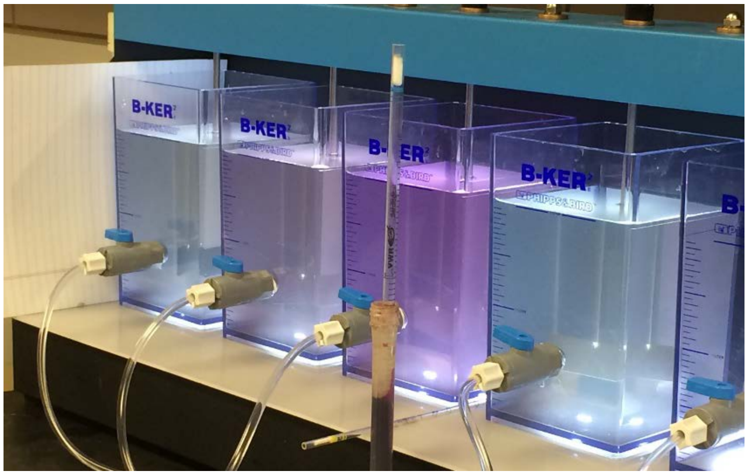


Figure 1-6: Chemical Demand Testing

1.2.5. Site-Specific Short-List of Alternatives

Short lists of site-specific management approaches (combination of prevention, control, and reactive strategies, along with operational and design considerations) were then defined for each site considering:

- Evaluation criteria
- Top ranked prevention, control and reaction strategies
- Physical, ecological and environmental characteristics of each site
- Calculations of pipeline velocities and residence times (refer to Appendix E)
- Results of chemical demand testing
- Previous project team experience
- COD preferences

1.2.6. Conceptual Layouts and Opinion of Probable Costs

Conceptual layouts and opinion of probable costs were developed for the short-list of alternatives selected for each site. Conceptual design criteria were established based on results of chemical demand testing. A preventative approach (i.e., preventing settlement of veligers) was recommended over a control approach (i.e., killing veligers or adults) based upon the results of the literature review suggesting that the doses and contact times required to kill veligers and adults were not feasible in the COD potable water systems. Various **chemical dosing strategies** (e.g. continuous and semi-continuous) were also discussed (summarized in Section 3.2.2), which have been successful in previous projects.

Based upon the design criteria that are outlined with the discussion of alternatives for each site, Class 4 Association for the Advancement of Cost Engineering International (AACE) opinions of probable capital, O&M and 20-year lifecycle costs were developed. Costs are for zebra mussel related facilities only and condition assessments were not completed on the existing facilities. With all projects, there may need to be other non-related upgrades as part of future projects. Conceptual layouts were then developed to highlight basic footprints and sizes of physical facilities and illustrate proposed improvements to the sites.

1.2.7. Alternative Comparison Matrices

Matrices were developed for each site to compare the short-listed alternatives selected with COD during the Alternatives Analysis Workshop, chemical demand testing, and subsequent discussions. Alternatives were compared by considering each of the evaluation criteria established during the Alternatives Analysis Workshop. In order to fully assess the implementability of alternatives (one of the evaluation criteria), **State and Federal regulations** were summarized and considered. Each short-listed alternative is listed in a matrix column. Each row in the matrix compares alternatives relative to each criterion. The alternatives were grouped in two categories:

- **Prevention approach –** alternatives that will prevent or minimize zebra mussel fouling to infrastructure
- **Reaction approach –** relying on physical removal and disposal following future infestations to clean infrastructure of fouling

In addition, one-page summary matrices were developed. In the summary matrices, each cell (each criterion per alternative) is highlighted in one of the following four categories:

- **Not favorable**
- **Many limitations**
- **Some limitations**
- **Favorable**

Lastly, a ranking matrix was developed by assigning numerical factors to each of the above four categories and weighting the factors based upon the evaluation criteria weighting factors determined during the Alternatives Analysis Workshop. Different approaches and/or alternatives were selected for each site based upon consideration of the risk of infestation, operational impact, and criterion comparison.

1.2.8. Recommendations

Site-specific alternatives were ranked based upon the comparison matrices, and site-specific recommendations were developed. Based upon the results of the evaluation criteria ranking exercise performed during the Alternatives Analysis Workshop, special consideration was given to effectiveness for zebra mussel control, ease of O&M and operational flexibility, which were ranked the highest by COD staff, in selecting alternatives. **Site-specific recommendations** included short- and long-term capital improvements, O&M enhancements, site inspection guidelines and recommended chemical dosing strategies, including an estimated annual average chemical dose for each site.

The three **short-listed alternatives** (i.e., sodium permanganate, copper ion generation systems, and physical removal and maintenance improvements) were ranked considering the alternative comparison matrices. Key considerations for each alternative were highlighted, including any potential limitations to effectiveness or unintended consequences downstream.

Recommendations for immediate action items were summarized to minimize the risk associated with the uncertainty of the extent of future zebra mussel infestations in COD raw water systems. Recommendations considered risk management approaches, development of new standard operating procedures (SOPs), and additional coordination that should occur prior to an infestation to mitigate future risks.

2. BACKGROUND

Zebra mussels pose a significant risk to facilities that transmit raw water from reservoirs or other water bodies to drinking water treatment plants. With a continuous flow of water to provide a constant food and oxygen source while also being devoid of predators, intake structures, piping, and appurtenances are ideal habitats for zebra mussel proliferation. Once a water body has been infested, adult zebra mussels can foul infrastructure (build a layer greater than 6 inches thick), severely constricting flows and clogging pumps, screens, and filters. In this case, the hydraulic capacity of trash racks, conduits, and pipelines will be reduced due to the reduction in flow area and the increase in friction factor (i.e., C factor). Furthermore, as zebra mussel colonies thicken, the mussels closest to the structures to which they have adhered may die from lack of nutrients or oxygen. These die-offs encourage sloughing of druses (i.e., large masses of mussels) that may cause the sudden plugging of smaller diameter downstream pipes or pumps.

Further, Asian clams, another invasive species, were recently found to comprise a significant volume of the shells removed from the RRWTP raw water lines during the 2015 zebra mussel cleaning effort. Although Asian clams do not attach to surfaces, as do zebra mussels, significant buildup of shell volumes is likely, especially in low points of lines, regardless of whether a future zebra mussel infestation occurs. The existence of an Asian clam population increases the likelihood of significant hydraulic impacts to the raw water system should a zebra mussel infestation also occur.

The immediate potential risk to both of COD's raw water systems is the potential failure to meet customer water demands. An estimate of the increased headloss across the LLWTP Upper Intake and RRWTP raw water system was calculated in an attempt to quantify the potential operational impact of a build-up of zebra mussels and/or Asian clams. Assuming a reduction in C-factor to 60 and a 12-inch decrease in pipeline diameter (assuming 6-inches thick around the pipeline circumference) due to mussel build-up, an additional 1.3 feet of headloss (or total 1.4 feet of headloss) across the LLWTP Upper Intake would occur at average flow (i.e., 8.44 MGD) and an additional 6.2 ft. of headloss (or total 7.1 ft. of headloss) through the RRWTP raw water system would occur at average flow (9.9 MGD). Impacts would be especially significant when the lake elevations are lower. Other risks associated with the physical removal of mussels include the potential failure to meet water demands if a plant is offline due to cleaning, increased annual operations and maintenance costs for removal and disposal and increased pipeline pitting or corrosion due to the attachment of mussel byssal threads in pipelines.

2.1. ZEBRA MUSSEL BIOLOGY CONSIDERATIONS

The zebra mussel (*Dreissena polymorpha*) is an invasive freshwater species. Zebra mussels are small (typically less than two inches total length), bivalve mollusk filter-feeders with elongated shells that are usually marked with light and dark alternating dorso-ventral bands that can resemble zebra stripes. Utilizing strong proteinaceous thread-like filaments known as byssus for attachment, zebra mussels can firmly attach and thus potentially colonize virtually any hard, non-toxic surface. Zebra mussels also readily attach themselves to existing mussels, thereby creating dense colonies that may be more than 12 inches thick. Knowing the biology of zebra mussels, including life cycle and population dynamics, is important to understanding their biofouling nature (why these mussels are so prolific and why they spread so rapidly). Due to their affinity for flowing water conditions, which allow for optimal oxygenation and higher filtration rates, raw water systems are especially vulnerable to zebra mussel establishment and growth.

Zebra mussels are prolific breeders. A large adult female zebra mussel can release over 1,000,000 eggs per spawning season into the surrounding waters where they may encounter sperm released by males. External fertilization of the eggs begins when water temperatures reach 54 degrees Fahrenheit (°F). Fertilized eggs become free swimming pelagic larvae (called veligers) within a few days. Veliger densities of greater than 14,000 per cubic foot of water have been reported in North America. Veligers remain in the water column for one to three weeks. During this time they can be transported great distances by currents. As they are very small (less than 300 microns), veligers easily pass through most screens and filters in raw water systems. Generally within three weeks of hatching, zebra mussels settle out of the water column and begin to attach to substrates. As settlement is a non-directed action, many veligers will settle on unsuitable substrate and die. Once settled, if conditions are favorable, the mussels begin to produce byssal threads and transform into adults. Growth is rapid during the first year and an individual mussel can attain a length of greater than 0.75 inches. As zebra mussel colonies thicken, the mussels closest to the structures to which they have adhered may die from lack of nutrients or oxygen. These die-offs encourage sloughing of large masses of mussels which may cause plugging of downstream piping or pumps.

Mussels can also negatively impact water quality and contribute to taste and odor problems due to chemicals that they release (e.g., metabolites and degradation products) through all stages of their colonization cycle (growth, death and sloughing). In addition, zebra mussel infestations may adversely affect the ecosystem and water quality. Zebra mussels filter large volumes of water and remove phytoplankton and zooplankton as well as silt and micro-detritus, increasing water clarity, and bioaccumulating contaminants. Increased water clarity allows for greater light penetration and may stimulate growth of blue-green algae (i.e., cyanobacteria) that are capable of producing 2-methylisoborneol (2-MIB) and geosmin, increasing taste and odor issues and also increasing the potential for Microcystin blooms that can produce neurotoxins in the source waters. Unfortunately, these potential future water quality issues can only be prevented or delayed through public education to control the spread of mussels.

Thus, zebra mussels pose a very serious risk to the successful operation of drinking water treatment plants. Although not addressed in this Manual, the COD should be aware of the potential for water quality changes (e.g. decreased turbidity and increased algal and cyanobacteria growth) due to zebra mussel infestations in source waters. The scope of this Manual is focused on addressing the immediate impacts of zebra mussel fouling to hydraulic capacities of raw water systems. The following physical and biological conditions must exist for a zebra mussel population to become established:

- Hard substrates to settle on and attach to
- Favorable water quality (e.g. calcium, temperature, pH and dissolved oxygen)
- Adequate nutrient sources

2.2. ZEBRA MUSSEL PROGRESSION IN THE US AND NORTH TEXAS

Zebra mussels were first identified in the United States (U.S.) in 1988 in the Great Lakes (Lake Saint Clair), but originate from the Black and Caspian Seas in Eastern Europe. Zebra mussels have spread rapidly across the US by interconnected waterways and unintentional overland trailering on recreational watercraft. Figure 2-1 illustrates zebra mussel sightings in the U.S. since 1988.

Zebra mussels were first found in Texas along the border of Oklahoma in 2009 in Lake Texoma. To date, the presence of live zebra mussels or veligers, or their larvae, has been confirmed in seven Texas water bodies: Lakes Texoma, Ray Roberts, Lewisville, Bridgeport, Belton, Lavon and Waco. Zebra mussel DNA has also been detected in Lakes Grapevine, Fork and Tawakoni. Although detection of DNA does not necessarily confirm that a zebra mussel infestation has taken place, it indicates that zebra mussels may be nearby or that boaters may be inadvertently moving zebra mussels or DNA from other lakes. Figure 2-2 illustrates zebra mussel sightings in the Dallas / Fort Worth (DFW) region.

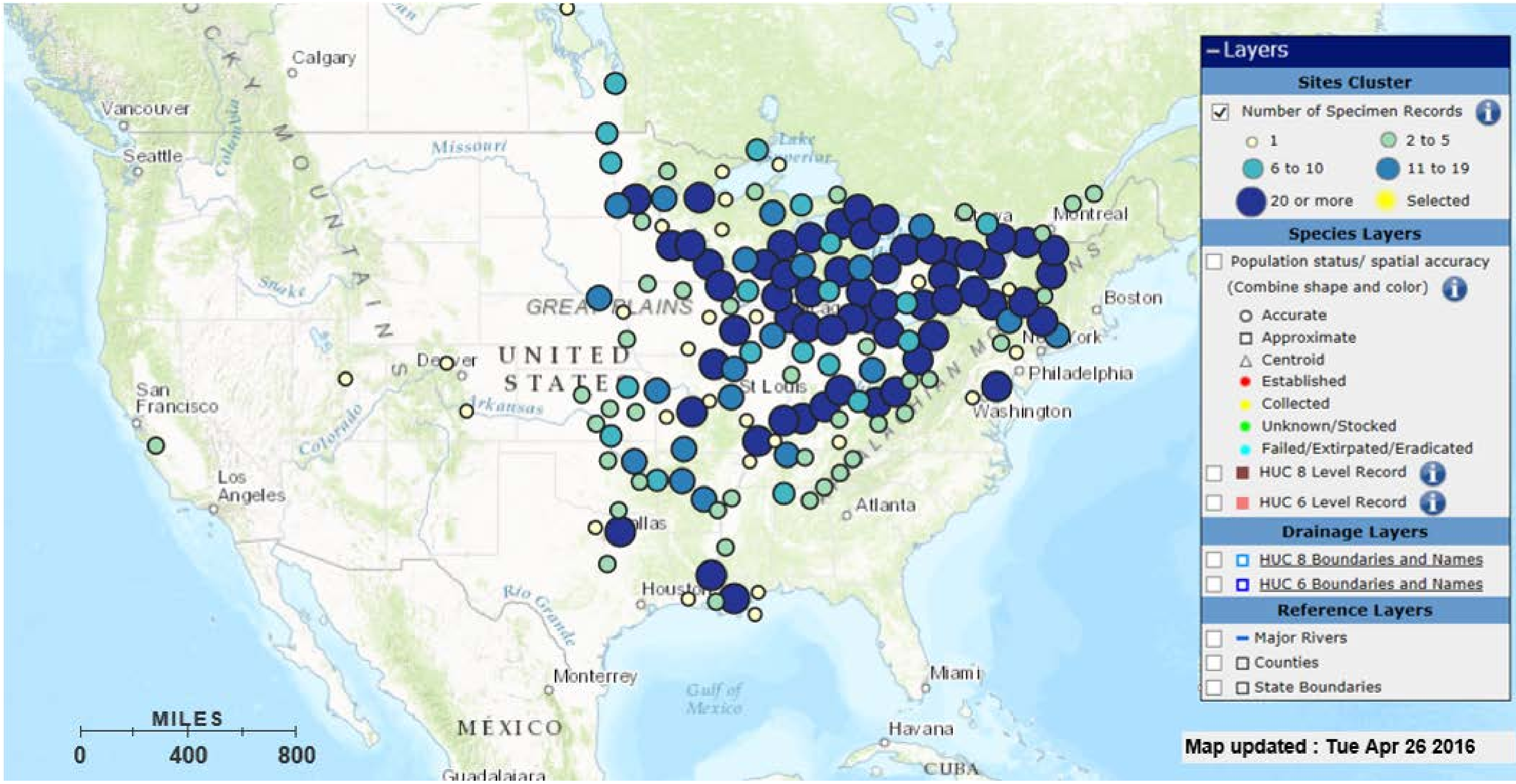


Figure 2-1: Zebra Mussel Sightings across the US (Source: U.S. Geological Survey (USGS) Nonindigenous Aquatic Species Website, http://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/, April 26, 2016)

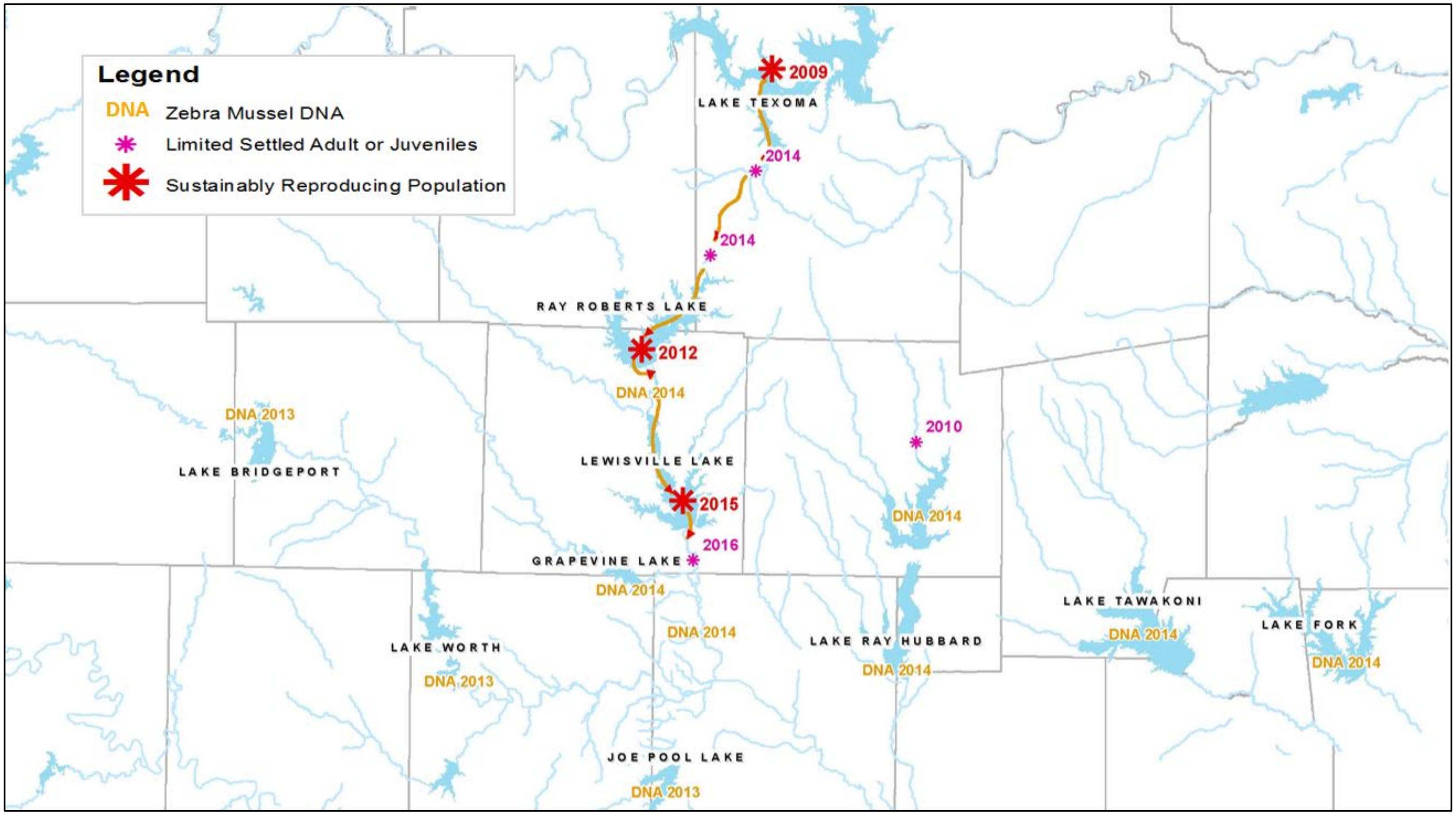


Figure 2-2: Zebra Mussel Sightings in DFW Region (Sources: Email from Chris Churchill, USGS, 7/16/15; USGS Point Map, 7/20/15; Texas Parks and Wildlife Department (TPWD) News Releases, 3/25/15; UTRWD Emails, 3/2/15; DWU Emails, 4/14/16; and Research by Bob McMahon)

In the DFW region, there are currently sustainably reproducing populations in Lakes Ray Roberts and Lewisville. The COD recently completed a zebra mussel cleaning project in the raw water system leading from the US Army Corps of Engineers outlet on Ray Roberts Lake to the RRWTP. At a low point in their 60-inch raw water pipeline, the COD observed approximately 70% clogging due to zebra mussel and Asian clam shells (Figure 2-3). The COD also had to clean mussel shells from their ozone contactors at the RRWTP. Upper Trinity Regional Water District (UTRWD) has also collected mussels ranging in size from juveniles to adults at their intake near the Lewisville Lake Dam (Figure 2-4), which suggests there is currently a reproducing population near the Lewisville Lake Dam. Changes in the flow path into Lewisville Lake during the last several years of drought that North Texas had been experiencing before the spring 2015 flooding, as illustrated in Figure 2-5, may have helped to keep a population from establishing throughout Lewisville Lake. From 2005 to 2014, significant silt buildup visible from aerial images appears to have restricted the channel where the Trinity River flows into the Northern side of the lake redirecting the flow through a shallower region of the Lake and possibly acting as a filter for veligers that do not like warm water temperatures and silty surfaces. However, due to recent flooding, a heavy settlement of juvenile mussels has also been observed in the Elm Fork arm of Lewisville Lake. Most recently, in the Spring of 2016, zebra mussels were discovered in the DWU Bachman WTP raw water line originating in Fishing Hole Lake along the Elm Fork of the Trinity River downstream of Lewisville Lake.

There is now a greater risk that a more dense population may establish in Lewisville Lake and veligers from Lakes Ray Roberts and Lewisville may settle at or closer to the COD LLWTP Intake. However, there is still limited knowledge about zebra mussel growth in Texas, and there are many unanswered questions about how shallower, higher temperature Texas lakes and longer warm water seasons influence zebra mussel proliferation. For example, recent data collected by Dr. McMahon suggests that the density of the zebra mussel population in Ray Roberts Lake has significantly decreased likely due to insufficient nutrients to support the previously explosive population. Thus, it is important to continue to monitor zebra mussel movement in Texas over the coming years as more information becomes available.

Figure 2-3: Zebra Mussel Shells in the COD Raw Water Pipeline and Ozone Contactors

Figure 2-4: Zebra Mussels Observed at the Upper Trinity Regional Water District Intake on Lewisville Lake

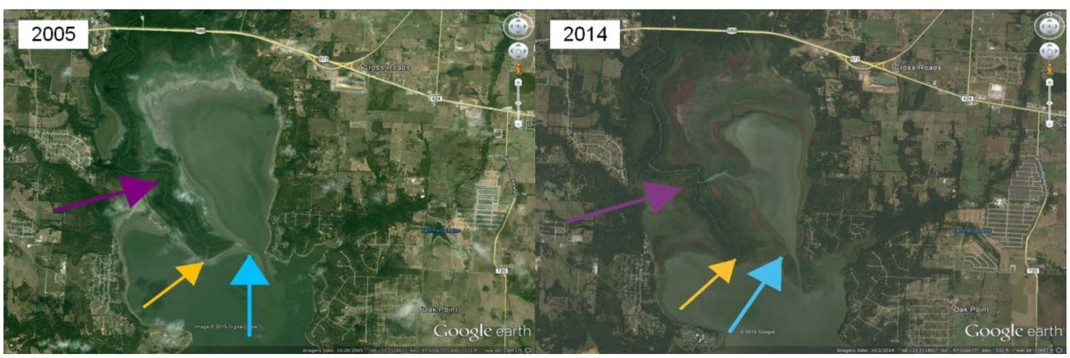


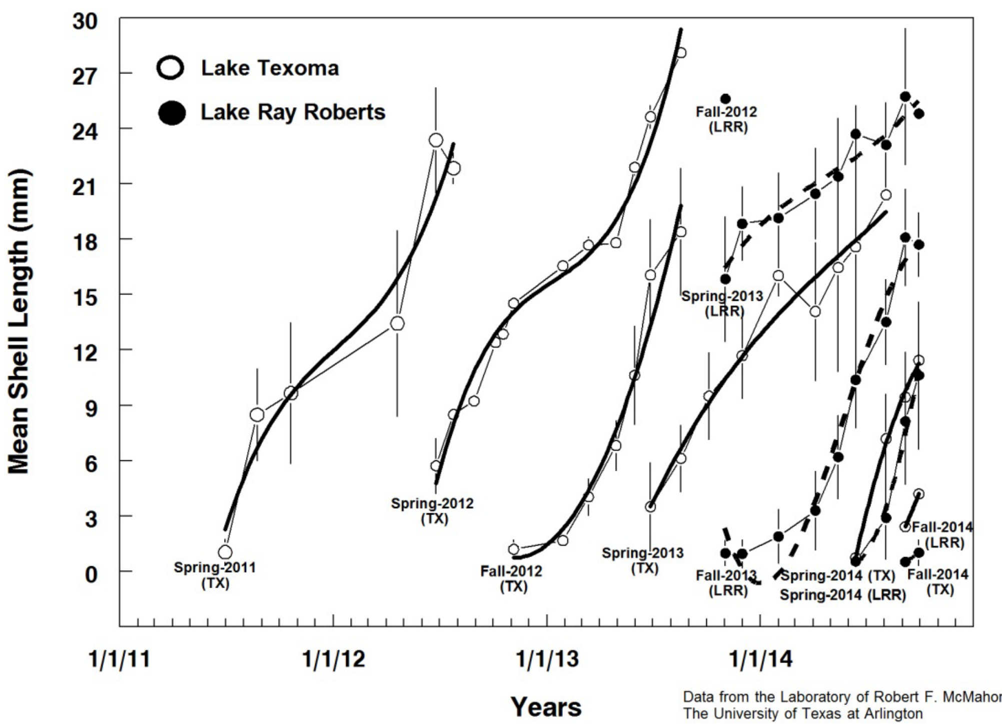
Figure 2-5: Changes in the Flow Path from the Elm Fork of the Trinity River into Lewisville Lake from 2005 to 2014.

2.3. LOCAL ZEBRA MUSSEL SETTLEMENT AND GROWTH RATES

An ongoing study of zebra mussel settlement and growth rates in Lake Texoma (R.F. McMahon, unpublished), indicates that zebra mussel life spans are much shorter and growth rates much faster in Texas water bodies than recorded for mussel populations in Europe and the northeastern United States (i.e., Great Lakes region). Based on Figure 2-6, mussels in Lake Texoma have life spans of approximately one year compared to the three- to four-year life spans observed in Europe and the northeastern United States. Further, McMahon's study has noted both spring and fall settlement seasons in North Texas due to warmer water temperatures favorable for settlement and growth. The study has observed mussels reaching maturity and spawning as little as one season following settlement (i.e., veligers that settle in the spring may be mature enough to spawn in the fall season). It is this rapid growth rate, early maturity and short life span that allowed zebra mussels to reach maximum densities in Lake Texoma in 2010, within one year of their initial discovery, extensively fouling the North Texas Municipal Water District raw water intake.

Similar rapid mussel growth rates and abbreviated life spans have been recorded in Ray Roberts Lake, resulting in severe clogging of the COD RRWTP raw water line downstream of the USACE outlet structure.

In North America, zebra mussels spawn at 16-18°C (McMahon and Bogan 2001), which corresponds to approximately eight months of the year. According to data collected by Bob McMahon (R.F. McMahon unpublished data), spawning and settlement of veligers in Ray Roberts Lake generally begins in May and continues until late August and early September when water temperatures peak and settlement is inhibited. If a second (i.e., fall) reproductive cycle occurs, which varies from year to year, settlement begins again in late August when water temperatures decrease and continues until mid-December. Thus, settlement monitoring in North Texas has shown that zebra mussels spawn and settle anywhere from 4 to 8 months of the year.



Mean shell lengths of zebra mussels sampled from artificial substrates (house bricks) submerged at a depth of approximately 1.5 m from a floating dock at Eisenhower Yacht Club Marina in Lake Texoma, Texas (TX, open circles) and in Ray Roberts Lake (LRR, solid circles). Solid lines represent the best fit of mean shell length values to a third-order polynomial regression. Horizontal bars about means represent standard deviations. Note that a fall settlement of zebra mussels was only recorded in Lake Texoma during 2012 (Fall-2012).

Figure 2-6: Growth Rates of Generational Cohorts of Zebra Mussels, *Dreissenia polymorpha*, in Lake Texoma 2011 through 2014 and Ray Roberts Lake 2013 through 2014. (Source: Dr. Robert F. McMahon unpublished data)

2.4. THE COD RAY ROBERTS EXPERIENCE

COD staff started monitoring the zebra mussel situation in Ray Roberts Lake when they were first discovered in 2012. Early efforts by staff included becoming more educated on zebra mussel infestation problems experienced by water utilities with water treatment plant intakes in the Great Lakes region that became infested in 1988. COD staff began investigating the impact of zebra mussels and potential mitigation strategies, and also had numerous discussions with engineering consultants and other utilities in the region that have experience with or are gaining experience with managing zebra mussels in potable water facilities. At that time, plant management and operations personnel were asked to diligently watch for signs that zebra mussels had migrated into plant piping and process units including changes in plant operations, reduction in hydraulic capacity and required equipment maintenance.

In the fall of 2013, approximately 15 months after zebra mussels were first discovered in Ray Roberts Lake, staff observed and reported to management that a few unattached adult zebra mussels were found during routine maintenance of a pre-ozone contactor at the head works of the RRWTP. The pre-ozone contactor is the first process unit located at the head of the water treatment plant process. This observation was the first indication that zebra mussels may have entered the city's raw water piping system. Later in the fall of 2013, staff were invited by the USACE to witness their inspection of the trash racks at the lake side of their outlet works on Ray Roberts Lake. This inspection revealed there was a zebra mussel infestation on the intake screens. The water intake system for the water treatment plant at Ray Roberts Lake utilizes the USACE outlet works and piping system to transfer water from the lake outlet works structure, under the dam through a 60 inch pipe to the USACE low flow discharge outlet channel located on the downstream side of the dam. This inspection confirmed that zebra mussels had begun to colonize on the inlet side of the low flow release piping system on Ray Roberts Lake.

Figure 2-7: Zebra Mussel Infestation of the Ray Roberts Lake USACE Outlet Trash Racks (October 31, 2013)

In March of 2014, the COD inspected the raw water intake piping at the RRWTP. Two sections of the piping system were inspected using closed circuit television (CCTV) cameras and a map of these inspection areas is attached for reference. This inspection revealed a moderate (about 70% coverage one layer deep) zebra mussel infestation on the 60 inch raw water pipeline from the raw water pumping station to the USACE's low flow outlet piping. A significantly lesser (about 20% coverage) infestation was observed on the 42 inch raw water piping near the head works of the water treatment plant. This inspection confirmed an infestation of the RRWTP raw water pipelines.

Figure 2-8: Zebra Mussel Shells in the City of Denton Raw Water Pipelines (March 11, 2014).
The Top Two Photos are the 60" Pipeline and the Bottom Two Photos are the 42" Pipeline.

Following inspection of the pipelines, COD staff proposed four new capital projects in the Water Production Division's 5 year Capital Improvements Program to address the infestation over the next three years. The projects totaling over three million dollars are outlined in Table 2-1.

Table 2-1: Proposed Capital Projects to Address the Current Zebra Mussel Infestation and Prepare for Future Infestations

Fiscal Year	Project Description	Budget	Actual Cost
2015	Cleaning and removal of zebra mussels in the RRWTP raw water piping including installation of new manways	$ 500,000	Manways: $ 265,818 Cleaning: $ 224,493 Denton Staff: $6,000
2015	Preliminary design evaluation for zebra mussel mitigation strategies for the LLWTP and RRWTP (the current study)	$ 150,000	$ 148,632
2016/2017	Design and construction of recommended improvements for zebra mussel management at the RRWTP	$ 2,800,000	Unknown
2016/2017	Design and construction of recommended improvements for zebra mussel management at the LLWTP	$1,200,000	Unknown

The cleaning project was initiated immediately. The City received two bids but had to go with the more expensive contractor due to scheduling constraints. Manway installation began in December 2014. Seven new manways were added by Archer Western Construction along the pipeline, primarily at low points and bends, for cleaning access as shown in Figure 2-9. Clean-Co Systems then performed the cleaning of the pipelines using water blasting and a vacuum truck (Figure 2-10). Photos taken at the manway locations (Figure 2-11) show that the infestation was much more severe closer to the intake.

Figure 2-9: Location of RRWTP Raw Water Manways (December 2014)

Figure 2-10: Hydroblasting the Raw Water Lines (Left) and a Fouled Pipeline Coupon (Right)

Figure 2-11: Zebra Mussel Observations at the Location of RRWTP Raw Water Manways (December 2014)

In January 2015, the COD also drained their pre-ozone contactors for an inspection. A large volume of zebra mussel shells were observed (Figure 2-12) and removed from the north contactor. The outlet cells yielded approximately 3 cubic yards of shells. These shells were most likely washed downstream through the raw water system as ozone contactors are not a feasible location of mussel attachment and growth due to the high oxidant concentration. COD questioned whether mussels shells flowed into the ozone drain and may also be in the 12" lines. Additional drain testing would be required to determine whether any shells that entered the drain are impacting the flow rate through the drain system.

Figure 2-12: Zebra Mussel Observations and Removal in the Ozone Contactors at the RRWTP (January 2015)

Pipeline cleaning continued into February 2015. At the lowest section of the 60" pipeline leading from the USACE outlet structure on Ray Roberts Lake, 50-80% blockage with mussel shells was observed and removed (Figure 2-13). This low point was the primary concern and likely had the greatest hydraulic impact on COD operations due to the volume of shells that had accumulated. As the COD transfers water out of Ray Roberts Lake from the USACE outlet, the COD will continually need to remove accumulated mussel shells from this location. Even if a more proactive strategy is implemented to prevent mussels from attaching to the COD pipelines, mussel shells will still travel through the unprotected USACE outlet into COD facilities. Implementing design approaches to ease future physical removal from this location will be a key component of the overall COD management approach for the RRWTP raw water system.

Figure 2-13: 50-80% Blockage of Mussel Shells in the Low Section of the 60" RRWTP Raw Water Pipeline Downstream of Ray Roberts Lake (February 2015)

Once cleaning was complete, removed mussel shells were placed in an empty sludge lagoon (Figure 2-14) and sprinkled with HTH (calcium hypochlorite). Toxicity characteristic leaching procedure (TCLP) testing was successfully completed by the COD on mussels collected from the lake prior to transport by the City and disposal in the Denton Landfill (owned by the City). CCTV was completed on cleaned pipelines to verify project completion. Some pitting of the pipelines is visible on the CCTV from removal of the mussels. In addition to mussel shells being very sharp, byssal threads from the mussels pull small pieces of concrete off with them when removed and accelerate pitting and corrosion rates when left in place. Bacteria can live in the space between byssal threads and the pipe material and produce acid compounds through anaerobic respiration (Mackie and Claudi, 1994).

Figure 2-14: Asian Clams and Zebra Mussels Stored in the RRWTP Lagoons

The COD noted that a portion of the shells removed from the RRWTP raw water system were Asian clams (Figure 2-14). Asian clams were also recently found blocking about 50% of a raw water pipeline at the Dallas Water Utilities (DWU) Bachman Water Treatment Plant downstream of Lewisville Lake along the Elm Fork of the Trinity River. Although Asian clams do not attach to surfaces, as do zebra mussels, significant buildup of shell volumes is likely, especially in low points of lines, regardless of whether a future zebra mussel infestation occurs. The existence of both zebra mussel and Asian clam populations increases the likelihood of significant hydraulic impacts to the raw water system.

As the first utility in North Texas to face physical removal and disposal, the City faced a large learning curve and overcame several challenges. Local pipeline cleaning contractors did not have experience with removing mussels. The cleaning took far longer than estimated and required the City to provide some equipment including a water connection from a fire hydrant, ladders, generators, etc. The cleaning head used in the project was not sized sufficiently for the 60" pipeline and thus had to make multiple runs to complete cleaning of the larger line. Lastly, the contractor left the site before completing removal and transport of the mussels from the final line segment. Thus, the City staff had to enter the line to remove the remaining mussels and debris with their own vacuum trucks. Based upon these lessons learned, the City will be able to provide more detail in future cleaning contracts and is considering completing future cleaning events in-house.

2.4.1. USACE Zebra Mussel Management Plan for the Ray Roberts Lake Outlet

The USACE contract number 14-C-0076 (September 2014) called for cleaning (including mussel removal and disposal) and painting of the service gate wells (approximately 65 feet deep) and trash racks with Coal Tar Epoxy Paint (Elite C-200 equal to or better). The COD immediately began discussions with the USACE as coal tar epoxy is not National Science Foundation (NSF) approved for potable drinking water supplies and the COD transfers water from the USACE outlet to the RRWTP for potable drinking water treatment. As of November 2014, the USACE is planning to use the Sher-Release System Seaguard® Tie Coat and Surface Coat System on the trash racks and gate wells. The Sher-Release coating is a silicon-based coating with ANSI/NSF 61 approval for use in drinking water systems. The low surface energy will likely reduce the amount of fouling and ease future cleaning efforts. However, silicon-based coatings are very susceptible to abrasion (Nalepa and Schloesser, 2014) and will likely require recoating at least every 6 years (Wells and Sytsma, 2009). Additionally, the COD should be aware that pieces of the abraded coating may travel downstream into the COD raw water system. As of March of 2015, the USACE was rebuilding new trash tracks with the Sher-Release coating and had plans to divert additional funding toward zebra mussel mitigation evaluations and potential additional capital projects.

2.5. WATER QUALITY CONSIDERATIONS

The water quality review included monthly data collected by COD on temperature, pH, total organic carbon (TOC), dissolved organic carbon (DOC), alkalinity, hardness, calcium, iron and manganese. Certain water quality conditions are more favorable for zebra mussel establishment, growth and proliferation than others. Table 2-2 presents the ranges where key water quality parameters have been historically favorable to zebra mussel growth and the ranges of those parameters in which zebra mussels are unlikely to establish. However, it is important to note that zebra mussels have adapted and evolved to become established in environments previously considered to be uninhabitable (e.g., based on thermal tolerance studies the surface waters in the southern US were considered uninhabitable by zebra mussels due to high water temperatures).

Table 2-2: Water Quality Conditions Favorable and Unfavorable to Zebra Mussel Growth (Source: Mackie and Claudi, 2010 and Team Experience)

Water Quality Parameter	No Potential for Establishment of a Population	Moderate Potential for Nuisance Infestations	High Potential for Massive Infestations
Temperature (°C)	<16, >32	16-20, 30-32	20-30
pH	<7.8, >9.0	7.8-8.2, 8.8-9.0	8.2-8.8
Alkalinity (mg $CaCO_3$/L)	<55	55-100	100-280
Hardness (mg $CaCO_3$/L)	<55	55-100	100-280
Calcium (mg Ca/L)	<12	12-20	>20

Data collected by COD from 2013 through 2014 for Ray Roberts Lake and Lewisville Lake are presented in Figure 2-15 through Figure 2-19 for temperature, pH, alkalinity, hardness, and calcium, respectively. Red boxes highlight the range of each water quality parameter with moderate to high potential for zebra mussel infestations based upon Table 2-2. The dashed lines on Figure 2-15 represent regions outside which zebra mussels are not likely to survive.

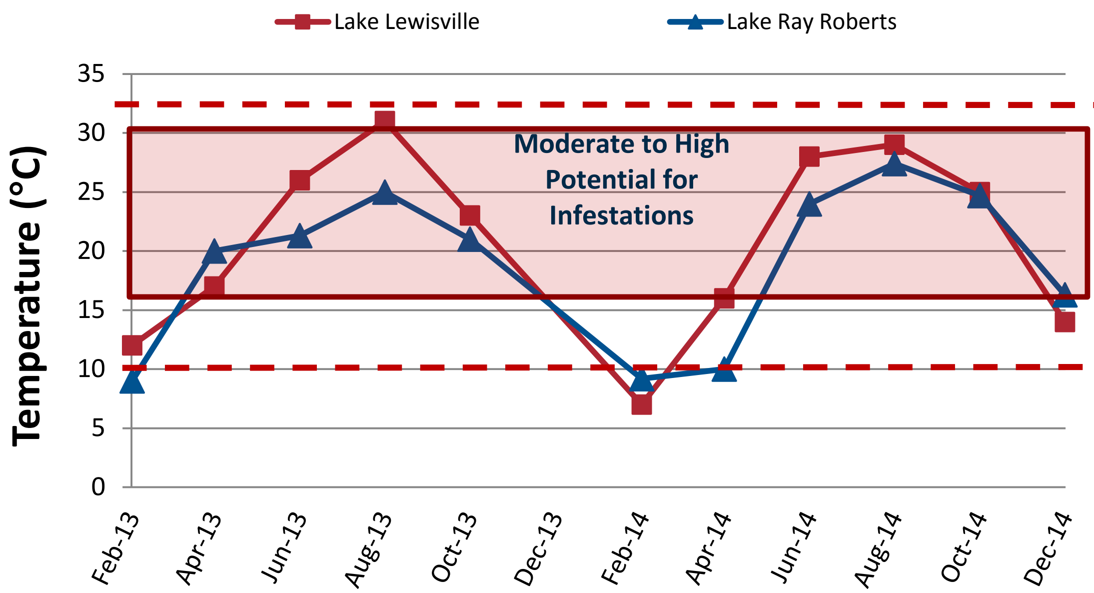


Figure 2-15: Temperature in COD Source Waters from 2013-2014 Compared to Conditions Favorable for Zebra Mussel Infestations

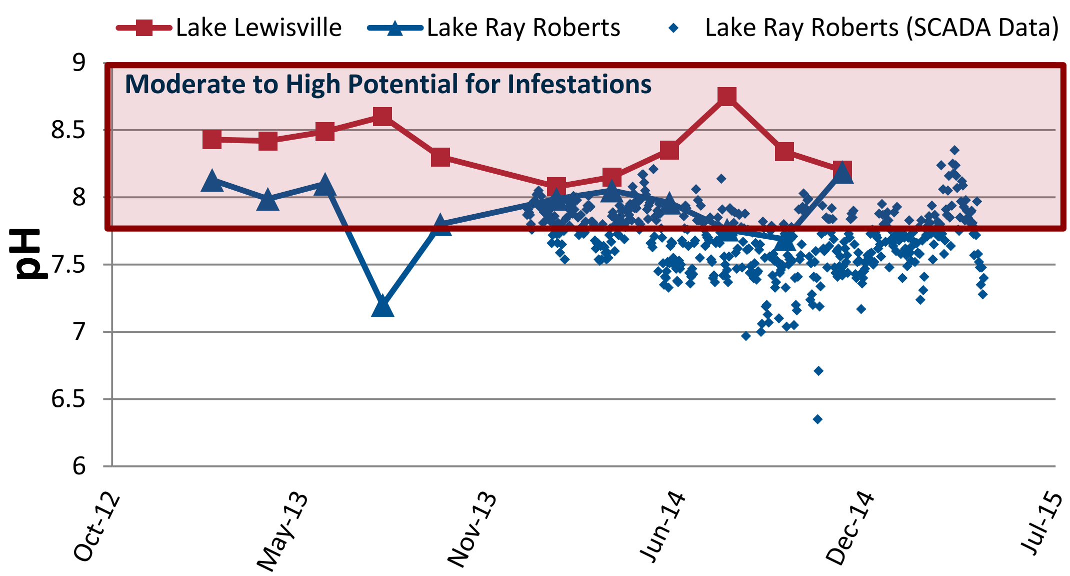


Figure 2-16: pH in COD Source Waters from 2013-2014 Compared to Conditions Favorable for Zebra Mussel Infestations

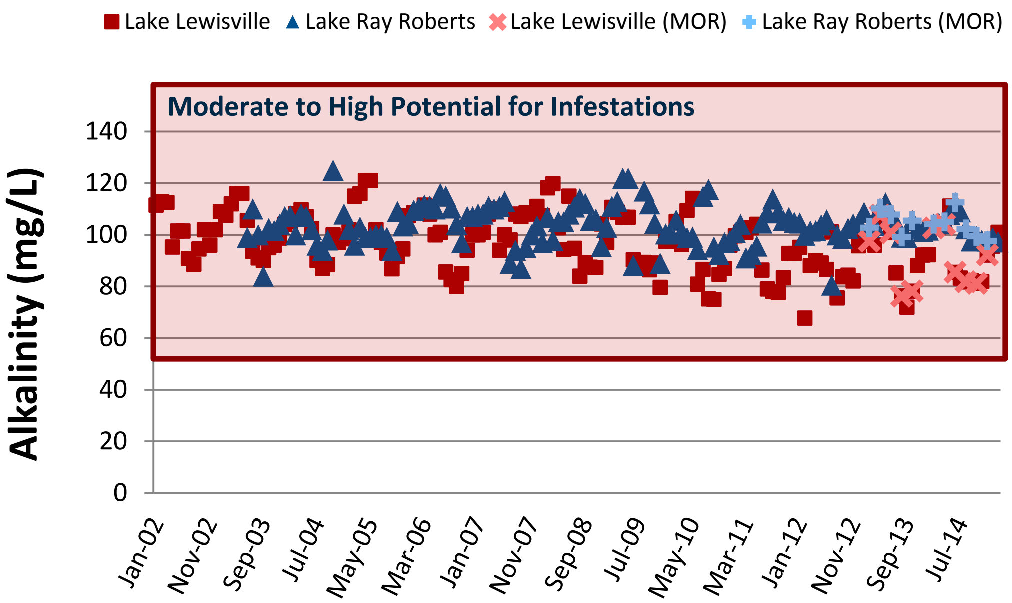


Figure 2-17: Alkalinity in COD Source Waters from 2013-2014 Compared to Conditions Favorable for Zebra Mussel Infestations

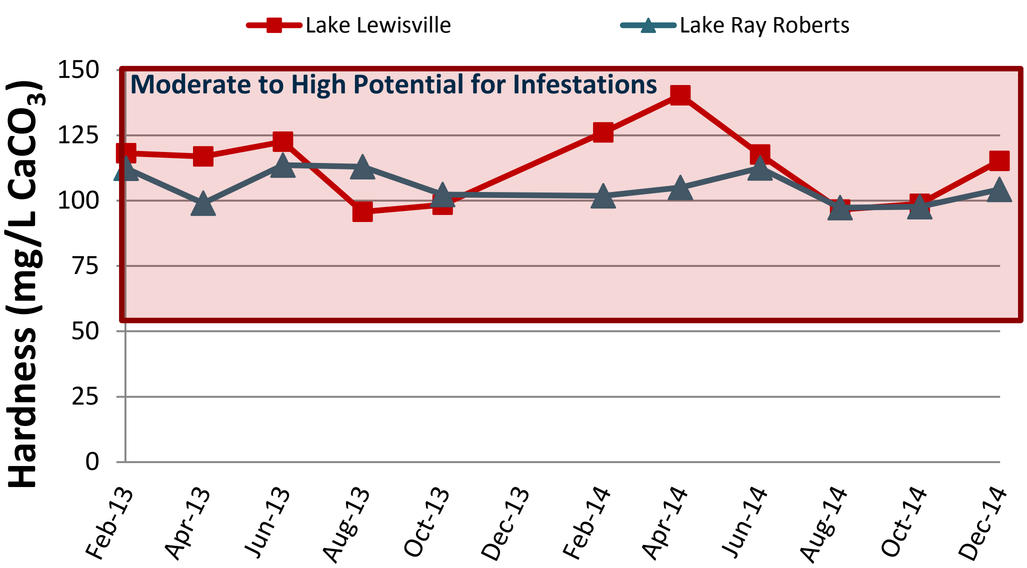


Figure 2-18: Hardness in COD Source Waters from 2013-2014 Compared to Conditions Favorable for Zebra Mussel Infestations

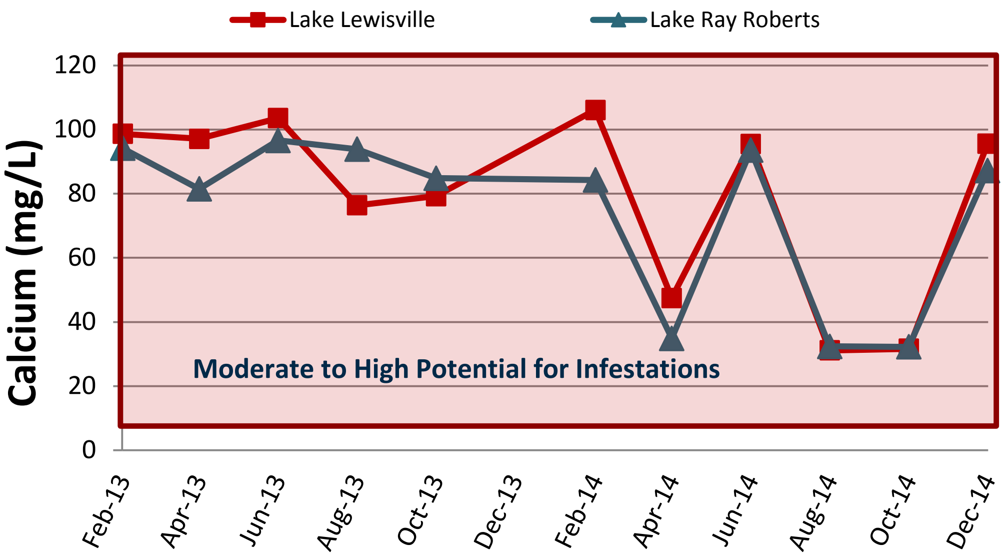


Figure 2-19: Calcium in COD Source Waters from 2013-2014 Compared to Conditions Favorable for Zebra Mussel Infestations

The key water quality parameters that support zebra mussels for COD source water data generally fall within the range for moderate to high potential for zebra mussel infestations (i.e., the red boxes). April through December appears to be the most likely season, locally, for zebra mussel propagation. December through April appears to generally have water too cold for zebra mussel settlement. However, these temperatures may not be limiting to zebra mussel populations in Texas. Additionally, zebra mussel veligers will likely not settle the entire period (i.e., approximately 8 months) that the temperature is favorable. Settlement monitoring is required to determine the exact timing of local mussel settlement.

2.6. RELATED REGULATIONS

Zebra mussel management will require coordination with multiple regulatory agencies throughout the planning, design, and construction phases of the project. Which agencies are involved depends on the selected zebra mussel management approach and the application (e.g., additional permits may be required for any alterations to the valve vaults owned by the USACE upstream of the COD raw water lines). Table 2-3 and Table 2-4 below summarize regulatory agencies and regulations that may be required for zebra mussel management alternatives. Additional regulatory considerations include confirmation that no structures will be built below the ordinary high water mark and investigation of the relation of the 100-year floodplain to locations of chemical storage, transfer, and feed facilities. COD permits may also be required. For example, a building permit may be required if the project scope includes construction of a chemical storage building.

Table 2-3 outlines potential applicable regulations through the **US Environmental Protection Agency (USEPA) and the TCEQ.** USEPA and TCEQ will be involved in all zebra mussel management approaches for potable water facilities and may also require a Pesticides General Permit for potable facilities if application of a chemical to or near a water of the United States (US) is involved. A Texas Pollutant Discharge Elimination System (TPDES) Construction Permit and Stormwater Pollution Prevention Plan may also be required if construction activities disturb more than one acre, or are located within ¼ mile of other construction. To date, there have been very few, if any, zebra mussel management approaches permitted through TCEQ for potable water systems. Therefore, TCEQ is not familiar with all the zebra mussel management approaches (coatings, chemicals, etc.) and other unique attributes of these projects, such as application of a chemical at a raw water intake (normally this would be done at the treatment plant or in the raw water pipeline for oxidation or to meet other water quality goals). Arcadis proposes presenting likely zebra mussel management approaches to TCEQ and working with them through the process to determine what is needed to permit the technology. For example, for chemical application at a raw water intake, flow modeling or tracer studies may be employed to demonstrate that the chemical feed system will be designed to ensure there is no backflow into the source water. It may also be useful to supply full-scale installation lists for less common zebra mussel management approaches that are in use in other places. Working hand-in-hand through the permitting process with TCEQ will expedite the schedule for permit approvals.

Regulatory agency guidance specific to zebra mussel disposal is limited. Experience with the first wave of mussels through the Great Lakes showed there was a great deal of difference from jurisdiction to jurisdiction on the “legally approved” disposal method. For example, in New York, the approved disposal method was different from New York State Department of Environmental Conservation (NYSDEC) region to region – in Western New York removed mussels could be left at the intake (any mussels brought to the surface required landfilling) but on the Hudson River all mussels had to be collected and landfilled. One local office went so far as initially requiring hazardous landfill disposal (later retracted). There is not a toxic material concern associated with land disposal of zebra mussels based upon RCRA (Resource Conservation and Recovery Act), TSCA (Toxic Substances Control Act), or USEPA contaminated dredged sediment criteria. TCLP testing of the mussels has already been completed by the COD for mussels from Ray Roberts Lake. Similar testing may be required if mussels are removed from the LLWTP raw water system or if mussels were to be transported to a different landfill. Nearly all zebra mussel populations that have been studied do not accumulate toxins at levels that violate USEPA dredged sediment criteria (USEPA 1990) according to bulk or leachate testing (Doherty et al. 1993; Kreis et al. 1994, Secor et al. 1993, van der Velde et al. 1992). There are no RCRA or TSCA concerns that have arisen from zebra mussel disposal practices. Nonetheless, populations in water bodies known to be highly contaminated should be considered for toxicity tests to eliminate that disposal toxicity concern (Roper et al. 1996). Disposal methods, other than landfilling, may require additional regulatory coordination. For example, aquatic disposal (e.g., side-casting back to the water bodies or barge transport and aquatic disposal) would lead to Clean Water Act concerns under both Section 401 and 404.

Table 2-3: Summary of USEPA and TCEQ Potential Regulations/Permits that may be Applicable to Zebra Mussel Management

Potential Regulations	Considerations / Details
• Safe Drinking Water Act (potable water)	• National Sanitation Foundation/American National Standard Institute (NSF/ANSI) 60 and 61 compliant water system chemicals and components • Primary drinking water regulations
• Section 401 of Clean Water Act Certification	• Section 404 permits (see below under US Army Corps of Engineers) require a discharge to comply with state water quality standards, which are reviewed under Section 401 of the Clean Water Act • 401 certification may be required for construction activities
• TCEQ Public Water System Plan Review	• Required for any changes to a public water system
• TCEQ Pesticides General Permit TXG870000	• Required if a biological or chemical pesticide that leaves a residue in the water will be applied into, over, or near waters of the US
• TPDES No. TXR150000 Construction General Permit, with associated Stormwater Pollution Prevention Plan (SWPPP)	• Required for all projects that disturb more than one (1) acre, or that are located within ¼ mile of other construction work (as a permit condition known as "Common Plan of Development". Also note that SWPPP now requires maintaining vegetative buffers "or equivalent measures" for work along water bodies, and certification of no potential impacts to Threatened & Endangered Species.
• Contaminant Dredged Sediment Criteria	• None
• TSCA	• None
• RCRA Subtitle D	• TCLP testing of the mussels was completed prior to disposal of mussels from Lake Ray Roberts
• TCEQ Special Waste Regulation (RG-22)	• Form TCEQ-0152 must be completed to request authorization for disposal of a special waste
• TCEQ 30 TAC Subchapter R §§335.501-335.515, 335.521	• Testing of the waste is required to determine the waste classification

Involvement by the **USACE, US Fish and Wildlife Service (USFWS), and TPWD**, as outlined in Table 2-4, may be required for zebra mussel management projects that may have the potential for adverse environmental effects or affect native species in source water or other environments. Coordination with these agencies will need to be included in the project planning and scheduling phases. Previous project experience indicates that, at a minimum, coordination with USFWS and TPWD will require submittal of a letter stating that any chemical applied within the intake structure will flow directly into the treatment plant and pumping system interlocks will be used to prevent chemical release into the aquatic environment. The review process typically takes 30 days. If no recent surveys for presence/absence of indigenous species are available for the immediate vicinity, the agencies may also request a presence/absence survey to understand which species could be impacted.

Table 2-4: Summary of USACE, USFWS and TPWD Regulations and Permits that may be Applicable to Zebra Mussel Management

Agency	Potential Regulations	Considerations / Details
USACE	• Nationwide Permit (NWP) for impacts to waters of the US (Section 404(e) of Clean Water Act)	• Required for projects that do not exceed the thresholds for work within the Ordinary High Water Mark of a stream • Important note: The Environmental Protection Agency/United States Army Corps of Engineers (EPA/USACE) are currently promulgating rulemaking that will expand 404 jurisdiction beyond bed and banks/ordinary high water mark (OHWM) into the adjacent floodplain – this project would likely be impacted by this rulemaking • Handled through USACE with copies to TWM/SWM/FPM • Requires pre-construction notification to the district engineer prior to commencing activity • 45-day review
	• Section 404 Permit	• Required for projects that exceed the thresholds for a NWP; Handled through USACE with copies to TWM/SWM/FPM. Note this may take significantly longer to attain than work covered under the NWP.
	• Section 408 Permit	• Required for projects that alter/modify existing USACE projects in certain circumstances
	• 100-year floodplain	• Confirmation no structures or fill will be constructed below the OHWM
USFWS	• Informal Coordination	• 30-day review which may require a presence/absence survey
TPWD	• Aquatic Resource Permit and sensitive species assessments • Sand and gravel permit	• 30-day review for sensitive species and may require an aquatic protection/relocation plan • 30-day review plus 30-day public notice period (required for any work in any state water body wider than 30 feet)

3. ZEBRA MUSSEL MANAGEMENT, OPERATION AND MAINTENANCE APPROACHES

Management, operation and maintenance approaches were identified and evaluated for the COD systems. Management approaches (Section 3.1) evaluated includes preventative, control and reactive strategies as well as disposal methods. Based upon these evaluations, the COD selected top alternatives for site-specific detailed evaluations in Sections 4 and 5. O&M approaches (Section 3.2) evaluated include O&M enhancements, chemical dosing strategies, and risk management approaches. From here forward, only zebra mussel management will be referenced. However, management approaches for zebra mussels would also limit Asian clam growth.

3.1. MANAGEMENT APPROACHES

A review was conducted to identify and evaluate zebra mussel management technologies (i.e., preventative, control, and reactive strategies), as well as disposal methods. Ideally, all zebra mussel management strategies should comprise a multi-barrier approach, incorporating a strategy from each of these categories. For example, a management approach might include an oxidant that can prevent settlement of veligers when low doses are maintained through the system (i.e., a preventative strategy) and kill adult mussels at a higher dose (i.e., a control strategy), as well as provisions for physical removal and disposal (i.e., a reactive strategy).

During the Alternatives Analysis Workshop, COD ranked evaluation criteria (Section 3.1.1) to establish a basis for selecting alternatives. Upon reviewing and discussing all of the alternatives identified through literature reviews and previous project experience, COD staff selected the most feasible alternatives for implementation at the COD raw water systems to be further evaluated (Section 3.1.2). Based upon these evaluations, the COD selected top alternatives for site-specific detailed evaluation including development of costs and conceptual layouts. Detailed evaluations and recommendations specific to each WTP are summarized in Sections 4 and 5.

3.1.1. Evaluation Criteria

Quantitative and qualitative criteria were developed to evaluate each zebra mussel management alternative. Costs can be quantified, whereas, qualitative criteria are subject to opinion and interpretation. Although quantitative criteria are typically the leading factor in choosing an alternative for implementation, qualitative criteria provide a relative score for non-economic factors that should also be considered. The quantitative and qualitative evaluation criteria considered for this evaluation are shown in Table 3-1.

Table 3-1: Evaluation Criteria

Criteria	Description
Life Cycle Cost (Capital and O&M)	Net present value (NPV) of the alternative. This value provides the cash value of the alternative after 20 years in present day dollars. NPV accounts for capital, operation, and maintenance costs as well as inflation over a 20-year period. An interest rate of 3% and escalation factor of 3.5% will be assumed.
Effectiveness for Zebra Mussel Control	A relative measure of the alternative's effectiveness in preventing zebra mussel infestations (i.e., likelihood to completely kill veligers or adults or prevent mussel attachment/settlement). Consideration is given for whether or not chemicals can prevent settlement or kill veligers with a cost effective dose and practical contact time. Additionally, consideration is given for water quality conditions that may lower effectiveness and whether toxicity will lessen over time.
Ease of O&M and Operational Flexibility	A relative measure of the alternative's operational simplicity and resources required for operation (sustainability). Additionally, consideration is given for the flexibility to adjust operation based on source water conditions and the extent of zebra mussel infestation.
Impact to Downstream Water Quality and Water Treatment Plant	A relative measure of the alternative's impact to downstream water quality or infrastructure.
Impact to Environment / Ecology	A relative measure of the alternative's impact to the ecology and environment surrounding the application point including the likelihood of obtaining regulatory approval. Also, consideration is given for the risk associated with chemical spills.
Implementability	A relative measure of the difficulty in constructing the alternative's facility, ease of acquisition for equipment, replacement parts, and chemicals, and availability of manufacturer support. Specifically, considering the complexity of equipment and timeliness with which an alternative could be installed or constructed, including the time required to obtain approval or permits from regulatory agencies.
Health & Safety	A relative measure of the alternative's health and safety risk to personnel on site and the surrounding community.
Status in the Industry / Record of Performance	A relative measure of whether the alternative has been proven effective in previous full-scale applications and is generally accepted by the industry as an effective alternative.
Public Acceptability	A relative measure of whether the alternative would generate concern from stakeholders of the public water system (e.g. due to the implementation of a new technology or the potential for an unintended water quality consequence downstream).

Evaluation criteria were confirmed with COD staff during the Alternatives Analysis Workshop, and staff was asked to rank each criterion in order from most important (1.0) to least important (9.0). The participant responses are compiled in Appendix D.

Table 3-2 summarizes the participant responses. All of the criteria were considered throughout the alternative evaluation process, with special attention to effectiveness for zebra mussel control, ease of O&M and operational flexibility, status in the industry / record of performance and life cycle cost, which were ranked the highest by COD staff.

Table 3-2: Evaluation Criteria Ranking Results

Criteria	COD Team Average Ranking	Overall Ranking	Weight[1]
Effectiveness for Zebra Mussel Control	1.3	1	22%
Ease of O&M and Operational Flexibility	3.1	2	16%
Status in the Industry / Record of Performance	3.8	3	15%
Life Cycle Cost (Capital and O&M)	3.9	4	14%
Impact to Downstream Water Quality and Water Treatment Plant	5.2	5	11%
Health & Safety	5.8	6	9%
Implementability	6.2	7	8%
Impact to Environment / Ecology	7.7	8	4%
Public Acceptability	8.2	9	2%

1 – Weight calculated as the average COD team ranking divided by the sum of the average COD team rankings such that the weights sum to 100%.

3.1.2. Preventative, Control and Reactive Strategies

A review was conducted to identify and evaluate zebra mussel management approaches. Mussel management approaches can be classified as preventative, control, or reactive strategies, or a combination thereof. Figure 3-1 provides an overview of the difference between a preventative, control and reactive management strategy.

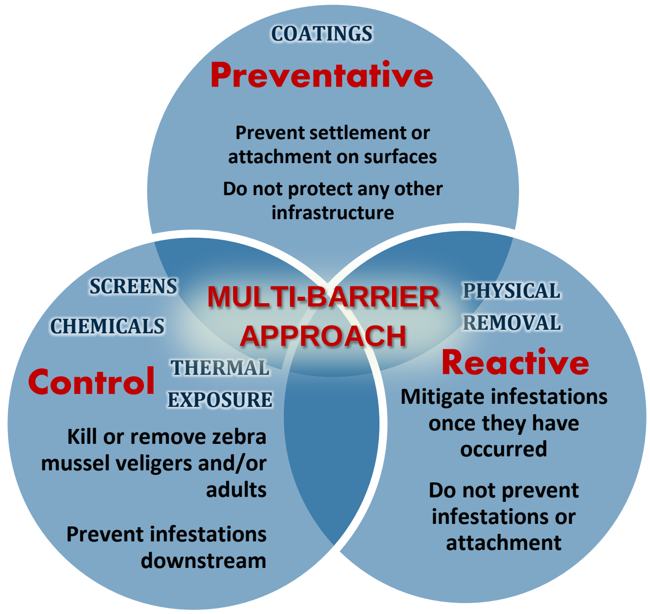


Figure 3-1: Preventative, Control, and Reactive Strategies

Preventative approaches prevent zebra mussel settlement or attachment on surfaces but do not mitigate existing zebra mussel infestations. These alternatives must be applied throughout the system requiring protection as they will not prevent an infestation in unprotected downstream components (e.g. a low concentration chemical residual must be maintained throughout the system).

Control strategies kill or remove zebra mussel veligers and/or adults. These alternatives prevent infestations from occurring downstream of the application point by killing or removing veligers or adult mussels from the water source. However, these alternatives may not be feasible in all applications depending on the physical constraints (e.g. pipeline residence times or existing structures).

Reactive strategies mitigate and remove zebra mussel infestations once they have occurred. Every management approach will have some component of physical removal, whether it is removing mussel shells that have accumulated in pipeline low points after die-off events in the water source or removing mussels that accumulate over time, even with the best management approaches. There may also be cases where more proactive strategies are not feasible or cost effective. For example, physical removal will likely be required long-term in the Ray Roberts 60" raw water line as shells will likely continue to be flushed into the COD pipelines through the USACE outlet.

Ideally, a comprehensive management approach would include a strategy from each of these categories. For example, a management approach might include an oxidant that can prevent settlement of veligers when low residuals are maintained through the system (i.e., a preventative strategy) and kill adult mussels at a higher dose (i.e., a control strategy) as well as provisions for physical removal (i.e., a reactive strategy).

During the Alternatives Analysis Workshop, preventative, control and reactive strategies were discussed. Considerations related to feasibility of each potential management approach for COD, such as effectiveness and operational impacts, were derived from discussions with the technical advisors for this project, discussions with vendors, and a review of available literature (e.g. Nalepa and Schloesser, 2014; Mocek, 2013; McMahon, 2013; and others presented in Appendix A), as well as the results of site visits and reviews to understand the design and operation of the COD facilities at risk for zebra mussel fouling. COD staff then scored each strategy based on the level of feasibility for implementation in the COD system. Scoring was completed on a scale from A – D (or 1 – 4) where:

- A (1.0) – Very feasible
- B (2.0) – Feasible but some limitations
- C (3.0) – Feasible but many limitations
- D (4.0) – Not feasible / not interested

A summary of preventative, control and reactive strategies evaluated including the average results of the scoring exercise is shown in Table 3-3 for chemical alternatives and Table 3-4 for non-chemical alternatives. Appendix D provides individual scoring.

Table 3-3: Summary of Zebra Mussel Management Alternatives Evaluated: Chemical Alternatives

Alternative	Strategy	Description[1,2]	Primary Considerations	Ranking by COD	Selected for Further Consideration?
Sodium Permanganate	Preventative & Control	0.25 parts per million (ppm) residual required prevent settlement; 1.5-2.0 ppm dose likely required to prevent settlement	• 40% liquid solution is easy to operate • No regulated disinfection by-product (DBP) formation • Could increase manganese concentrations and result in colored water or turbidity if treatment processes are not optimized	1.4	Yes (Section 3.1.2.1)
Potassium Permanganate	Preventative & Control	0.25 ppm residual required to prevent settlement; 1.5-2.0 ppm dose likely required to prevent settlement	• Labor intensive batch mixing of dry chemical • No regulated DBP formation • Could increase manganese concentrations and result in colored water or turbidity if treatment processes are not optimized	1.8	Yes (Section 3.1.2.1)
Non-Oxidizing Molluscicides	Preventative & Control	Cationic Polymers and Polyquarternary ammonium compounds (e.g. Bulab 6002, Calgon, Veligon)	• May form NDMA or other by-products • Limited municipal potable water installations for zebra mussel management • Long-term NSF limit of 0.5 ppm	2.3	Yes, Bulab 6002 (Section 3.1.2.1)
		Copper Ion Generation Systems (e.g. Fortress MC or MacroTech)	• Increased copper concentrations (Secondary Maximum Contaminant Level (SMCL) of 1 ppm; Lead and Copper Rule Action Level of 1.3 ppm) • Alum floc settling in and coating the pipeline (aluminum SMCL of 0.2 ppm) • Limited municipal potable water installations for zebra mussel management		Yes (Section 3.1.2.2)
		Copper Sulfate Algaecides (e.g. EarthTec QZ)	• Increased copper concentrations (SMCL of 1 ppm; Lead and Copper Rule Action Level of 1.3 ppm) • Simple bulk chemical feed system • Limited municipal potable water installations for zebra mussel management due to new permit		Yes (Section 3.1.2.2)
		Aromatic Hydrocarbons (e.g. Mexel 432, Bulab 6009)	• Used in non-potable industrial applications • Not NSF certified for drinking water applications		No

Alternative	Strategy	Description[1,2]	Primary Considerations	Ranking by COD	Selected for Further Consideration?
		Endothall (e.g. EVAC)	• Greater than 0.3 ppm required for zebra mussel management (MCL of 0.1 ppm) • Limited municipal potable water installations for zebra mussel management		No
		Potassium compounds (e.g. potash, potassium chloride)	• Increased potassium concentrations • May require downstream removal • Limited municipal potable water installations for zebra mussel management		No
Chlorine Dioxide	Preventative & Control	0.125 ppm residual required to prevent settlement; >1.5 ppm dose likely required to prevent settlement	• Results in chlorite DBP (MCL of 1 ppm corresponding to about 1.5 ppm of chlorine dioxide) • Requires on-site generation with multiple chemicals	2.4	Yes (Section 3.1.2.1)
Chloramines	Preventative & Control	1.5 ppm residual required to prevent settlement; 5 – 7 ppm dose likely required to overcome pipeline demand	• May increase nitrification and N-nitrosodimethylamine (NDMA) formation • Operational complexity due to fluctuating ammonia concentrations in the raw water • Requires quenching before the biological filters	3.1	Yes (Section 3.1.2.1)
Hydrogen Peroxide	Preventative & Control	Approximate 9 ppm dose may be required	• Limited information available on effectiveness	3.6	No
Bromine	Preventative & Control	Recommendations on dosing not available	• Limited information available on effectiveness	3.7	No
Ozone	Preventative & Control	Demand testing conducted by the City of Dallas suggested a dose greater than 8 ppm would be required due to fast decay kinetics	• Not feasible with existing plant facilities due to fast decay rates • May require bromate mitigation	3.8	No
Chlorine / Sodium Hypochlorite	Preventative & Control	Greater than 5 ppm dose likely required to overcome ammonia and organic demand	• Formation of regulated DBPs (i.e. Total Trihalomethanes (TTHMs) and Haloacetic Acids (HAAs)) • Proven effective • Hazardous chemicals	4.0 / 3.8	No

1 – Reported chemical residuals and doses are based upon literature (San Giacomo and Wymer, 1997, McMahon et al., 1994, McMahon, 2013; Mackie and Claudi, 2010; McMahon, 2014; and Van Benschoten et al., 1993), vendor recommendations and previous project experience. The bulk of chemical dosages reported in the literature are based on Great Lakes water which generally has lower organic content than the local source water. Doses presented in this table do not reflect demand testing conducted on COD source waters and do not account for pipeline biofilm demand, unless otherwise stated.
2 – Doses to control (i.e. kill mussels) are higher than those listed for settlement and may require long contact times at the higher doses.

Table 3-4: Summary of Zebra Mussel Management Alternatives Evaluated: Non-Chemical Alternatives

Alternative	Strategy	Description	Primary Considerations	Ranking by COD	Selected for Further Consideration?
Metal Alloy Materials of Construction or Coatings	Preventative	Materials such as copper or brass are toxic to mussels, and thus, prevent attachment (Nalepa and Schloesser, 2014); zinc and zinc oxide may also be toxic to a lesser extent	• Proven effective • Limited vendors • Leach metals at low rates • Warranty for 5 years	1.4	Yes. (Sections 4.2 and 5.2)
Physical Removal	Reactive	Removal of mussels by manual cleaning with scrapers, brushes and high pressure water sprayers or pigging of pipes	• Labor intensive • Requires disposal • Likely required long-term in the RRWTP pipelines	1.5	Yes (Section 3.1.2.3)
Dewatering / Desiccation	Reactive	Removal of water, drying and periodic cleaning of components that could serve as settlement and attachment sites for veligers	• May not be 100% feasible in pipelines • Requires complete isolation • May waste large volumes of water	1.5	Yes as an O&M Strategy. (Section 3.2.1)
Foul-Release Coatings	Preventative	Hydrophobic silicone-based or fluorocarbon-based coatings inhibit zebra mussel fouling due to low surface energy and low elastic modulus	• Prevents strong attachment / eases removal • High life cycle cost due to frequent replacement (every 2-6 years) • Damaged easily by debris	2.4	No
Anti-Fouling Coatings	Preventative	Paints that leach biocides such as cuprous oxide	• Environmental concerns due to toxin release • Limited lifespan (1-2 years)	2.8	No
Oxygen Deprivation	Reactive	Isolation of pipes to reach an oxygen concentration below 30% of full air oxygen saturation for 1-2 weeks (Mikheev, 1986 and McMahon, 2013)	• Requires complete isolation or use of chemicals such as carbon dioxide, sodium sulfite or hydrazine (toxic) • Potential for increased corrosion • Handling of deoxygenated water	2.9	No
Biological Treatment	Control	Zequanox is a molluscicide composed of dead cells of *Pseudomonas fluorescens* which cause mortality in both larval and adult mussels once ingested	• Not EPA approved for potable water systems (only open water use) • Does not result in 100% mortality • Expensive (50-200 mg/L active ingredient required)	3.1	No

Alternative	Strategy	Description	Primary Considerations	Ranking by COD	Selected for Further Consideration?
Electric Shock / High Voltage Electric / Low Voltage Electric Magnetism	Control	Electric currents may either kill mussels (potentially by preventing shells from forming) or alter their behavior	• Research on effectiveness is inconsistent • No full-scale potable water installations	3.4	No
Maintenance of High Water Velocities	Preventative	Water velocities above 6.5 ft./s (Mackie and Claudi, 2010) prevent the settlement of veligers	• Control of velocities in pipelines may be difficult due to flow changes, joining streams, bends, etc.	3.4	No
Acoustics	Preventative & Control	Acoustic energy discourages settlement immediately downstream and results in mortality to both adults and veligers	• Research on effectiveness is inconsistent • No full-scale potable water installations	3.6	No
Strainers or Screens	Preventative & Control	Backwashable strainers or screens with a 40µm mesh size remove veligers and adult mussels	• In use since the late 1990's • High energy (headloss) and maintenance costs	3.8	No
Bank or Sand Filtration	Preventative & Control	Removal of adult and larval zebra mussels by bank or sand filtration with a 0.5-1.0 gpm/ft^2 loading rate (Russell, 2013)	• Requires large surface area to filter at the required low flow rate • Not feasible due to site-specific physical constraints	3.8	No
UV Light	Preventative	High intensity UV light installed in small diameter pipes. 110 mJ/cm^2 prevents settlement of veligers (Whitby, 2011)	• In the development stage • Not feasible with high turbidities • High power / maintenance requirements	3.8	No
Thermal Exposure	Control & Reactive	Exposure of mussels to temperatures above 38°C for 6 to 26 hours or as high as 50-60°C (McMahon and Ussery, 1995)	• Expensive and energy intensive to heat large volumes of water • Headloss and location of heat exchangers	3.8	No

Upon reviewing and discussing all of the alternatives identified through literature reviews and previous project experience, COD staff selected the most feasible alternatives for implementation at the COD raw water systems to be further evaluated. Four chemicals were further evaluated through demand testing (Section 3.1.2.1), copper ion alternatives were further evaluated through a detailed literature review and discussions with product manufacturers (Section 3.1.2.2), and physical removal and disposal methods were further evaluated through literature reviews and previous team experiences (3.1.2.3).

3.1.2.1. Further Evaluation of Chemical Alternatives with Demand Testing

Based upon an initial review of alternatives during the Alternatives Analysis Workshop, the COD selected four chemicals to perform demand testing with an intent to better understand the doses that would be required in the COD raw water systems. Demand testing was conducted in two phases for both COD source waters (Lewisville Lake and Lake Ray Roberts) based upon average raw water system detention times to target a sample point in the spring and summer seasons when conditions are favorable for zebra mussel settlement. Phase I samples were collected on April 21st, 2015 and tested using permanganate (from which the equivalent sodium permanganate demand can be calculated), chlorine dioxide, chloramines and a polyquaternary ammonium compound (i.e., Bulab 6002). Phase II samples were collected on June 10th, 2015 and tests were repeated with potassium permanganate and chlorine dioxide. The complete testing plan, data and analysis are provided in Appendix C.

A summary of the demand testing results and the recommended design doses is presented in Table 3-6 and Table 3-7 for the LLWTP and RRWTP, respectively. Chemical facility design doses consider the highest chemical demand at the average flow for each system, the chemical residual (discussed in Section 3-24) required to prevent settlement based upon literature and project team experience, and a small buffer to account for unknowns. Recommended average annual chemical doses were calculated by summing the target residual and the average demand (i.e., the average of the two demand data points collected for COD source waters as part of this study based upon an average residence time through the raw water systems). ***Unknown factors such as demand due to biofilm formation on pipelines, changes in water quality (e.g. seasonal changes in water temperature or organics concentrations), and changes in flow (i.e., a higher dose is required when flow decreases cause an increase in detention time) may significantly change the dose required. The team recommends that chemical feed be optimized following start-up of any chemical systems using biological monitoring (e.g. veliger settlement monitoring and bioboxes). Monitoring may significantly reduce the required dose and duration of chemical feed systems. Conceptual layouts and cost estimates are based upon a minimum of 15 days of storage at the highest measured demand; monitoring may reduce the frequency of delivery using the recommended chemical storage and feed equipment sizes.*** In addition, Table 3-5 summarizes the water quality regulations that must be considered in interpreting the feasibility of the estimated doses.

Table 3-5: Chemical Regulatory Considerations

Chemical	Regulatory Considerations
Chlorine Dioxide	Chlorite MCL of 1.0 mg/L
Chloramines	Nitrate MCL of 10 mg/L as N Nitrite MCL of 1 mg/L as N Nitrate & Nitrite (Total) MCL of 10 mg/L as N NDMA (anticipated future regulation)
Bulab	NDMA (anticipated future regulation) NSF long-term application limit of 0.5 mg/L
Permanganate	Manganese SMCL of 0.05 mg/L

Table 3-6: LLWTP Conceptual Design Doses

Chemical	Phase I Chemical Demand @18°C	Phase II Chemical Demand @30°C	Chemical Residual Required to Prevent Settlement	Estimated Dose[1] at Average Flow @ 18°C	Estimated Dose[1] at Average Flow @ 30°C	Conceptual Chemical Facility Design Criteria	Estimated Annual Average Chemical Dose
Chlorine Dioxide (mg/L active)	>1.5	>1.5	0.25	>1.5	>1.5	NR	NR
Chloramines (mg/L active)	0.1	NR	1.5	5-7	NR	NR	NR
Bulab (mg/L active polyquat)	0.5	NR	0.5	>1.0	NR	NR	NR
Sodium Permanganate (mg/L active)	1.4	4.5	0.25	1.7	4.8	5.5	3.5
Potassium Permanganate (mg/L active)	1.5	5.0	0.25	1.8	5.3	6.0	3.5

NR – Not recommended or further evaluated based upon discussions with COD staff reviewing the required doses, related regulatory considerations, and potential downstream water quality or treatment consequences.

1 – Doses are based on a TOC concentration of 6.05 and 6.39 m/L for Phases I and II, respectively, and do not account for pipeline demand. Doses are rounded up to two significant figures.

Table 3-7: RRWTP Conceptual Design Doses

Chemical	Phase I Chemical Demand @18°C	Phase II Chemical Demand @30°C	Chemical Residual Required to Prevent Settlement	Estimated Dose[1] at Average Flow @ 18°C	Estimated Dose[1] at Average Flow @ 30°C	Conceptual Chemical Facility Design Criteria	Estimated Annual Average Chemical Dose
Chlorine Dioxide (mg/L active)	0.75	>1.5	0.25	1.0	>1.5	NR	NR
Chloramines (mg/L active)	0.05	NR	1.5	5-7	NR	NR	NR
Bulab (mg/L active polyquat)	0.25	NR	0.5	>1.0	NR	NR	NR
Sodium Permanganate (mg/L active)	0.5	1.8	0.25	0.8	2.1	2.5	1.5
Potassium Permanganate (mg/L active)	0.5	2	0.25	0.8	2.3	3.0	1.5

NR – Not recommended or further evaluated based upon discussions with COD staff reviewing the required doses, related regulatory considerations, and potential downstream water quality or treatment consequences.

1 – Doses are based on a TOC concentration of 4.65 and 5.22 mg/L for Phases I and II, respectively, and do not account for pipeline demand. Doses are rounded up to two significant figures

The demand testing results highlight that no one chemical is ideal. There are advantages and risks regardless of which chemical is selected. Based upon the results of demand testing and discussions with COD staff, it was determined that **the following three chemicals would not be further evaluated**.

- **Chloramines** – The doses required for chloramines are reasonable. However, the use of chloramines at the intakes could exacerbate nitrification within the water treatment plant, which can result in seeding of ammonia oxidizing bacteria into the distribution system. Chloramines addition also leads to NDMA formation. The use of chloramines prior to ozonation, which degrades NDMA precursors, would be expected to result in higher NDMA concentrations in the finished water and distribution system than currently observed. While not yet regulated, NDMA has been found to be a potential carcinogen at low nanogram per liter concentrations and it is under consideration by the EPA for a future regulatory determination. Further, chloramines would have to be quenched prior to biofiltration. Quenching would require an additional capital chemical project and additional chemical costs. Chloramines are not recommended as a primary management approach for zebra mussels. However, pre-formed chloramines could be considered for a short-term approach if the potential risks are recognized.

- **Bulab** – The doses required for Bulab are above the NSF long-term application limit. In addition, Bulab was shown to be an NDMA precursor. Bulab has limited installations for zebra mussel management. The only known use of Bulab for zebra mussel fouling prevention was by the City of Oregon, OH. City of Oregon used 3 mg/L of Bulab at the onset of their zebra mussel issues but has since converted to permanganate for coagulation benefits. Additionally, the Bulab dose is dependent upon the clay particles in the water (i.e. during high turbidity events control of the dose would be difficult). Bulab is not recommended as a primary management approach for zebra mussels. However, Bulab could be tested post-startup if there is interest recognizing the potential risks.

- **Chlorine Dioxide** – Due to the chlorite regulation of 1 mg/L, chlorine dioxide can only be applied at doses up to 1.5 mg/L without requiring a downstream chlorite removal treatment process. Chlorine dioxide may be effective at a dose below 1.5 mg/L, but may only protect a limited portion of the raw water system (i.e., approximately 0.5 miles of the shorter pipelines and 1 mile of the longer pipelines based upon demand testing at 30°C).

Permanganate is a very feasible alternative considering the design and average doses required based on demand testing. The main concern with permanganate is increased dissolved manganese concentrations resulting in purple colored water or turbidity if treatment process controls are not in place to prevent resolubilization of particulate manganese or over-ozonation. Permanganate is available as a dry chemical in the form of potassium permanganate or a liquid chemical in the form of sodium permanganate. Based upon the results of demand testing and discussions with COD staff, it was determined that **sodium permanganate would be further evaluated** by developing conceptual layouts and a cost estimate.

3.1.2.2. Further Evaluation of Copper Alternatives

There are two alternatives for zebra mussel management using copper ions, copper sulfate compounds and copper ion generation systems. Copper ions have been commonly used for treatment of algae and bacteria, but there are limited municipal drinking water installations for zebra mussel control. The information available on copper toxicity to zebra mussels is limited and varies from study to study as outlined in Table 3-8. Figure 3-2 provides a schematic of the Fortress MC system which is summarized in Table 3-9. Table 3-10 summarizes copper sulfate chemicals (e.g. EarthTec QZ) for zebra mussel management.

Table 3-8: Copper Toxicity Studies and Recommendations

Study	Conclusion
Nalepa and Schloesser 2014	Copper ions are toxic to mussels at 0.01 ppm during early developmental stages
McMahon and Tsou 1990	5 ppm of copper ions was required for 24 hours to kill 100% of veligers
Prasada and Khan 2000	0.1 – 0.8 ppm of copper was toxic to mussels with increasing toxicity with increasing temperature from 20°C to 25°C
Fortress MC and MacroTech Vendor Recommendation	0.005-0.010 ppm copper
EarthTec QZ Vendor Recommendation	0.03 – 0.15 ppm copper

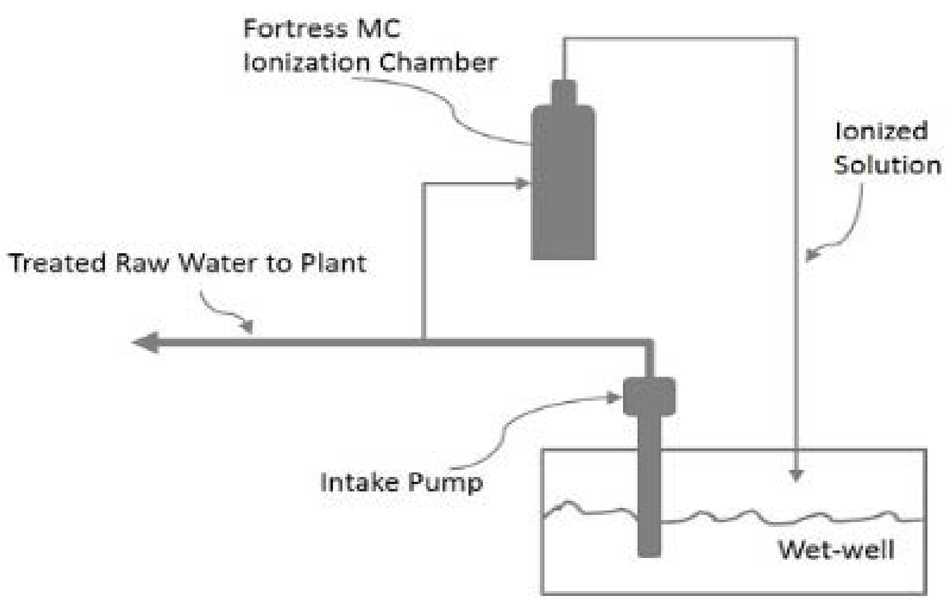


Figure 3-2: Fortress MC System

Table 3-9: Summary of Copper Ion Generation Systems

Description	Copper and aluminum anodes supply copper ions, which are toxic to mussels, and a gelatinous aluminum hydroxide, which aids in precipitating veligers and deposition of copper ions on surfaces acting as an antifouling coating. Manufacturer recommends a 0.005-0.010 ppm application rate.
Considerations	▪ Limited municipal installations for zebra mussel control ▪ Limited published research papers describing efficacy ▪ Limited manufacturers ▪ Adult mussels detect copper ions and close, lessening effectiveness on adults ▪ Previous experiences suggest that the flocculation may be more effective than the low level copper toxicity ▪ Anodes may require frequent replacement ▪ May not eliminate all macrofouling ▪ **Cost:** Inexpensive compared to chemical alternatives but high power cost ▪ **Design:** Skids can hold up to 6 cells; Requires pressurized water; may require tapping the pump discharge piping ▪ **Regulatory Considerations:** o Copper SMCL is 1.0 ppm o Copper Action Level at 1.3 ppm o Aluminum SMCL is 0.2 ppm o No known DBP Formation ▪ **Potential unintended consequences:** o Alum flocs will settle in pipelines; may require sediment removal from pipelines o Resuspension of settled floc may result in large water quality spikes in the plant influent o Rapid corrosion of galvanized steel piping in presence of free copper (Schock, M. 1999) o Anodes may degrade and foul over time resulting in varying copper concentrations (Claudi, R and Prescott, T., 2014) o May result in colored water o Iron coagulation may remove copper ions in WTPs o Biofilm may release from pipeline during initial use ▪ Dependent upon water hardness
Relevant Studies	Sidestream biobox study with zebra mussels at Toledo, OH (1993) ▪ 0.1 ppm resulted in about 60% reduction in settlement during summer
Existing Municipal Installations for Zebra Mussel Control (Complete List)	A summary of discussions with operators of existing municipal installations of copper ion generation systems is provided in Appendix F. ▪ City of Wichita (80 MGD): Contact: Eric Meyer (316-540-3574) ▪ City of Emporia (15 MGD): Contact: Phil Cooper (620-340-6371) ▪ RWD#5 – Kansas (5 MGD) ▪ Milford Utilities (5 MGD) ▪ City of Wahpeton, Iowa (0.4 MGD): Contact: Dough Hanna (712-320-4460)

Table 3-10: Summary of Copper Sulfate Compounds for Zebra Mussel Control

Description	Copper sulfate compounds are copper salts used as an algaecide with a maximum recommended application of 0.5 ppm as Cu. EarthTec QZ is a specific manufacturer of a copper algaecide considered further below. The chemical is an algaecide/bactericide composed of 20% copper pentahydrate in liquid form with a maximum application rate of 1 ppm as Cu. EarthTec QZ has a proprietary chelating compound that holds copper ions in solution over long periods. Earth Tec QZ is certified to ANSI/NSF 60 for drinking water with maximum application rate of 1 ppm of copper and typical dose of 0.03 – 0.15 ppm as copper. Other copper compounds may require a Special Local Need Label (EPA FIFRA Section 24-c).
Considerations	▪ Limited municipal installations for zebra mussel control ▪ Limited published research papers describing efficacy ▪ Limited manufacturers ▪ Adult mussels detect copper ions and close, lessening effectiveness on adults ▪ **Design:** Liquid bulk chemical storage and feed system ▪ **Regulatory Considerations:** o Copper SMCL is 1.0 ppm o Copper Action Level at 1.3 ppm o No known DBP Formation ▪ **Potential unintended consequences:** o Increased copper concentrations in plant influent water o May result in lysing of any present algae releasing microcystin and/or taste and odor compounds o Rapid corrosion of galvanized steel piping in presence of free copper (Schock, M. 1999) o May result in colored water o End reactions of proprietary chelating agent is not fully understood o Biofilm may release from pipelines during initial use
Relevant Studies	Mobile flow-through laboratories testing copper sulfate with zebra mussels on the San Justo Reservoir (Claude, et al., 2014): ▪ 25%-50% adult mortality after 96 hr. at 0.5 ppm as Cu EarthTec QZ bench scale studies of Quagga mussels (Watters et. al., 2012): ▪ 100% adult mortality after 96 hr. at 1 ppm as Cu ▪ 100% juvenile mortality after 96 hr. at 0.3 ppm as Cu ▪ Prevention of veliger colonization after 30 min at 0.2 ppm as Cu Mobile flow-through laboratories testing EarthTec QZ with zebra mussels on the San Justo Reservoir (Claude, et al., 2014): ▪ 100% adult mortality after 84 hr. at 0.5 ppm as Cu ▪ 100% adult mortality after 72 hours at 1.0 ppm as Cu
Existing Municipal Installations for Zebra Mussel Control (Complete List)	If further evaluated, existing municipal installations would be contacted to solicit feedback on zebra mussel management performance. It should be noted the product has significant experience at equivalent doses for algae, organics, and taste and odor treatment. ▪ City of Norwalk, OH (4 MGD) – Rick Schaffer (419-663-6725) ▪ Burlington, VT (5 MGD) – Laurie Adams or Steve Roy (802-863-4501) ▪ Moon Township, PA (2 MGD) – Burt Rateau (412-264-0564) ▪ City of Scottsdale, AZ (40-60 MGD) – Levi Dillon (480-312-5319) or Joe Hernandez (480-312-8733)

Based upon a review of the information summarized in this Section, the COD selected to continue with a detailed evaluation of the copper ion generation system including a cost estimate and conceptual layouts and not further evaluate copper sulfate compounds.

3.1.2.3. Further Evaluation of Physical Removal and Disposal Alternatives

The goal of a good management approach should be to minimize the amount of physical removal required. A preventative approach to zebra mussel management is recommended (i.e., using preventative and control strategies such as chemicals), as it will eliminate or minimize the volume of zebra mussels requiring disposal. Alternatively, if reactive strategies (e.g. physical removal) are implemented, they should be used frequently enough such that mussels removed are small and biomass management is reduced. Thus, every zebra mussel management approach should include a plan for zebra mussel removal and disposal. The three largest concerns with zebra mussel removal and disposal are highlighted in the following list.

- **Potential for Large Volumes** – Using the RRWTP raw water pipeline leading from the USACE outlet as an example, a one-inch layer of mussels covering a 0.2-mile long, 60-inch pipeline and a 0.8-mile long, 48-inch pipeline would equate to about 215 cubic yards (CY) of mussels (i.e., 7 truckloads with a 30 CY capacity).

- **Severe Odors** – Decaying mussels produce a strong, noxious odor which may lead to complaints from the public (i.e., complaints from nearby neighbors if mussels are above water or complaints from end water users if mussels decay in water sources).

- **Toxin Accumulation** – Zebra mussels can bioaccumulate heavy metals, polychlorinated biphenyls, and petroleum hydrocarbons in their tissues. However, toxicity testing has been completed by the COD and zebra mussels are accepted for disposal by the COD landfill.

The COD recently completed physical removal and disposal of mussels in the RRWTP raw water system (see Section 2.4). Mussels were removed from dewatered pipelines by hydroblasting and scraping mussels from the pipeline and a vacuum truck was used for extracting the shells. Mussels were ultimately disposed of in the COD landfill. Although this same strategy will likely be repeated in the future, a high level identification of physical removal and disposal alternatives was conducted. Table 3-11 summarizes physical removal alternatives, and Table 3-12 summarizes disposal alternatives.

Table 3-11: Summary of Physical Removal Alternatives

Alternative	Description	Primary Considerations	Selected for Further Consideration?
Physical Removal with Divers	Underwater components must be cleaned by divers by either physical scraping or power washing	▪ Generally restricted to forebays, screens, trash racks, intakes, etc. ▪ Penetration dives are dangerous and very expensive	Yes
Physical Removal in Dewatered Pipes	Pipelines that can be isolated and dewatered can be cleaned manually with physical scraping and power washing followed by extracting mussels using a vacuum truck	▪ New manways may be required (every 1500-2000 linear feet, at bends and at low points) ▪ Plant will be offline to allow for cleaning at about 200-300 LF per day unless an alternative raw water pipeline is available (i.e., in the LLWTP raw water system) ▪ Safety risks with entry into confined spaces ▪ Damage to pipelines (i.e., pitting) may occur with repeated removal activities	Yes
Pipe Pigging	Pigging systems force plugs (also called pigs) through pipelines to scrape mussels from pipe walls	▪ Most applicable to small diameter pipelines and new construction ▪ Custom pigs would have to be fabricated for larger lines (i.e., 32”-60” diameter); large pigs require cranes and trailers for transport and insertion ▪ Existing pipelines would require custom pig launchers and retrievers and ponds for waste water (potentially additional easements) ▪ Requires replacement of butterfly valves with full port valves ($250,000 each) ▪ May result in severe damage to concrete pipelines due to crushing sharp shells	Not recommended for COD as it will require substantial capital investment, may damage existing facilities and has limited implementations in large diameter pipes for zebra mussel removal.

Table 3-12: Summary of Disposal Alternatives

Alternative	Description	Primary Considerations	Selected for Further Consideration?
Landfill	Mussels are transported to a municipal solid waste landfill. In most cases, mussels are not from highly contaminated water bodies, and thus, tests show low toxicity and mussel debris are accepted by landfills. Even so, there is at least one case on the lower Hudson River where it was necessary to dispose of the mussels in a hazardous waste landfill due to concerns of accumulated metals.	▪ Off-site solution / terminal option (no follow-up or maintenance required) ▪ Leachate test may be required ▪ Transportation required ▪ Requires a willing landfill ▪ On-site handling and holding prior to transport ▪ Negative revenue potential ▪ COD owned landfill has already accepted zebra mussels ▪ TCLP testing and ignitability, corrosivity, and reactivity tests are required	Should be further considered
Composting	Long windrows (i.e., rows of compost) of zebra mussels mixed with plants and sediments that also result from cleaning are created and occasionally turned. The composted material could be used as soil topdressing (e.g. in agricultural applications in the case of Ontario Hydro and to grow grass on old coal holding areas in the case of Detroit Edison). The inorganic shell debris may help raise soil pH and aerate soils, and the organic components enhanced soil fertility.	▪ Produces potentially usable product / positive revenue potential ▪ Saves landfill space ▪ Growing acceptance as waste disposal method ▪ Potential odors or runoff ▪ Requires maintenance and monitoring ▪ If not on-site, need to identify waste recipient ▪ Control of vermin and other vectors ▪ Requires dedicated space ▪ Other organic materials may be required to optimize conditions (peat, sawdust, and poultry litter have been suggested) ▪ Significant startup costs / no current composting operations ▪ Significant coordination ▪ Requires a product market ▪ Zebra mussel bioaccumulation of cadmium would need to be studied. Cadmium in food crops has become an issue, especially in the western US, primarily due to soil conditioners.	Not recommended due to limited experience, regulatory risks and unknown potential revenue / markets

Alternative	Description	Primary Considerations	Selected for Further Consideration?
On-Site Burial	If sufficient land and equipment are available, on-land or on-site burial may be a feasible disposal option. Shallow burial (1-2 feet of soil coverage) should be sufficient to preclude scavenging by raccoons, other mammals, and birds, and rapid processing of material will minimize odor issues.	▪ Rapid, on premises solution ▪ Cost-effective ▪ Minimal transport ▪ Land availability and equipment ▪ Public perception ▪ Potential odor complaints ▪ Future land use concerns ▪ May attract predators, vermin and other vectors ▪ Negative revenue potential ▪ Permitting concerns (cradle-to-grave)	Not recommended due to risk of uncertain future regulations
Leave-in-Place	If mussels are cleaned from an underwater surface and not brought to the surface, they could be left to be removed naturally by water currents.	▪ No additional cost or logistical requirements ▪ Water flow must be sufficient to naturally remove debris ▪ Biological oxygen demand may be unacceptable, especially in warm water seasons ▪ Taste and odor problems due to decaying mussels ▪ Mussel debris from cleaning operations nearly always pass sediment criteria ▪ Shells may reenter the water systems clogging pumps and downstream pipelines ▪ Permitting concerns ▪ Negative revenue potential	Not recommended due to water quality impacts and the risk of shells reentering the water systems
Other Beneficial Uses	Other beneficial uses of zebra mussels have been proposed including animal feed (i.e., crushed mussel shells) and biogas production during composting.	▪ Innovative ideas that recycle mussels ▪ No full-scale implementation ▪ Limited supportive research ▪ Negative revenue potential ▪ Significant startup costs ▪ High risk due to lack of information ▪ Green technologies	Not recommended due to lack of available information

Based upon this evaluation and the previous COD experience with removal and disposal from the RRWTP raw water system, physical removal with power washing and scraping (including both diving and dewatered pipelines) and disposal in the COD landfill were selected for further evaluation with cost estimates.

3.1.3. Summary of Management Approaches Selected

Considering the preventative, control, and reactive strategies for zebra mussel management identified and evaluated in this section, a limited number of management approaches, listed below, were selected to be evaluated in detail (Sections 4 and 5) for each site including development of costs and conceptual layouts.

- Copper alloy construction materials and coatings for bar screens
- Sodium permanganate (and interim use of the existing LLWTP potassium permanganate system)
- Copper ion generation systems
- Physical removal by power washing and scraping
- Disposal in the COD landfill

In addition to these primary management approaches, various O&M approaches, such as dewatering and desiccation which were also ranked highly by the COD, will also be considered. O&M approaches are discussed in detail in Section 3.2.

3.2. OPERATIONS AND MAINTENANCE APPROACHES

In addition to preventative, control and reactive strategies to better manage zebra mussels, a multi-barrier zebra mussel management approach should include O&M improvements. O&M approaches include enhancing daily operational activities and improving designs to ease maintenance activities (Section 3.2.1), optimizing chemical dosing strategies (Section 3.2.2), and initiating programs to manage future risks (Section 3). These improvements provide opportunities to get the best value from capital or annual O&M investments. However, they are not stand-alone approaches and should be implemented in combination with preventative, control and/or reactive strategies for zebra mussel management. Recommendations for operational and maintenance enhancements at each facility are provided in Sections 4 and 5.

3.2.1. O&M Enhancements

O&M enhancements that will optimize zebra mussel management are outlined in Figure 3-3. These are not intended to be stand-alone approaches to managing zebra mussels however they are good practices that give operators a second level of management. For example, if a trash rack were being reconstructed in stainless steel to allow for application of a metal alloy coating, the reconstruction could include increased opening sizes to prevent clogging with mussels and a means for removing the trash racks for cleaning and coating replacement.

Operational Enhancements

- Operate all moving equipment frequently
- Clean trash racks and screens frequently
- Isolate and dewater components during shutdowns or maintenance to desiccate any attached mussels
- Clean silt away from gates and screens to allow operation and rakes to fully clean components
- Alternate pipeline use when parallel pipelines are available to allow for oxygen deprivation (may require flushing anoxic water)

Maintenance Enhancements

- Include redundant or oversized pipelines
- Replace stationary screens with travelling screens
- Design trash racks with 6 inch or greater openings
- Design removable bar screens and trash racks to ease cleaning
- Include pressure washing or pigging stations
- Allow for isolation of components (e.g. replace any leaky or non-functioning gates)

Figure 3-3: O&M Enhancements

3.2.2. Chemical Dosing Strategies

Dosing strategies to manage zebra mussels using chemicals in raw water systems include prevention, control and reaction approaches as outlined in Figure 3-4. Determining which approach to use depends on specifics of the facility's raw water system, the level of management required and the management approach selected. Regardless of the dosing strategy, a biological monitoring program should be implemented as a feedback mechanism to allow for adjustments in timing and dosing of the chemical. Specific chemical dosing recommendations for the copper ion generation system and sodium permanganate are provided in Sections 3.2.2.1 and 3.2.2.2, respectively.

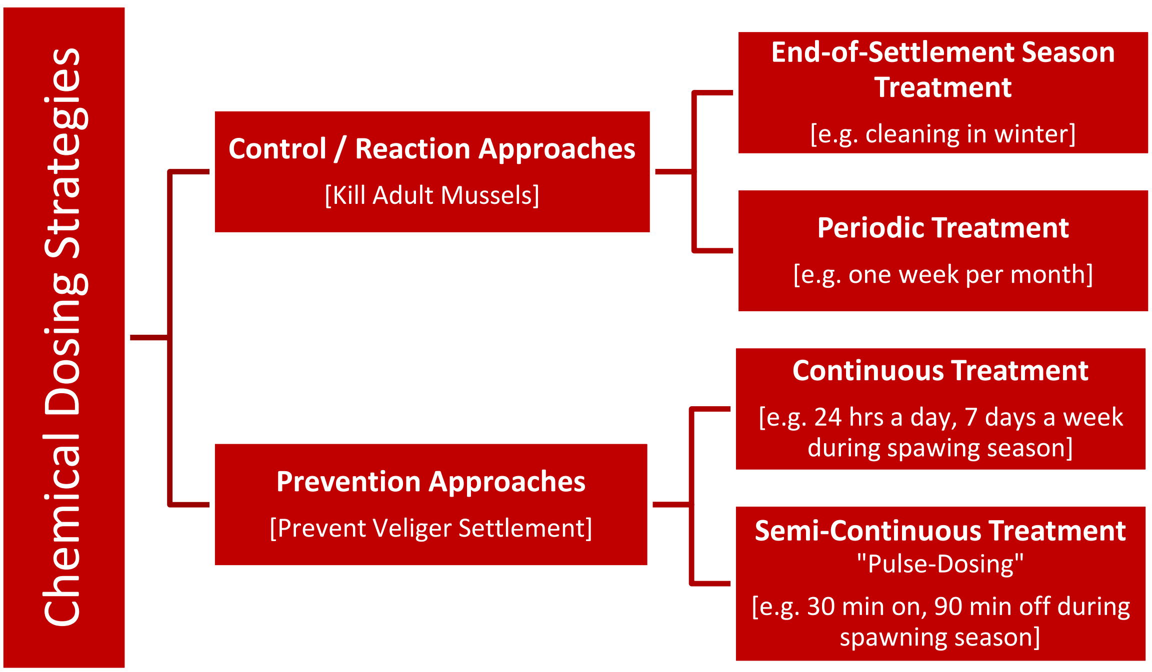


Figure 3-4: Chemical Dosing Strategies

Control or reaction approaches include end-of-settlement season treatment and periodic treatment. These approaches target mussels that have already settled in a water system. Control or reactive approaches are used only in systems or on components within a system that can tolerate a degree of mussel fouling. These approaches are usually not recommended for potable water systems, but may have application in structures between reservoirs and on dams.

- End-of-settlement season treatment is a reactive strategy that accompanies physical removal and disposal. In some cases, it may be beneficial to use a chemical to kill all the mussels to ease physical removal efforts. This strategy may result in hydraulic capacity reductions as the settlement season progresses.
- Periodic treatment is a control strategy where chemicals are used to periodically kill adult mussels within a system. This strategy can be effective if a system can tolerate a degree of mussel fouling

(i.e. hydraulic capacity reduction) but will still require physical removal and disposal of shells and could result in clogging of downstream components as shells move through the system. This strategy also requires higher chemical doses to kill juvenile and adult mussels than a preventative approach, which may also affect the water quality entering downstream water treatment plants during chemical application events.

Preventative chemical approaches are designed to prevent veligers from settling, either by damaging veligers so they cannot physically attach or by creating an environment that is not conducive to mussel attachment or growth. Preventative approaches are recommended in areas that cannot tolerate any mussel fouling or if facility operators do not want to deal with secondary effects of treating adult mussels (e.g. disposal of dead mussels or downstream blockages of released mussels). Prevention includes continuous treatment and semi-continuous treatment, which can be applied seasonally when zebra mussel veligers are present.

- With the continuous treatment strategy, a low concentration of chemical is maintained throughout the system where prevention of fouling is required. Zebra mussel veligers detect the presence of many chemicals, including oxidants, and will be carried through the system without settling. Therefore, as long as a low residual is maintained throughout the system, it is not necessary to kill the veligers. Those that fall out of the water column in low flow areas may initially survive, but will eventually succumb to the chemical.

- With a semi-continuous or “pulse dosing” strategy, a chemical is applied in an on/off cycle to create an environment where zebra mussel veligers will not settle while minimizing the amount of chemical used. Dosing strategies including 15 minutes of chemical on followed by 15 minutes off, 15 minutes on followed by 30-45 minutes off and 30 minutes on followed by 30-90 minutes off have all been demonstrated to be effective for other utilities. A longer “off” period may be effective in Texas, due to the increased efficacy of most of the chemicals at higher temperatures.

In reality, the most effective application concentrations and durations for prevention of a zebra mussel infestation will depend on the molluscicide selected and the unique conditions associated with the raw water body and structures being treated. Water body physical and chemical conditions that impact both oxidizing and non-oxidizing molluscicide effectiveness include water temperature, pH, dissolved oxygen, total suspended solids, conductivity and concentration of organic carbon and humic acids, among others. In addition, the efficacy of molluscicides against zebra mussels generally declines with decreasing water temperature.

3.2.2.1. Copper Ion Generation Dosing Strategy

Copper ion generation technology produces water with high concentrations of copper and aluminum ions. Positively charged copper ions bind to negatively charged sites, and penetrate veliger cell walls, poisoning cellular processes. Copper ions also denature proteins in byssal threads weakening mussels' ability and strength to anchor. Moreover, copper/aluminum ions form a floc layer (i.e., $[Al(OH)_4]Cu$) coating interior surfaces of raw water pipes denying mussels a suitable surface for attachment and growth while entrapping and immobilizing veligers (ONG Consulting LLC). The following strategies should be implemented following startup to optimize the chemical management approach.

1. **Optimize the Dose:** The manufacturer of the Fortress MC system, ONG Consulting LLC, recommends a dose of approximately 5 parts per billion (ppb) copper and 0.05 ppb aluminum during settlement season, and a dose of approximately 2 ppb copper and 0.02 ppb aluminum during non-settlement seasons. A summary of studies on the toxicity of copper was provided in Section 3.1.2.2. Further, the required dose will change throughout the year as the water quality changes. If available, conductivity, temperature and total suspended solids, which have the greatest impact on the required dose, should be provided to the system Programmable Logic Controller (PLC). Additionally, monitoring for mussel settlement should be conducted at the farthest point in the system requiring protection.

2. **Optimize the Dosing Frequency:** The manufacturer of the Fortress MC system, ONG Consulting LLC, recommends a continuous dosing strategy. The manufacturer does not recommend idling the cells without flow.

3. **Monitor for Settlement:** Application of the higher chemical dose to prevent mussel settlement need only occur during months when mussel veliger larvae are present in the water column, which is approximately 4-5 months of the year compared to the 8 months of the year that are favorable for settlement based upon temperature data (see Section 0 for more information). Thus, annual O&M costs can be reduced by implementing an intensive monitoring program and decreasing the dose when settlement is not observed.

3.2.2.2. Sodium Permanganate Dosing Strategy

As an oxidizing agent, the molluscicidal properties of sodium permanganate centers on its capacity to oxidize biological organic compounds in living cells. Oxidation leads to changes in molecular structure and function and, ultimately, death of the target organism. While the actual mode of action of oxidizing biocides on macrofouling organisms such as zebra mussels has been little studied, it has been intensely studied in micro-organisms such as bacteria and fungi and protozoa. In many cases the oxidants react with unsaturated carbon-carbon bonds or amino acids in proteins or enzymes leading to loss of function and eventually death (World Health Organization 2004; ChlorDiSys, 2015; and The Sabre Companies, 2015). Oxidants may also oxidize the organic components of cell membranes increasing membrane permeability and impacting the function of membrane-bound enzymes (United States Environmental Protection Agency 1999b, World Health Organization 2004). The following strategies should be implemented following startup to optimize the chemical management approach.

1. **Optimize the Dose:** Based on literature sources (i.e., primarily laboratory studies for non-potable water systems) summarized in Table 3-13 and team expertise, a target permanganate residual of approximately 0.25 mg/L must be maintained throughout the entire system to effectively protect against zebra mussel fouling (e.g. through the entire raw water pipeline). It should be noted that most studies in literature are based on potassium permanganate, which shares the same active

component (i.e., permanganate) as sodium permanganate, and do not necessarily account for local water quality (e.g. high temperatures and high organic concentrations). Demand of the local water was considered in order to determine approximate chemical doses required for COD source waters (see Section 3.1.2.1 and Appendix C for more information). Further, the required dose will change throughout the year as the water quality changes and should be monitored by measuring the chemical residual and monitoring for mussel settlement at the farthest point in the system requiring protection.

Table 3-13: Toxicity and Application Methodology of Permanganate for Management of Zebra Mussel Fouling

Molluscicide	Life Stage	Management Approach[1]	Application Method[2]	Dose	Contact Time	Reference
Potassium Permanganate	Adults	Control	Continuous	≥2.1 mg/l	6 days	Van Benschoten et al., 1992
	Veligers	Prevention	Continuous	≥1.0 mg/l	Not Available	Mackie & Claudi 2010
	Veligers	Prevention	Continuous	≥0.25 mg/l	Not Available	Mackie & Claudi 2010
Sodium Permanganate	Similar to that for potassium permanganate based on previous project experience and Findlay, OH study.					

1 – Control: apply long enough to eradicate an existing mussel infestation with applications occurring frequently enough to prevent fouling from attaining levels that negatively impact operations. Prevention: apply during periods when zebra mussel veligers are present in the water column to prevent settlement and subsequent fouling.
2 – Application Method: Continuous = applied without ceasing until a mussel infestation is eradicated or to prevent larval settlement, Semi-continuous = applied in a pulsed fashion with a period of chemical feed followed by a period without chemical feed (*e.g.*, 30 min application followed by 90 minutes of non-application).

2. **Optimize the Dosing Frequency:** In practice, the dosing strategy will be determined after start-up by monitoring the raw water infrastructure and using biological monitoring techniques such as bioboxes and plankton net sampling. It is recommended, based on previous project experience that COD begin by applying a semi-continuous dosing strategy (e.g. 30 minutes on and 90 minutes off) to balance mitigation of zebra mussel veliger settlement with minimizing chemical costs. For the purpose of estimating chemical costs and developing conceptual layouts, it was conservatively assumed that chemical would be applied following a 30 minute on and 30 minute off strategy (i.e. chemical would be applied for 12 hours each day). However, if COD operations prefer to have a consistent water quality entering the head of the plant or is interested in dual-benefits such as pre-oxidation, continuous dosing may have added value.

3. **Monitor for Settlement:** Application of permanganate to prevent mussel settlement need only occur during months when mussel veliger larvae are present in the water column, which is approximately 4-5 months of the year, compared to the 8 months of the year which are favorable for settlement based upon temperature data (see Section 0 for more information). Thus, annual O&M costs can be reduced by implementing an intensive monitoring program and only applying chemical when settlement is observed (or applying reduced doses when settlement is not observed for taste and odor oxidation and pipeline maintenance).

3.2.3. Risk Mitigation Approaches

Both of the COD's raw water intakes (i.e., the LLWTP Intake and the RRWTP Intake) are currently at risk for future zebra mussel infestations if preventative measures are not in place. While the RRWTP has already experienced a zebra mussel infestation (see Sections 2.2 and 2.4), it is unknown what zebra mussel density Lake Ray Roberts will be able to sustain long-term based upon recent data collected by Dr. McMahon, which suggests the population collapsed this year due to lack of nutrients. Similarly, while a heavy settlement of zebra mussels was identified this year in the Elm Fork arm of Lewisville Lake, it is unknown whether Lewisville Lake will support a sustainably reproducing population due to the shallow depth of the lake. However, zebra mussels have proven to be adaptive, demonstrating the ability to proliferate in habitats that were previously thought to be non-conducive to their survival. Considering these unknowns regarding the density of long-term zebra mussel infestations in COD source waters combined with the short zebra mussel life spans (approximately one year), fast growth rates and two settlement seasons per year observed in North Texas (Section 0), it may be difficult to get a permanent chemical feed system designed, bid and constructed before another severe infestation of one of the COD raw water systems takes place.

Figure 3-5 displays the results of a team exercise where each COD staff member in attendance at the Alternatives Analysis Workshop was asked to place a zebra mussel sticker (shown as stars) along the timeline showing their position on what level of implementation is required when zebra mussels are first observed in the LLWTP raw water system. The timeline shows balanced concerns between:

- Spending public funds given the many other CIP priorities of the agency, and
- Not risking reduced hydraulic capacity or public confidence should an infestation occur.

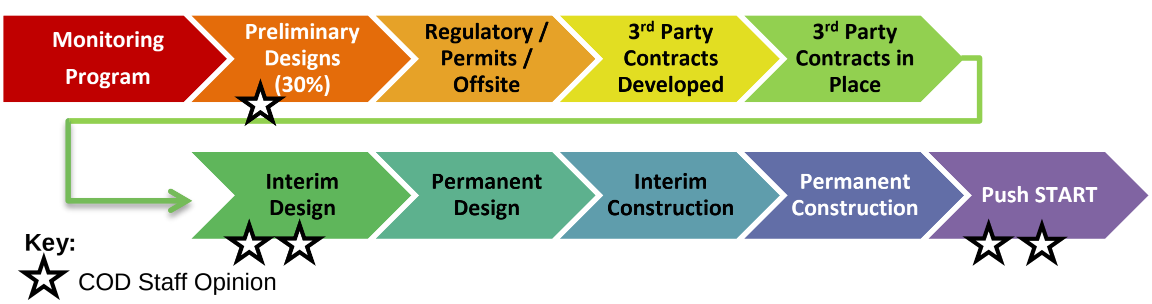


Figure 3-5: Risk Management / Implementation Timeline for the LLWTP Intake

The following questions about how to effectively balance these two concerns have been asked by water supply professionals at hundreds of public water utilities in the Northeast and Central parts of the country.

- How much capital should I invest prior to an infestation?
- How prepared should I be?
- What if an infestation does not occur; what if it does?
- What interim steps could I take?

Each utility handles the risk question differently based on the risk tolerance of the utility's leadership; however, some common themes and approaches have emerged. Utilities that have been uncertain about the risk of infestation in some or all their water sources have utilized one or more of the following approaches to mitigate future risk while minimizing upfront capital spending. Based upon the level of risk, the ultimate control approach may use some combination of these three approaches (i.e. these approaches are not mutually exclusive). Further, recommended approaches for both the LLWTP and RRWTP raw water systems are provided in Sections 4 and 5.

1. Implement a robust monitoring program
2. Design permanent control systems but do not construct
3. Temporary Control Systems (including modification of existing equipment)
4. On-call contracts

3.2.3.1. Approach 1: Implement a Robust Monitoring Program

Zebra mussel monitoring should be incorporated into every management program. Figure 3-6 displays a timeline showing how the goals of a zebra mussel monitoring program change over time. It is important to have the monitoring program in place prior to mussels becoming established in the raw water source to understand the level of risk of the raw water systems to infestation. For facilities at risk of infestation, continued monitoring will allow for more accurate estimates of how quickly management measures are required (i.e., act as an early warning system). Further, continued monitoring following the implementation of management improvements will allow for optimization of the selected management approach.

Figure 3-6: Monitoring Program Goals

Table 3-14 provides brief descriptions of the different types of monitoring that may be incorporated into an effective monitoring plan. Monitoring can take place in the source water outside the facility, or within the facility, and the monitoring techniques used may differ before and after a zebra mussel population is established.

Table 3-14: Brief Descriptions of Monitoring Methods

Method	Description
Information Gathering / Collaboration	Create an information network with the multiple agencies across the state that are currently performing monitoring: ▪ TPWD Contact: Brian VanZee http://www.tpwd.state.tx.us/newsmedia/releases/news_roundup/zebra_mussels/ ▪ USGS Contact: Chris Churchill http://nas2.er.usgs.gov/viewer/omap.aspx?SpeciesID=5 http://tx.usgs.gov/ ▪ Other Nearby Utilities (e.g. NTMWD and TRWD) ▪ **Public Outreach** through News Media and Social Media (e.g. providing a forum for recreationalists to report any mussel findings on boats)
Water Quality Monitoring	Monitor key water quality parameters to understand the level of risk for zebra mussel establishment in each water body and when zebra mussels are most likely to proliferate. The following water quality parameters and frequencies are generally recommended: ▪ **Calcium** –monthly ▪ **Temperature** – daily ▪ **pH** – daily ▪ **Dissolved Oxygen** – daily
Veliger Monitoring	Collect veligers through the use of **plankton nets**. Veligers are identified in part by a distinctive 90° "Maltese Cross" (Figure 3-7) using cross-polarized light under a microscope. Alternatively, the possible presence of zebra mussels, including veligers, can be detected in a lab by running polymerase chain reaction (PCR) analysis to identify zebra mussel DNA.
Substrate Samplers	Substrate samplers (Figure 3-8) are used to collect recently settled juvenile and adult mussels. **Multiple settlement plates with standardized substrate** are placed in the water in or near the facility of concern prior to the reproduction season and removed at a set frequency to visually inspect for juvenile or adult mussel attachment.
Direct Site Inspections	**Trained utility staff visually inspect** dewatered surfaces during maintenance activities or facility shutdowns and visually inspect debris (e.g. trash and submerged aquatic vegetation) removed via travelling screens or by trash rack rakes. Observed mussels (Figure 3-9) are collected via predetermined procedures and sent to a lab for identification. If surfaces can be dewatered frequently, this method may detect initial settlement before substrate samplers yield a similar result due to greater surface area.
Control Validation	**Bioboxes** (Figure 3-10) can be inserted into the system at the critical points where control is required or tested using a side stream of water from critical locations to confirm mussel mortality (i.e. control approach effectiveness).

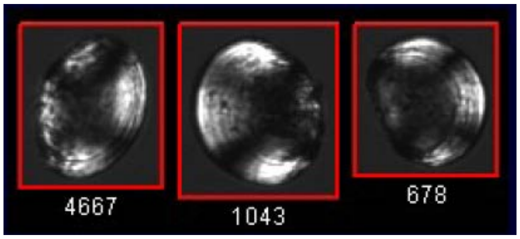


Figure 3-7: Maltese Cross

Figure 3-8: Example of a Substrate Sampler

Figure 3-9: Visual Observation of Mussels

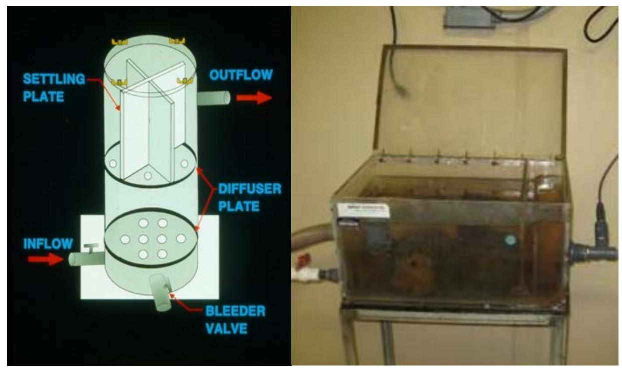


Figure 3-10: Example Side Stream Bioboxes

3.2.3.2. Approach 2: Design Permanent Chemical Systems but Do Not Construct

One risk management option is to design permanent zebra mussel control systems but not construct the systems until they are needed. The rationale for this risk mitigation approach is that "pre-designing" the systems reduces the implementation time by six months to a year, which is critical given that zebra mussel infestations have been noted to occur in less than 1.5 years. If this approach is selected, a clearly defined trigger for completion of design documents must be established based upon data from monitoring efforts.

Permanent chemical systems generally consist of chemical storage tanks and containment, metering pumps and piping, carrier water piping, diffuser systems, and associated instrumentation and electrical controls. In addition, permanent systems could include modifications or refurbishment of isolation gates, additional stop logs for enhanced diver safety, construction of redundant piping, and redesign of trash racks for removability and/or the addition of coatings.

The frequently cited downside of this approach is the risk that the designs will lose viability over time if changes are made to the facilities. Designs that are "on the shelf" will need to be verified prior to bidding. However, spending 10% to 15% of the capital cost now should significantly reduce implementation time in the event of an infestation and might be considered a reasonable investment to mitigate risk. In addition, pre-designing the systems up front allows for the thoughtful input by operations personnel in a non-pressure situation, while designing after an infestation will naturally prioritize speed over operational input.

Variations of this approach are outlined in Figure 3-11. Based upon risk, some facilities or components may require a greater level of preparedness (design effort) than others.

Design Memorandum or Report Only	60% Design Contract Documents	90% Design Contract Documents
▪ Establishment of design criteria ▪ Input from Operators ▪ Development of pre-design sketches and drawings ▪ Coordination with regulatory agencies and pre-approvals of concepts ▪ Reduces the risk of loss of design viability over time	▪ Further reduces implementation time ▪ Acknowledges that designs may not age well ▪ Final design will need to be thoroughly checked against current conditions prior to being finalized for bidding	▪ Shortest implementation time ▪ Regulatory approval may be obtained ▪ Detailed estimate of probable costs ▪ Final design will need to be thoroughly checked against current conditions prior to being finalized for bidding

Figure 3-11: Variations to Approach 2: Designing but not Constructing Permanent Zebra Mussel Control Systems

3.2.3.3. Approach 3: Interim Chemical Systems

Interim chemical systems offer a lower capital cost alternative to permanent systems as a risk management measure. Interim control systems for zebra mussels are typically oxidant storage and feed systems, although a non-oxidizing molluscicide could be implemented as well. These systems tend to be portable to allow for transportation between facilities, or they can be implemented simultaneously at multiple facilities. For example, while a permanent system would include chemical storage tanks sized for multiple months of operation and permanent secondary containment, an interim system might include chemicals supplied on the bed of a truck in totes or by tanker trucks temporarily parked near the site. A permanent system would also likely include hard piped and permanently routed chemical conveyance piping and injection diffusers, whereas an interim system might include piping routed from the back of the container on a truck, or from the tanker truck, overland with temporary secondary containment. Temporary diffuser systems (e.g. holes punched in polyvinyl chloride (PVC) pipe) could be included or chemical could be fed directly into the intake to reduce cost and installation time. Note that provisions (e.g., pump interlocking or new staff protocols) should be implemented with interim systems to prevent chemical spills or backflow into the lake when intakes are not drawing flow. Some pictures from an example temporary storage and feed system for sodium permanganate are shown in Figure 3-12. Variations to the interim control system approach are outlined in Figure 3-13. It should be noted that regulatory approval may be required prior to starting interim chemical systems, and thus, regulatory coordination using interim conceptual designs should begin in advance of anticipated implementation.

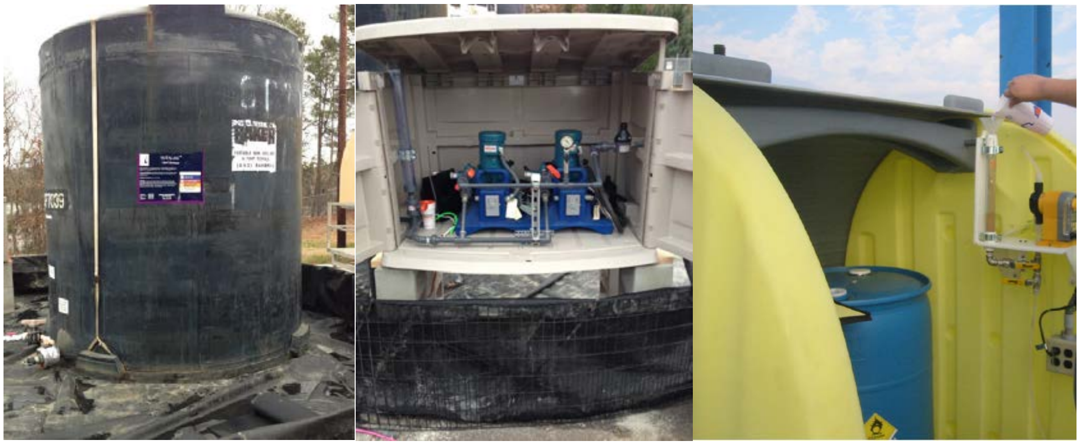


Figure 3-12: Example Temporary Chemical Storage and Feed System

An interim chemical system, as discussed here, would also provide the opportunity to implement demonstration testing (additional data on oxidant demand and the effectiveness of the chemical dosed in this source water). Data collected once the interim chemical feed is in place (e.g. chemical residual, monitoring for mussels, monitoring water quality downstream) would help in developing standard operating procedures and accurately sizing equipment for the permanent system.

Prepare 90% Design Documents for Interim Control Systems	Complete Design Documents and Install Interim Control Systems (Owner to Operate)	3rd Party Contract to Design, Install and Operate Interim Control Systems
▪ Reduces implementation time ▪ Acknowledges that designs may not age well ▪ Final designs will need to be checked against current conditions prior to being finalized for bidding	▪ Wait to fill chemical tanks and install pumps until mussels observed ▪ Allows for the fastest response without compromising functionality of equipment installed and not exercised or chemical degradation ▪ Requires additional investment.	▪ Develop a Contingency Contract ▪ 3rd Party contractor is contracted to implement and operate temporary control systems

Figure 3-13: Variations to Approach 3: Interim Control Systems

3.2.3.4. Approach 4: On-Call Contracts

On-Call contracts are another approach for mitigating the risk of a future zebra mussel infestation. On-Call contracts allow for rapid mobilization of contractor forces and can be bid ahead of a zebra mussel infestation on an annual or multi-year basis. On-Call contracts can be prepared separately, or in combination, for the services outlined in Figure 3-14. For example, on-call contracts may be developed for remote operated vehicle (ROV) inspections or physical removal of mussels. An ROV is typically a tethered unmanned mini-sub that is operated from the surface by a joystick; it is often used to inspect inside pipes and other manmade underwater structures in the Great Lakes. Physical removal may include power washing or scraping off mussels and disposing of them. Based upon the level of risk, the ultimate control approach may use some combination of on-call contracts (i.e., these services are not mutually exclusive). Further, the type of on-call contract or combination of on-call contracts selected may vary from facility to facility or component to component.

On-Call contracts should provide the detail necessary to allow lump sum bidding of the services listed above at a subset or all of the facilities and would put the winning contractor on standby to perform those services within a predetermined period of time after being notified of the need for the services. Drawings should be included to the level of detail necessary to allow contractors to clearly understand and price the work to be performed. A list of example specification sections and drawings for an on-call cleaning contract is provided in Figure 3-15.

Monitoring On-Call Contracts	Inspection On-Call Contracts	Cleaning On-Call Contracts
3rd Party contract to provide as-needed services such as: ▪ Plankton net sampling ▪ Settlement sampling ▪ Veliger identification ▪ Biobox installation and monitoring	3rd Party contract to provide as-needed services such as: ▪ Underwater divers ▪ Juvenile or adult mussel identification ▪ Underwater video ▪ Remote operated vehicle (ROV) inspections	3rd party contract to provide as-needed services such as: ▪ Physical mussel removal ▪ Underwater divers ▪ Disposal coordination

Figure 3-14: Variations to Approach 3: On-Call Contracts

Example Drawings	Example Specification Sections
▪ Allowable cleaning methods (scraping, hydroblasting and/or vacuum methods) and mussel collection and disposal requirements, ▪ Minimum content/requirements of diver safety plans, ▪ Coordination with Owners Operations (when/time of day can cleaning be conducted and who is responsible for stop log installation and gate operation), ▪ Permits and regulatory coordination requirements, ▪ Public coordination, ▪ Cleaning requirements (written description of the cleaning to be conducted at each facility that coordinates with the drawings), and • Mobilization-demobilization requirements.	▪ Site access, ▪ Temporary storage, ▪ Parking or laydown areas, ▪ Drawing of the facilities to be cleaned sufficient to allow quantity take-offs, ▪ High and low water elevations, etc.

Figure 3-15: Example Specifications and Drawings for On-Call Cleaning Contracts

4. LAKE LEWISVILLE WATER TREATMENT PLANT

The LLWTP is the larger of the two COD water treatment plants. The plant was originally constructed in 1957 but has been upgraded several times in 1964, 1972 and 1988 to the current capacity of 30 MGD. Average flow is approximately 8.4 MGD (based upon flow data from 2012-2015) while minimum flow is approximately 5 MGD. A major improvements project just finished construction this year which included addition of ozone and biologically active filtration to the treatment plant. The existing main treatment processes include:

- The ability to feed potassium permanganate to the raw water as an oxidant for taste and odor and to reduce pipeline biofilm
- Rapid mix followed by coagulation and sedimentation with polymer and ferric sulfate for particle and organics removal
- Intermediate ozonation primarily for *virus* and *Giardia* inactivation and taste and odor control
- Biologically active filtration for turbidity removal, organics removal and trace contaminant removal
- Caustic addition to increase pH of finished water for transmission for corrosion control, maintenance of disinfection residual and increased chemical stability
- Disinfection with free chlorine and chloramines (chlorine combined with ammonia) through the clearwell and chloramines disinfection through the distribution system
- Fluoride addition prior to the clearwells for dental hygiene

The LLWTP has one intake (i.e., the LLWTP Intake) on Lewisville Lake. Raw water is pumped from Lewisville Lake to the LLWTP through a 30-inch and/or 27-inch concrete pipeline. The site survey results including a detailed description of the existing raw water system, an assessment of the risk of a future zebra mussel infestation and an evaluation of future improvements are provided in Section 4.1. The results from the site surveys (Section 4.1) facilitated the development of site-specific zebra mussel management approaches and recommendations (Sections 4.2 and 4.3).

4.1. SITE SURVEY RESULTS

Site surveys included desktop design document review (e.g. as-built drawings, treatment plant process schematics, raw water quality data, plant operational data and local zebra mussel data) and site visits (conducted March 23, 2015) with operations staff from both water treatment plants. In addition to explaining the physical characteristics of each site, operations staff provided insight into how the facilities are currently operated and any operational constraints that may exist. Considering all the information collected and reviewed, a risk assessment was conducted (Section 4.1.1) to evaluate the level of risk of a future zebra mussel infestation at the LLWTP Intake. Lastly, a list of planned future improvements to the raw water system, including identification of potential implications to future zebra mussel management, was developed (Section 4.1.3). The results from the site surveys facilitated the development of site-specific zebra mussel management approaches and recommendations (Sections 4.2 and 4.3).

4.1.1. Description of Existing Raw Water System

The raw water system consists of the intake structure (i.e., the LLWTP Intake), a RWPS including a potassium permanganate storage and feed system and two pipelines from the RWPS to the plant. An overview of the LLWTP raw water system is shown in Figure 4-1 and the raw water system components are shown schematically in Figure 4-2. The total distance from Lewisville Lake to the LLWTP is approximately 8.6 miles.

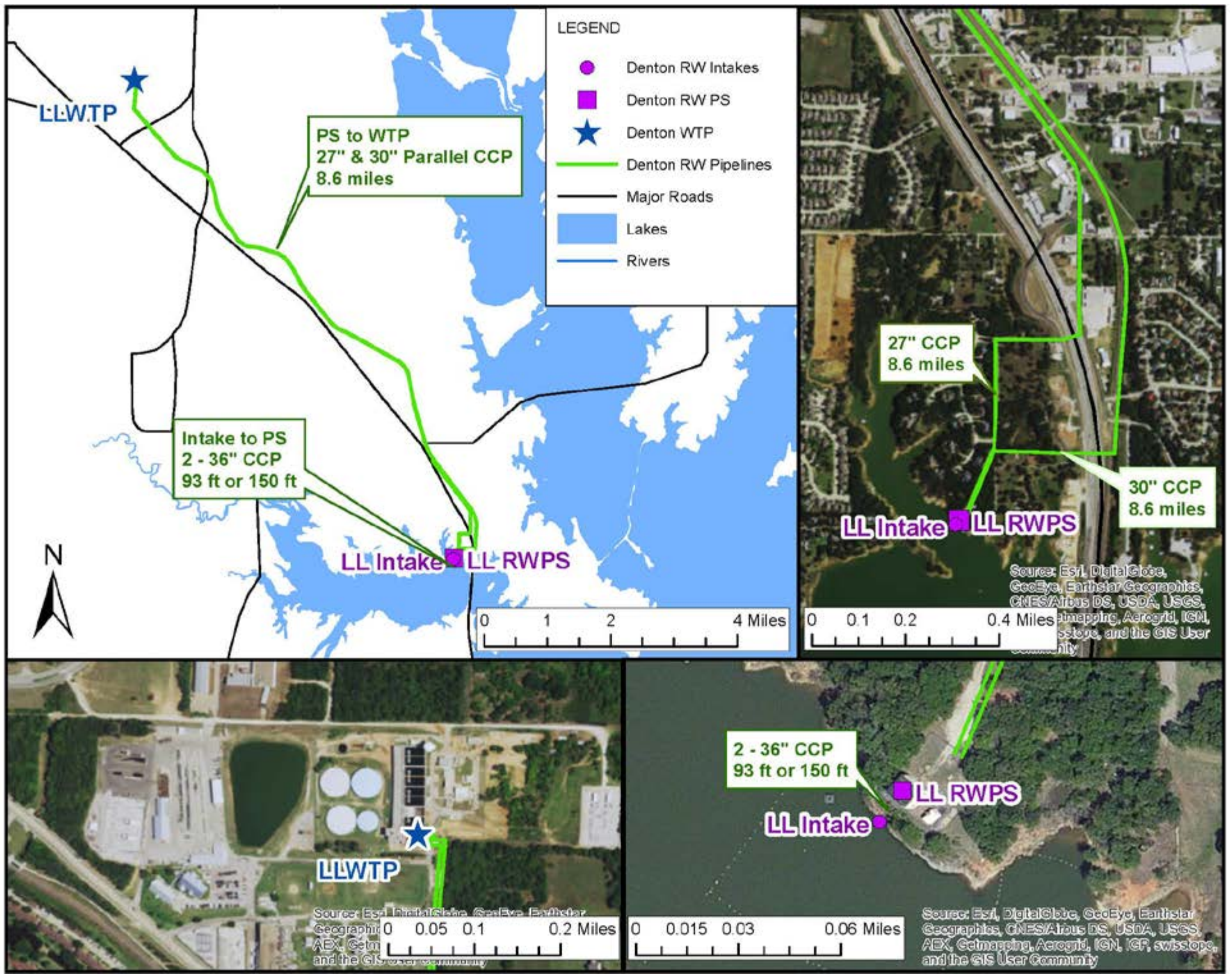


Figure 4-1: LLWTP Raw Water System Overview

The LLWTP Intake provides water from Lewisville Lake to the RWPS wet well through two 36" prestressed concrete cylinder pipe (PCCP) raw water lines, also referred to as the lower and upper intake. The lower intake pipe, located at an elevation of approximately 480 ft, extends for 150 ft into the wet well and the upper intake pipe, located at an elevation of approximately 505 ft, extends for a length of 93 ft into the wet well. The intake structure contains a concrete box on each 36-inch raw water pipeline and houses a bar screen with bars spaced 2" apart.

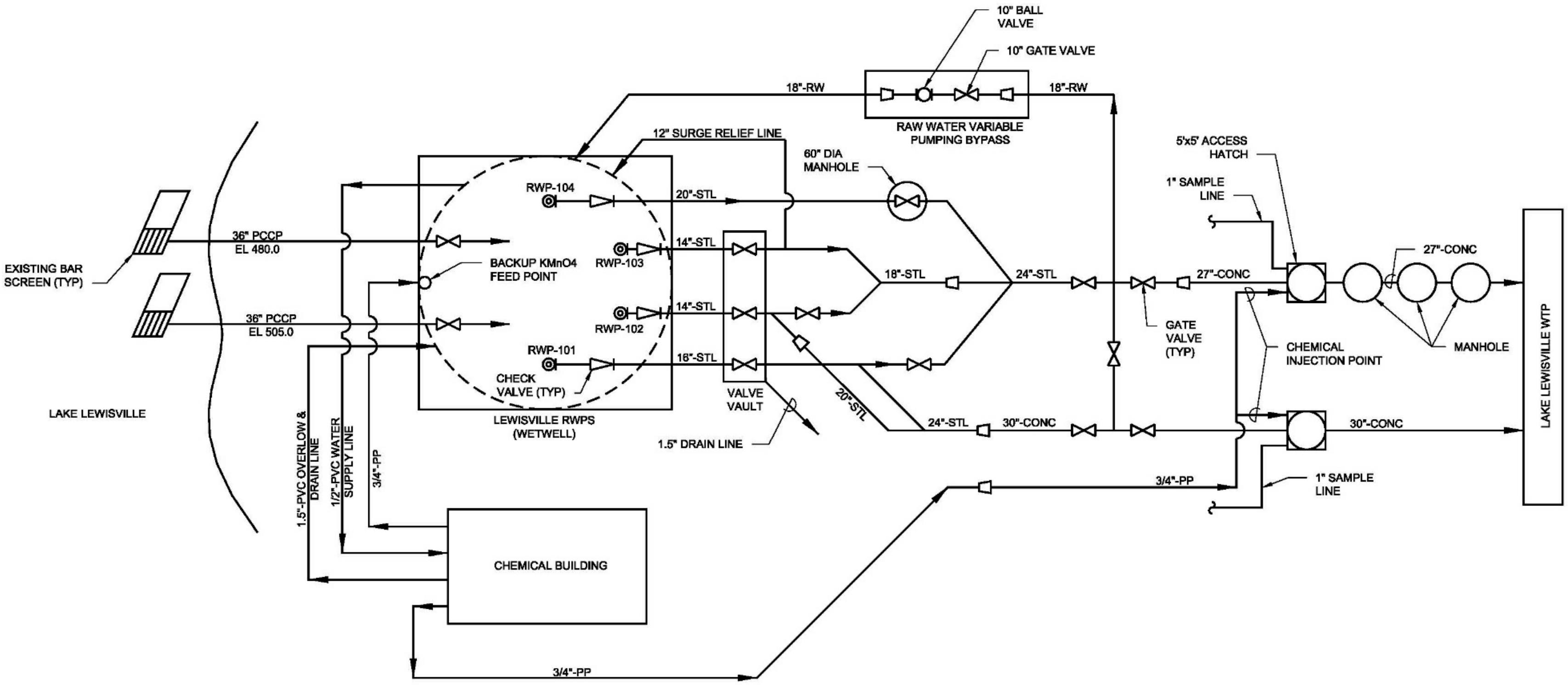


Figure 4-2: LLWTP Raw Water System Schematic

The RWPS building (Figure 4-3) includes a wet well with an approximate depth of 57 ft and four vertical enclosed-lineshaft pumps. On the discharge side of the pump building, two parallel concrete 27-inch and 30-inch raw water pipelines extend for approximately 8.6 miles to the LLWTP. The discharge header off the pump building also includes a surge relief valve and is equipped with a bypass (Figure 4-3) to reduce the flow. During site visits, it was noted that roadway improvements may be required for tote chemical delivery, and bulk chemical delivery may not be feasible due to the limited turning radius of the site. The COD has recently acquired additional land adjacent to the RWPS site.

Figure 4-3: LLWTP RWPS (Left) and RWPS Bypass (Right)

Adjacent to the RWPS building is a chemical building (Figure 4-4) that encloses the existing dry potassium permanganate feed system. This system was installed to control taste and odor and for pipeline maintenance. The facility housing the permanganate feed equipment has limited space with its existing setup. Originally, prior to modifications in 2011, potassium permanganate was fed on the suction side of the raw water pumps. In 2011, the chemical feed system was altered to dose the chemical directly through a ¾-inch polypropylene (PP) line into the 27 and 30-inch raw water lines. The chemical feed point inside the wet well is still in place but is not in use. At the time of these modifications, an automated control valve was added to the solution water supply line and the PLC was reprogrammed for remote control. Although no potable water access is currently in place, raw water from the wet well is withdrawn through a 1 ½-inch PVC line to serve as solution water for potassium permanganate. The current configuration is shown in Figure 4-2. Existing pumps can deliver up to a dose of 1.6 mg/L of potassium permanganate at maximum flow (much lower than the dose likely required for zebra mussel management as summarized in Section 3.1.2.1). Corrosion of the existing pumps and the area above the wet well (Figure 4-5) was observed likely due to use of potassium permanganate with sufficient chemical mixing. COD staff noted that the existing pumps are exhibiting approximately 10 year life cycles.

Figure 4-4: LLWTP Potassium Permanganate Chemical Building

Figure 4-5: LLWTP RWPS Corrosion

4.1.2. Risk Assessment

A risk assessment was conducted to rank the overall relative risk to the LLWTP raw water system and to note potential impacts. In addition to the operational and physical characteristics of the site (Section 4.1.1), the risk assessment considered zebra mussel biology and ecology, local zebra mussel occurrences and local water quality as summarized in Section 2. The assessment considered the likelihood of infestation and potential impact to the COD as summarized below.

- **High Likelihood of Infestation** – The LLWTP raw water system was classified as high likelihood of infestation due to water quality generally within the range for moderate to high potential for zebra mussel infestations and the presence of a zebra mussel population in the Elm Fork arm of the lake and near the dam.

- **High Potential Impact to the COD** – The LLWTP raw water system was classified as high potential impact, meaning that it is susceptible to fouling due to the presence of many hard surfaces with small openings (i.e., bar screens, pipelines) and would pose a significant risk to COD operations if flow was constricted.

- **High Overall Risk** – Due to the high likelihood of an infestation and the high potential impact, the LLWTP raw water system was classified as high overall risk.

During site surveys, key components of the raw water system were identified, key considerations were recorded and the potential impacts of fouling to each component were evaluated (Table 4-1). The immediate potential impact to all components includes hydraulic capacity reductions due to fouling. The components at greatest risk include the upper intake 36-inch line and bar screen and the small diameter chemical piping. The upper intake and bar screen will likely be the first components to become fouled due to the presence of hard surfaces favorable for fouling and small bar screen openings. As the lower intake is currently not functional due to silt buildup, the system would have to be taken offline to perform cleaning of the upper intake. The solution water line for the permanganate system is highly at risk of fouling due to the small diameter (1.5-inches) and absence of chemical protection. Valves are also particularly susceptible to zebra mussel fouling and accumulated zebra mussel shells in the wet well could clog the pumps. In addition, mussels could lead to degradation of pipelines due to corrosion and pitting following physical removal. Shells within the raw water pipelines could be carried all the way to the rapid mix chamber at the plant. Additionally, a mussel infestation may result in an increase in taste and odor compounds in the water entering the treatment plant.

Table 4-1: LLWTP Raw Water System Evaluation of Major Components

Component	Considerations	Impacts
Intake Bar Screens	▪ 4'x1" cast iron bar screens bolted on a concrete box ▪ 16 – ¾" bars; 17 – 2" openings; 1 ¾" thick	Zebra mussels may build up on the bar screens and constrict flow.
Raw Water Pipeline	▪ Two 36"concrete intake pipelines ▪ Lower: 150' @ 480 ft elevation (silted in, but dredging in CIP) ▪ Upper: 93' @ 505 ft elevation	Mussels may foul the pipelines and constrict flow to the plant; long-term impacts may include accelerated degradation of pipelines due to corrosion and pitting from mussel attachment and removal.
Raw Water Pump Station	▪ 36" gate valve on each intake line ▪ Wet well ▪ 4 Vertical enclose line-shaft pumps (approx.. 10-11 MGD each) ▪ Check and gate valves on discharge lines (14" -24")	Zebra mussels may foul the pumps and support infrastructure and wet well. The wet well could serve as a safe location for mussel growth and reproduction. Valves are particularly susceptible to mussel fouling.
Bypass	▪ Variable bypass steel pipe (18") and control valve ▪ 8 MGD capacity; target of 5 MGD	Zebra mussels may foul the bypass line and valves reducing the current flexibility in flow to the plant.
Potassium Permanganate System	▪ 15'10" x 10' & 11' high chemical building ▪ ¾" PP solution line to injection vault ▪ ½" PVC raw water line for mixing ▪ Design dose of 0.4-1.2 mg/L ▪ Chemical injection in vaults on each raw water pipeline ▪ Backup feed point in the RWPS wet well	The existing permanganate system could be reused but due to increased doses for adequate zebra mussel control would be very labor intensive. Additionally, the small diameter raw water lines could become clogged with mussels.
Raw Water Pipelines	▪ 27" and 30" parallel CCP lines ▪ Approximate length of 8.1 miles to the WTP ▪ Only 3 manways on the 27" line ▪ No access to the 30" line ▪ ARVs and mud-legs with flanges could be evaluated for modification as future access points	Zebra mussels may foul the lines and constrict flow to the plant; long-term impacts may include accelerated degradation of pipelines due to corrosion and pitting from mussel attachment and removal. Redundant lines may allow for alternating pipeline use as a strategy to minimize the impacts of mussel fouling and/or to allow for physical removal.

4.1.3. Implications of Future Improvements

Future improvements of the LLWTP raw water system could potentially, both positively and negatively, impact management of zebra mussels. Table 4-2 summarizes the planned improvements to LLWTP raw water system and their potential implications developed during site visits and the Alternatives Analysis Workshop.

Table 4-2: Implications of Future Improvements to the LLWTP Raw Water System

Planned Improvements	Benefits to Zebra Mussel Control	Risks to Zebra Mussel Control
IH35 Improvements: Current construction underway on IH35 near the intake is bringing the highway and traffic closer to COD facilities	▪ Due to construction, manways have been added on both sides of the highway which provides access points to the lines	▪ Additional site security (fencing) may be required to protect chemical systems
Dredging of Silted Lower Intake: The CIP includes provisions to dredge the lower silted in intake	▪ Would provide a redundant intake if cleaning is required on the higher intake	▪ Zebra mussel improvements are not beneficial unless the lower intake is to be used in the future (i.e., dredging occurs) ▪ Would likely become re-silted in the future, requiring frequent maintenance to maintain
Addition of an Intermediate Intake: The COD is considering constructing an intermediate intake for use when lake levels are low	▪ The intake could be designed to improve zebra mussel management	▪ If unprotected, the intake would be at risk for fouling
Pipeline Assessments: Additional pipeline assessments are planned	▪ Would allow for complete inspection of the line to determine if any mussel fouling is present	▪ None
Increase 30" Raw Water Line to 42": There has been discussion about increasing the size of the larger raw water line	▪ Increased capacity could decrease the impact of fouling on water production ▪ Would allow for installing access manways at the time of construction	▪ Depending on the required flow to the WTP, zebra mussel fouling may still have a significant impact on flow to the WTP
Easement Agreement with USACE	▪ Would provide additional space for the construction of a new chemical building and associated piping ▪ Opportunity to discuss improvements for zebra mussel management	▪ None

4.2. MANAGEMENT APPROACH ALTERNATIVES

Considering the preventative, control, and reactive strategies for zebra mussel management identified and evaluated in Section 3, one reactive strategy and two preventative strategy alternatives were selected to be evaluated in detail, including development of descriptions and conceptual layouts (Section 4.2.1) and both quantitative (Section 4.2.2) and qualitative evaluation criteria established with the COD. O&M enhancements that require capital improvements are included within each of the management approaches. Management approach recommendations and all other O&M recommendations not requiring capital improvements are summarized in Section 4.3.

4.2.1. Description of Management Approach Alternatives

Three alternatives were selected to be further evaluated. These alternatives assume the lower intake will remain offline (i.e., dredging will not occur), a middle intake will be added and the upper intake will be improved for zebra mussel management. Variations to these improvements (e.g. improvements to the lower intake) are described in 4.2.1.4. A site plan showing the proposed improvements is displayed with an aerial view in Figure 4-6 and schematically in Figure 4-7. Proposed chemical feed points and routing are displayed schematically in Figure 4-8. Alternatives A1 and A2 are shown schematically and in cost estimates as Alternative A as the same chemical feed system would be used for either alternative. Should only one of the two chemicals be selected, then the chemical building size could be reduced and would only include the respective chemical storage or skid system.

4.2.1.1. Alternative A1 – Sodium Permanganate System

A preventative strategy to zebra mussel management would include capital improvements with means to prevent or minimize zebra mussel fouling to infrastructure. One preventative strategy would include improvements to the intake bar screen and the addition of sodium permanganate immediately after the bar screen to protect the intake, pump station and downstream pipelines. This alternative would include:

- **Improving the upper intake bar screen** – The upper intake bar screen should be replaced with a new bar screen built in a copper alloy material. The new bar screen should be designed to have increased bar spacing (4-6 inches) and have the ability to easily be removed for cleaning and re-coating.

- **New 36” mid-level intake** –A mid-level intake, with a copper alloy bar screen, will be constructed to provide operational flexibility.

- **Addition of a new sodium permanganate chemical system and feed points –** It is assumed that a new chemical building would be constructed for the new chemical storage and feed system. Sodium permanganate would be delivered in a 40% aqueous solution in 4-foot by 4-foot totes. A truck lift would be required to replace the totes and relocate them as needed. The system would also include two peristaltic metering pumps and instrumentation and controls to operate the chemical feed system. The totes would be installed in a chemical containment area, surrounded by a concrete barrier. Stainless steel 2-inch diameter chemical pipes (double walled in PVC pipe) would feed permanganate from the chemical building to primary and backup chemical feed points at the LLWTP Intake and RWPS. The new double wall chemical feed line would be floated in the water and then sunk with weights. Chemical injection quills would be attached to the downstream side of the bar screen and at the discharge end of both the lower and upper 36" intake lines into the raw water wet well. The chemical feed pumps will be interlocked with the raw water pumps to prevent chemical from spilling into the lake or permanganate concentration inside the wet well. Permanganate corrosion will be mitigated by interlocking the pumping systems and diffusing chemical immediately downstream of the bar screens to improve mixing and prevent the occurrence of high permanganate concentration pockets. The chemical injection points on the discharge side of the pumps (into the 27" and 30" raw water lines) will operate as additional backup chemical feed points. This alternative assumes an annual average sodium permanganate dose of 3.5 mg/L pulse-fed (i.e., 30 minutes on and 30 minutes off). Costs for both 8 months of chemical feed (i.e., based upon favorable temperatures for settlement) and five months of chemical feed only during settlement season (i.e., an annual monitoring cost is included) were calculated to understand the potential savings from monitoring for settlement (see Section 3.2.2).

- **Light physical removal and disposal –** This alternative also accounts for some small degree of physical removal and disposal that may be required. Light power washing of the intake bar screens may be required each year. In addition, some minor physical removal and disposal may be required from the intake and pump station. Closed-circuit television (CCTV) inspections should be conducted. Some light periodic cleaning by divers or by dewatering may be required but at a greatly reduced frequency, and it is assumed only a limited number of manways will be required (to be determined during development of cleaning contracts).

4.2.1.2. Alternative A2 – Copper Ion Generation System

A second preventative strategy would include improvements to the intake bar screen and the addition of a copper and aluminum ion solution immediately after the bar screen to protect the intake, pump station and downstream pipelines. Although some small degree of physical removal and disposal may be required, the level of effort and time offline would be minimal. This alternative would include:

- **Improving the upper intake bar screen** – The upper intake bar screen would be improved as described in Section 4.2.1.1.
- **New 36" mid-level intake** –A mid-level intake will be construction as described in Section 4.2.1.1.
- **Addition of a new copper ion generation system and feed points –** It is assumed that a new chemical building would be constructed for the new chemical system. The generation system would consist primarily of three-four cells containing copper and aluminum anodes, piping and a PLC unit. These components could either be fastened to a wall or provided on a skid (or the PLC could be fastened to the wall while the remaining components are provided on a skid). Plan and section views of the skid in these different configurations are provided in Appendix F. The cells

have a one-year warranty, and are expected to be replaced annually. A spare cell is recommended to minimize any downtime when replacement is required. Chemical containment is not required. Pressurized raw water would be provided to the system by tapping the 27-inch and 30-inch raw water lines in the chemical injection vaults downstream of the raw water pumps. During detailed design, it should be confirmed that the pump discharge provides sufficient head to overcome pipeline losses and the 3-5 feet of headloss across the cells while providing the necessary pressure for the chemical diffusers. In the case sufficient pressure is not available, a transfer / metering pump may be required. A backwashable strainer should be installed on the raw water feed line to minimize settlement and fouling of the cells. Potable water could also be used in lieu of raw water, if desired. The system would also include ancillary piping and valving, water quality monitors and instrumentation and controls to operate the system. PVC or Cross-linked polyethylene (PEX) 2-inch diameter chemical pipes would feed the copper and aluminum ion solution to a primary and backup chemical feed points at the LLWTP Intake and RWPS. The new double wall chemical feed line would be floated in the water and then sunk with weights. Chemical injection quills would be attached to the downstream side of the bar screen and at the discharge end of both the lower and upper 36” intake lines into the raw water wet well. The chemical injection points on the discharge side of the pumps (into the 27” and 30” raw water lines) will operate as backup chemical feed points. The chemical feed pumps will be interlocked with the raw water pumps to prevent chemical from spilling into the lake. This alternative assumes the copper and aluminum ion solution will be fed continuously throughout the year (although at a lower dose during non-settlement seasons) based upon manufacturer recommendations. Since the dose is based upon the amount of current directed at the anodes, only minor savings in power costs would be observed by monitoring for settlement, and thus the higher power cost was assumed.

- **Light physical removal and disposal –** This alternative also accounts for some small degree of physical removal and disposal which may be required as described in Section 4.2.1.1.

4.2.1.3. Alternative B – Physical Removal and Maintenance Improvements

A reactive strategy to zebra mussel management would include minimal capital improvements to ease future physical removal and disposal efforts. This alternative would include:

- **Improving the upper intake bar screen** – The upper intake bar screen would be improved as described in Section 4.2.1.1.
- **New 36” mid-level intake** – A mid-level intake will be construction as described in Section 4.2.1.1.
- **Physical removal and disposal** – As this reactive strategy would allow for a significant infestation of the intake to take place, pump station and raw water lines, physical removal and disposal would be required at least every two years (depending on the allowable reduction in hydraulic capacity). The intake bar screens and conduits would need to be cleaned using a dive team. Additional manways would need to be added and the existing blow-offs / mud legs at low spots with 18-inch openings along the 27-inch line would need to be improved to allow for pipeline access. Access

points should be installed at low points and pipe bends to allow for removal of accumulated mussel shells following die-off events and at least every 1500-2000 LF for access to perform hydroblasting. Additionally, manways could have mechanical systems to insert cameras for inspection. Further, any new pipelines should be designed with manways for access following these same guidelines. Following removal, mussels would be disposed of in rented dumpsters and transported to the COD landfill for disposal. It is assumed mussels would be transported directly from the site to the landfill on a more frequent basis due to the residential neighborhood nearby. An on-call contract for cleaning would accelerate the physical removal process to allow for removal before a severe infestation occurs.

4.2.1.4. Optional Additions and Substitutions

There are several variations to the alternatives listed in the previous sections. The list below consists of alternative additional selections or substitutions to any of the proposed alternatives represented above.

- **Substitution 1: Copper alloy coated stainless steel bar screens** – A new bar screen could be constructed of with a copper alloy coating on a new stainless steel bar screen in place of a copper alloy material. The bar screen would be redesigned with larger bar spacing regardless of the material selected. Although the capital cost would be less, the annual operation and maintenance cost would be higher as the bar screen would require re-coating. According to manufacturers, a life of 15 years can be expected (a warranty for 5 years is provided) for the copper alloy coating. The lifecycle cost was calculated assuming the coating would require replacement after 10 years. The life cycle cost also assumes at the time of replacement, a spare bar screen with a copper alloy coating will be fabricated to minimize time offline during coating replacement.

- **Substitution 2: Chemical feed lines (through pipeline) -** Instead of floating the new double wall chemical line in the water, the new chemical feed line could be installed through the back side of the gate valves to run inside the wet well and through the 36” intake pipeline. This alternative would require a greater capital investment, but would provide more protection for the chemical feed line.

- **Addition 1: Lower 36” intake improvements** – COD’s CIP includes a project to dredge the lower silted in intake. Although it is unknown for when this project is planned, it may be a necessary project if low lake levels prohibit proper use of the upper intake. Should the silt accumulation be physically removed around the lower intake in the future, installation of a new bar screen and a new chemical feed line to feed chemical immediately downstream of the bar screen could be added.

- **Addition 2: Potable water line** – Currently, chemical solution water is withdrawn from inside the wet well (i.e., raw water). A potable water line could be connected to the nearest potable water supply to provide chemical solution water with lower chemical demand.

- **Addition 3: Land rights for maintenance access –** Although the COD currently has access easements to the raw water pipelines, these easements may not allow for access, manway construction and/or physical removal of mussels. The physical removal process, including manway installation and cleaning, may be considered to over encumber the easement. The current easements and landowners may not allow physical removal and/or additional easements may have to be acquired. Access to the raw water lines should be evaluated in advance of an infestation if a reactive approach is selected.

- **Addition 4: Site improvements for maintenance access –** Significant clearing and grading may also be required to provide access to the manhole locations. This could include cutting and chipping trees and brush, soil stabilization and slope grading. Access to the raw water lines should be evaluated in advance of an infestation if a reactive approach is selected.

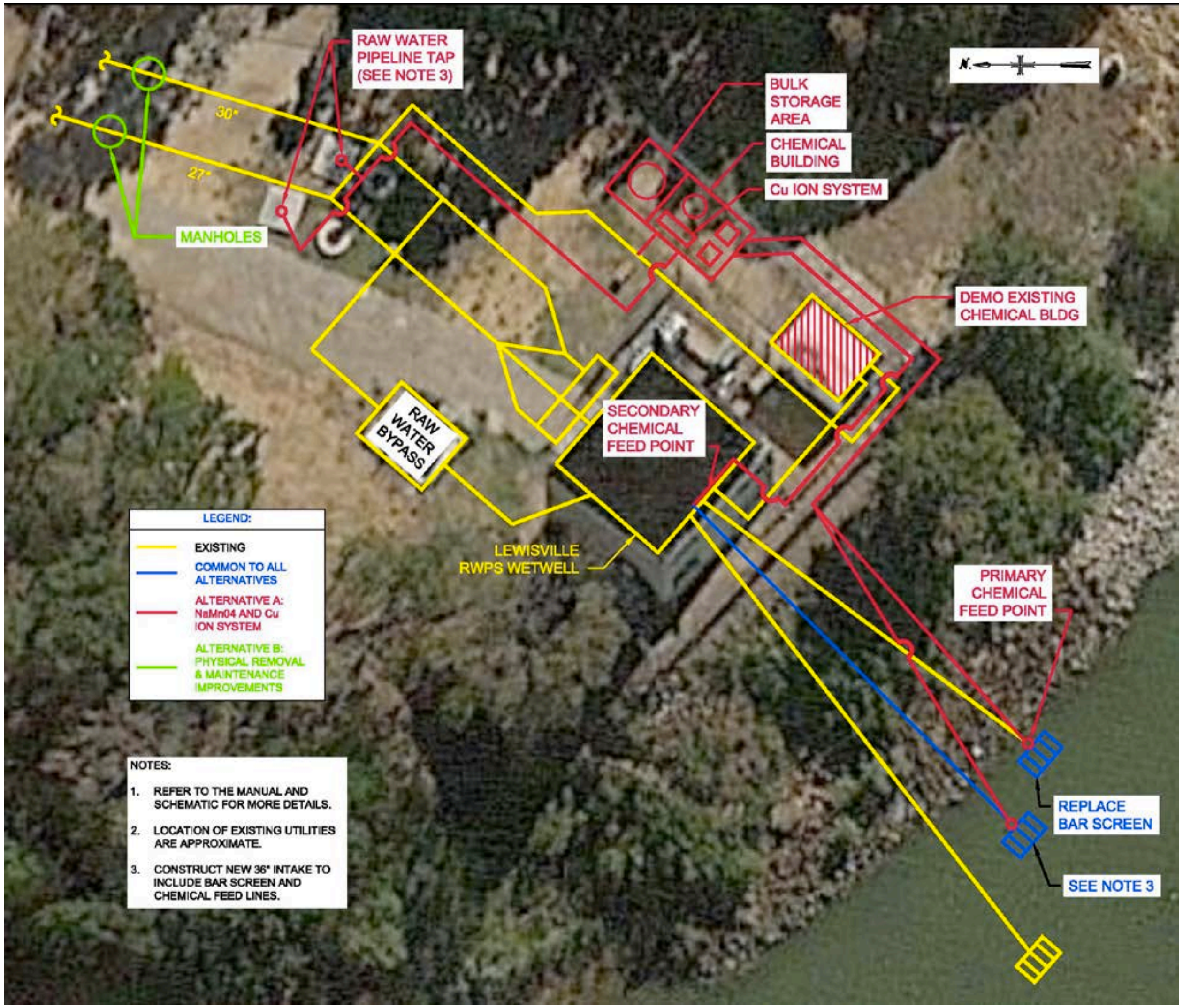


Figure 4-6: LLWTP Intake Aerial of Proposed Improvements

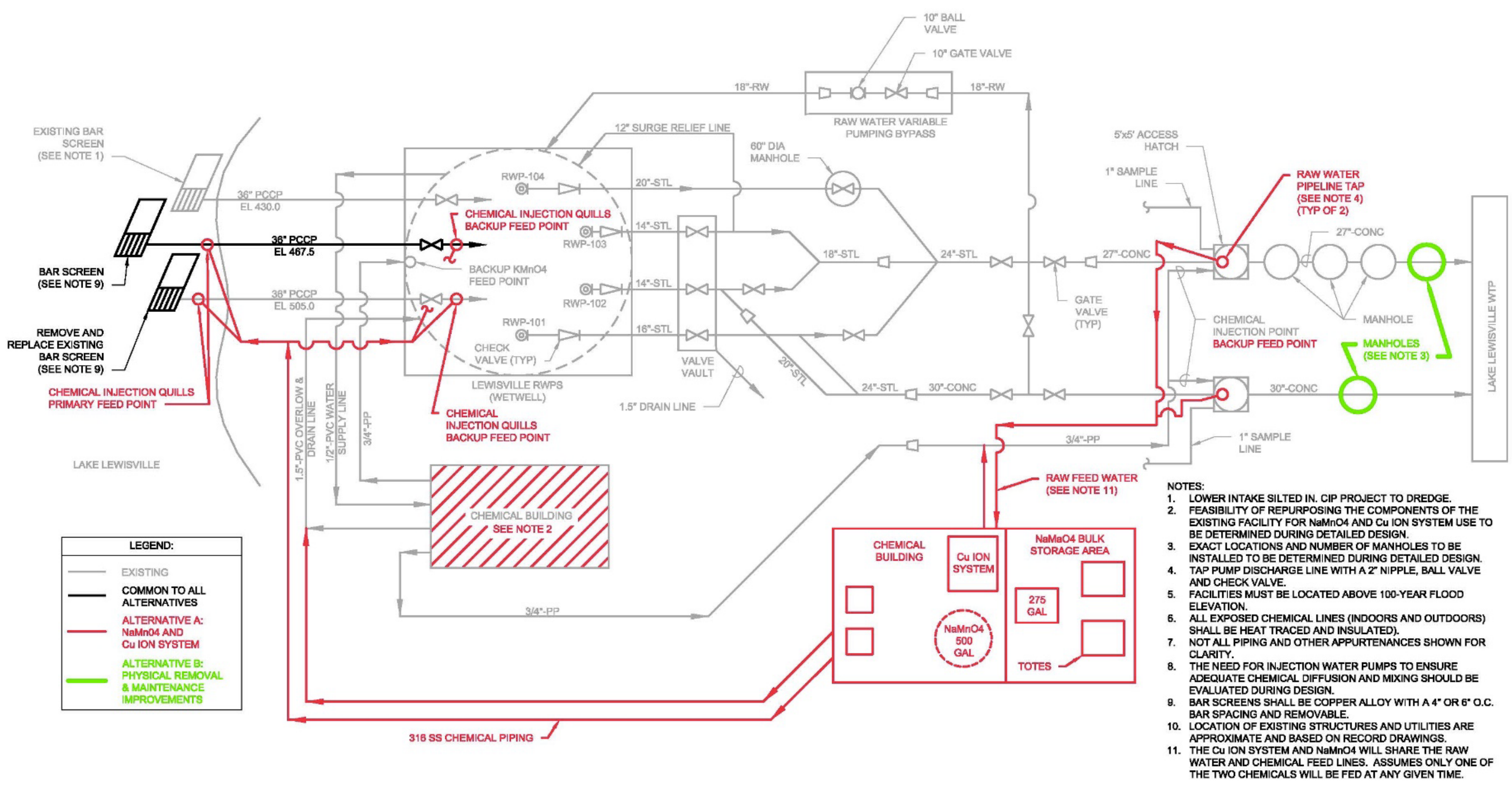


Figure 4-7: LLWTP Intake Schematic of Proposed Improvements

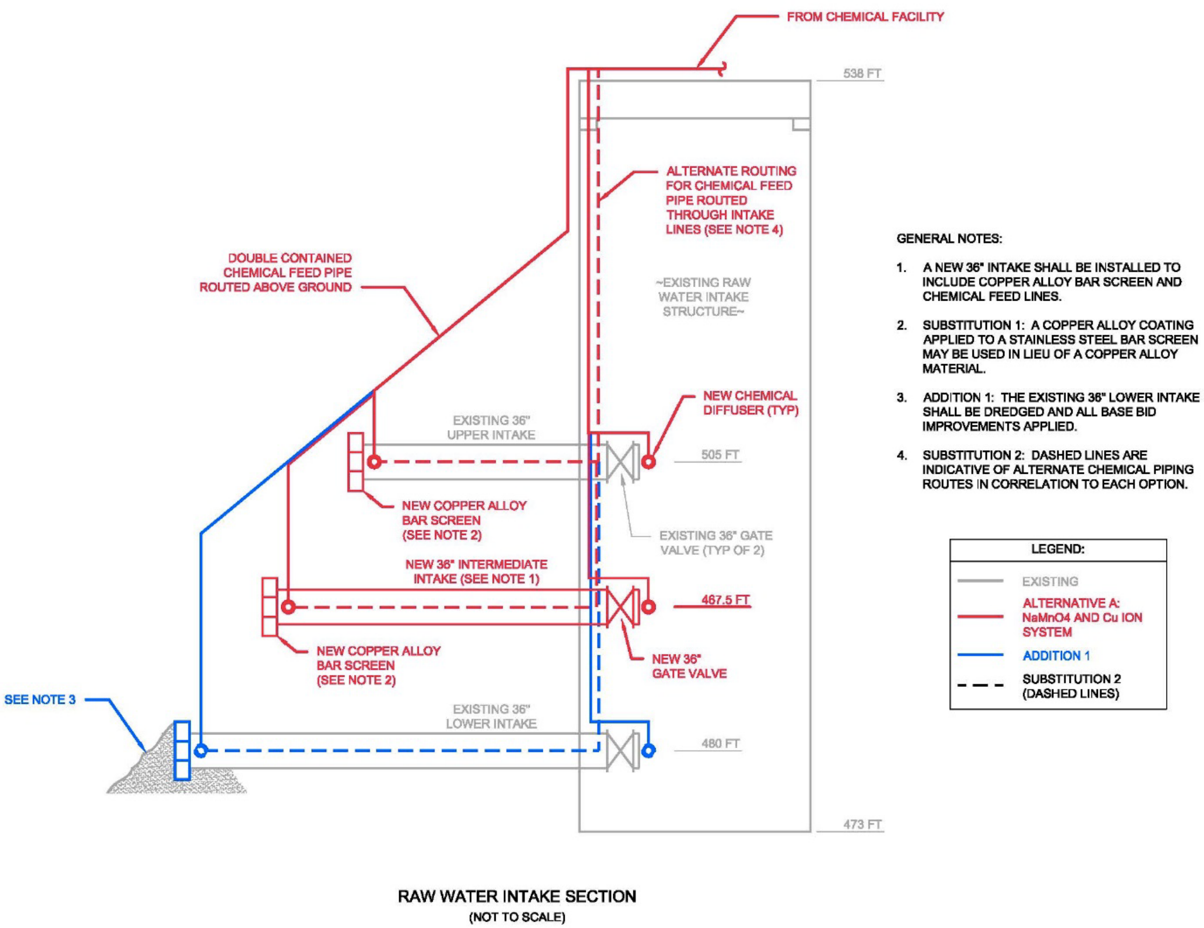


Figure 4-8: LLWTP Intake Proposed Chemical Feed Points

4.2.2. Cost Estimates

Design criteria for the chemical feed layouts and costs based upon expert knowledge and literature are summarized in Table 4-3. Table 4-4 summarizes the approximate capital costs, yearly operation and maintenance costs, and 20-year lifecycle costs for the zebra mussel management alternatives described in Section 4-9. These costs were based on manufacturer proposals and quotes, TxDOT low bid tabs, as well as construction costs from previous projects. Detailed probable cost estimates can be found in Appendix E.

Table 4-3: LLWTP Intake Design Criteria and Assumptions

Category	Unit Cost of Assumption			Basis
FLOW	Minimum Flow	5	MGD	Plant RW Flow Data from 2012-2015
	Average Flow	8.4	MGD	
	Maximum Flow	30	MGD	
CHEMICAL DOSE	Sodium Permanganate Design Dose	5.5	ppm	Chemical Demand Testing summarized in Appendix C
	Sodium Permanganate Annual Average Dose	3.5	ppm	
	Copper Dose (During Settlement)	5.0	ppb	Mfr Recommendations
	Copper Dose (No Settlement)	2	ppb	
	Aluminum Dose (During Settlement)	0.5	ppb	
	Aluminum Dose (No Settlement)	0.2	ppb	
CHEMICAL COST	Cost of Cu/Al Anode Cell	5,500	$/year	Mfr Cost Estimate
	Cost of Sodium Permanganate	1.65	$/lb	
	Delivery Cost	500	$/delivery	Estimate
CHEMICAL PROPERTIES	Sodium Permanganate Solution Strength	40%		Mfr Specifications
CHEMICAL DOSING FREQUENCY	Sodium Permanganate Dosing Frequency	12	hr/d	Estimate from Previous Project Experience
	Copper Ion Dosing Frequency	24	hr/d	Mfr Recommendations
	Months of Chemical Feed	8	mo/yr	Estimate from Previous Project Experience
	Months of Chemical Feed (Monitoring)	5	mo/yr	
ZEBRA MUSSEL CLEANING & DISPOSAL	Mussel Coverage Without Management	30%		Estimate from Previous Project Experience
	Mussel Coverage With Management	10%		
	Average Thickness of Mussel Coverage Without Management across the Pipeline	1	inch	
	Average Thickness of Mussel Coverage With Management across the Pipeline	0.5	inch	
	Mussel Density	76	lb/cy	
	Linear feet of pipe cleaned	300	lf/day	
	Frequency of cleaning (first mile of each line)	2	every...years	
	Frequency of cleaning (entire line)	5	every...years	
	Cost of Physical Cleaning	10,000	$/day	
	Dumpster fee	150	EA (30 CY)	
	Minimum Cost for Short Distance Hauling	350	$	
	Mussel Transport to landfill	9	$/mile	
	Mussel Disposal Fee	26	$/ton	
LIFECYCLE COST	Escalation Factor	3.50%		Estimate
	Interest Rate	3%		

Category	Unit Cost of Assumption			Basis
	Lifecycle	20	years	
O&M COST	Energy Cost	0.09	$/kWh	Current Industry Rates
	Water Cost	0.0027	$/gal	
	Ion Generator Power (Maximum)	0.64	kW	
	Ion Generator Power (Minimum)	0.08	kW	
	Operator Chemical Rate	50	$/hr	
	Instrument Technician Rate	60	$/hr	
	Mechanical Technician Rate	55	$/hr	
CAPITAL COST	Mobilization and Demobilization	3%		Estimate
	General Requirements	5%		
	Bonds and Insurance	2%		
	Contractor's Profit	15%		
	Contingency	30%		
	Labor and Installation	30%		
ENGINEERING & CONSTRUCTION ADMINISTRATION	Fee Percentage of Capital Cost	20%		Estimate

Table 4-4: LLWTP Intake Proposed Improvements Cost Estimate

	Alternative	Capital Cost[1]	Annual O&M Cost[2]	Annual Cleaning and Removal Cost[3]	20-Year Lifecycle Cost	Engineering and Construction Administration
A	Sodium Permanganate and Copper Ion Systems[4]	$2,360,000				$480,000
A1	Sodium Permanganate 8 Month Chemical Feed		$89,000	$58,000	$5,470,000	
	Sodium Permanganate 5 Month Chemical Feed (with Monitoring)		$74,000	$58,000	$5,154,000	
	Sodium Permanganate Potential Savings from Monitoring		$15,000	-	$316,000	
A2	Copper Ion Generation System		$41,000	$58,000	$4,901,000	
B	Physical Removal and Maintenance Improvements	$2,610,000	$26,000	$200,000	$10,329,000	$530,000
Optional Additions and Substitutions:						
Substitution 1: Copper Alloy Coated Stainless Steel Bar Screens[5]		($86,000)	$0	$0	($30,000)	$0
Substitution 2: Chemical Feed Line (Through Pipeline)[5]		$30,000	$0	$0	$30,000	$10,000
Addition 1: Lower 36” Intake Improvements		$372,000	$3,000	$3,000	$662,000	$80,000
Addition 2: PVC Potable Water Line		$29,000	$24,000	$0	$534,000	$10,000
Addition 3: Land Rights for Maintenance Access[6]		$244,000	$0	$0	$244,000	$50,000
Addition 4: Site Improvements for Maintenance Access[6]		$244,000	$0	$0	$244,000	$50,000

[1] Probable costs are based upon the recommended line items shown and are Class 4 Association for the Advancement of Cost Engineering International (AACE).

[2] Physical Cleaning and Removal not included. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.

[3] Physical Cleaning and Removal Cost is represented on annual basis for budgetary purposes, although in reality would occur every 2 years for the first mile of the line. A more extensive cleaning every 5 years is included as a replacement cost.

[4] The capital cost provided for Alternative A assumes both the copper ion and sodium permanganate systems are constructed to provide a redundant approach to zebra mussel management. If only one of the two chemical systems was implemented, the capital cost would likely be reduced by approximately $250,000-$300,000.

[5] Substitutions are represented by the price difference as compared to the respective base option(s).

[6] Potential variable costs that may be required for physical removal and disposal access in pipeline segments where property is not owned by COD. Necessity of these variable costs to be determined during detailed design.

4.2.1. Comparison of Alternatives

An alternative comparison matrix was developed to compare each of the alternatives based upon the evaluation criteria summarized in Section 3.1.1. Each of the three alternatives described previously are listed in a matrix column in Table 4-6. Each row in the matrices compares alternatives relative to each criterion. Following the alternative comparison matrix is a one-page summary matrix (Table 4-7) that highlights each matrix cell (each criterion per alternative) in one of the following four categories as summarized in Table 4-5. Lastly, Table 4-8 ranks the alternatives based upon the evaluation criteria weighting factors established during the Alternatives Analysis Workshop and summarized in Section 3.1.1. **Based upon the results of the ranking, sodium permanganate and copper ion systems were ranked the highest.**

Table 4-5: Ranking Categories

Description of Category	Highlight Color	Score
Not Favorable	Red	1
Many Limitations	Orange	2
Some Limitations	Yellow	3
Favorable	Green	4

Table 4-6: LLWTP Intake Alternative Comparison Matrix

Approaches	**Prevention Approach: Chemical Alternatives**		**Reaction Approach**
Improvement	**Alternative A1:** Sodium permanganate[3]	**Alternative A2:** Copper ion generation	**Alternative B:** Physical removal and maintenance improvements[4]
Life Cycle Cost[1] [Capital Costs][2]	**$5,154,000 - $5,470,000** [$2,360,000]	**$4,901,000** [$2,360,000]	**$10,329,000** [$2,610,000]
Effectiveness for Prevention of Zebra Mussel Fouling	• Effectively prevents settlement with a 0.25 mg/L residual • Based on oxidant demand, may be effective at an average dose of 3.5 mg/L. Based on water quality the required dose may range between 1.5 –5.5 mg/L	• Limited lab studies suggest a 0.01 – 5 ppm copper dose may be effective at preventing settlement • Manufacturers recommend a dose 0.005 ppm copper above background concentrations • Effectiveness is also due to formation of aluminum hydroxide flocs • Water quality (e.g. total suspended solids, DOC, temperature) impacts toxicity of the copper ion	• Will not prevent fouling but use of copper alloy coatings and the existing permanganate system at the maximum design dose of 1.2 mg/L may reduce fouling (see demand testing results in Section 3.1.2.1)
Ease of O&M and Operational Flexibility	• Simple application equipment (chemical feed system and storage for one liquid chemical) • Available in concentrations up to 40% • Will not protect trash racks • Will require maintenance	• Potential lawsuit of Fortress MC system by MacroTech • Alum flocs may settle in raw water pipelines • Requires pressurized (raw) water • Anode cells require annual replacement • Generation equipment, cells and PLC come on a skid or can be wall mounted. No bulk chemicals required • Electrodes will degrade and may foul over time requiring greater power to generate the same copper concentrations and resulting in varied copper concentrations	• Physical removal is labor intensive • May require extended shutdowns • Installation of a bulk mixing tank would ease labor requirements for increased potassium permanganate use • Damage to pipelines (i.e., pitting) may occur with repeated removal activities
Impact to Downstream Water Quality and Water Treatment Plant	• Oxidizes iron/manganese • May improve aesthetic quality of water • No regulated DBP formation • May result in increased manganese concentrations, color tinting or turbidity if not properly managed • Manganese SMCL of 0.05 mg/L must be considered	• Addition of copper must consider the copper SMCL of 1.0 ppm and Lead and Copper Rule Action Level of 1.3 ppm • Addition of aluminum ions must consider the SMCL of 0.2 ppm • No known DBP formation	• Taste and odor compounds may be generated by decaying mussels • Headloss across screens may result as mussels build up • May result in increased manganese concentrations, color tinting or turbidity if not properly managed • Manganese SMCL of 0.05 mg/L must be considered

Approaches	Prevention Approach: Chemical Alternatives		Reaction Approach
Improvement	**Alternative A1:** Sodium permanganate[3]	**Alternative A2:** Copper ion generation	**Alternative B:** Physical removal and maintenance improvements[4]
Impact to Environment / Ecology	• Nonselective and highly toxic to non-target organisms • Requires application point that would prevent flow into source water • Would require construction of new tanks/pumps above the 100-yr flood elevation	• Nonselective and highly toxic to non-target organisms • Requires application point that would prevent flow into source water	• None if mussels are removed and disposed of in a landfill • Potential impact if mussels are "left in place" due to bioaccumulation of contaminants
Implementability	• Minimal equipment (bulk and day tanks and feed pumps/piping) required • Chemicals should be stored in a cool, dry area in closed containers. May require a new chemical building • Requires regulatory coordination	• Potential lawsuit of Fortress MC system by MacroTech • Requires on-site generation • Minimal equipment fits on a small skid • Requires tapping of pump discharge lines • Requires regulatory coordination	• Requires construction of manways along the pipeline for access • Requires extended plant shutdowns • Requires regulatory coordination • Existing permanganate system in place
Health & Safety	• NFPA 430 Class II oxidizer • NFPA Ratings: Health = 2, Flammability = 0, Reactivity = 1, Special = OX • Strong (20-40%) concentration	• Copper NFPA Ratings: Health = 2, Flammability = 1, Reactivity = 0 • Al NFPA Ratings: Health =1, Flammability = 0, Reactivity = 0	• Safety concerns with underwater divers • Safety concerns with entry into confined spaces (i.e. pipelines) • Safety concerns due to sharp shells

Status in the Industry / Record of Performance	• Potassium permanganate has been used extensively for zebra mussel control by municipalities.
	• Sodium permanganate has been used less frequency but is gaining popularity. For example:
	  • City of Findlay, OH (including pilot study that proved effectiveness)
	  • Neenah Water Utility Water Treatment Plant, WU
	  • Keokik Municipal Waterworks, IA
		• Proprietary system and programming.
		• Limited research studies or municipal installations for zebra mussel control.
		• Complete list for the MacroTech system includes:
		  • City of Wichita (80 MGD)
		  • City of Emporia (15 MGD)
		  • RWD#3 – Kansas (5 MGD)
		  • Milford Utilities (5 MGD)
		• Fortress MC system Commissioned by City of Wahpeton, IA (0.4 MGD) in May 2015
			• Widely-used for trash racks and small diameter pipelines
			• Supplemental maintenance to most zebra mussel management approaches
			• Less commonly used as a primary management approach due to labor intensiveness and long shutdowns
			• Potassium permanganate has been used extensively for zebra mussel control by municipalities

Approaches	Prevention Approach: Chemical Alternatives		Reaction Approach
Improvement	**Alternative A1:** Sodium permanganate[3]	**Alternative A2:** Copper ion generation	**Alternative B:** Physical removal and maintenance improvements[4]
Public Acceptability	• Widely used in water treatment for pre-oxidation • Familiar technology	• Potential for unknown consequences due to limited information and installations available • Proprietary technology • Potential for increased copper or aluminum concentrations in the distribution system	• Potential for reduced consumer confidence if reduced hydraulic capacity cannot meet water demands

1 – Probable costs are based on Class 4 Association for the Advancement of Cost Engineering International (AACE).
2 – The capital cost provided for Alternative A assumes both the copper ion and sodium permanganate systems are constructed to provide a redundant approach to zebra mussel management. If only one of the two chemical systems was implemented, the capital cost would likely be reduced by approximately $250,000-$300,000. Chemical alternative costs include the cost for rebuilding bar screens in a copper alloy material, adding a mid-level intake, and light physical removal and disposal.
3 – Lifecycle costs for sodium permanganate is presented as a range based on chemical feed of 5 – 8 months per year. Based upon favorable water temperatures for zebra mussel settlement, 8 months of chemical feed per year is required. However, incorporation of settlement monitoring may reduce chemical feed to less than 5 months of the year. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.
4 – Physical removal and maintenance improvements costs include rebuilding bar screens in a copper alloy. Costs are presented as a range considering potential variable costs such as land rights and site improvements for maintenance access.

Table 4-7: LLWTP Intake Summary of Alternatives

Approaches	Prevention Approach		Reaction Approach
Improvement	**Alternative A1: Sodium permanganate[3]**	**Alternative A2: Copper ion generation**	**Alternative B: Physical removal and maintenance improvements[4] (including existing permanganate system)**
Life Cycle Cost **[Capital Costs]**	**$5,154,000 - $5,470,000** [$2,360,000]	**$4,901,000** [$2,360,000]	**$10,329,000** [$2,610,000]
Effectiveness for Prevention of Zebra Mussel Fouling	• Effective	• Effective, but dose required varies across studies	• Will not prevent fouling throughout system but use of existing permanganate system will limit fouling
Ease of O&M and Operational Flexibility	• Simple application equipment	• Impending lawsuit of Fortress MC system • Electrodes may degrade and foul over time • Settlement of alum flocs	• Labor intensive • May require extended shutdowns • Damage to pipelines
Impact to Downstream Water Quality and Water Treatment Plant	• May result in increased manganese, turbidity or color tinting of the water	• Addition of copper and aluminum ions may result in Lead and Copper Rule violations	• Potential for increased taste and odor • May result in increased manganese, turbidity or color tinting of the water
Impact to Environment / Ecology	• Toxic to non-target organisms	• Toxic to non-target organisms	• Minimal
Implementability	• Minimal equipment	• Impending lawsuit of Fortress MC system • Minimal equipment fits on small skid	• Requires extended plant shutdowns
Health & Safety	• Strong oxidizer	• Copper and aluminum ions	• Underwater divers • Confined spaces
Status in the Industry / Record of Performance	• Proven technology but limited installations	• Proprietary • Few municipal installations for zebra mussel control	• Proven technology
Public Acceptability	• Widely-used in water treatment	• Proprietary technology • Increased copper and aluminum ions	• Potential to not meet water demands

Key:

Not Favorable	Many Limitations	Some Limitations	Favorable

Table 4-8: LLWTP Intake Ranking of Alternatives

Criteria	Criteria Weighting Factor	Alternative A1: Sodium permanganate		Alternative A2: Copper ion generation		Alternative B: Physical removal and maintenance improvements	
		Raw Score	Weighted Score[1]	Raw Score	Weighted Score	Raw Score	Weighted Score
Capital and Lifecycle Costs	14.1%	3	0.42	3	0.42	1	0.14
Effectiveness for Prevention of Zebra Mussel Fouling	21.6%	4	0.86	3	0.65	2	0.43
Ease of O&M and Operational Flexibility	16.4%	3	0.49	2	0.33	1	0.16
Impact to Downstream Water Quality and Water Treatment Plant	10.6%	1	0.11	3	0.32	3	0.32
Impact to Environment / Ecology	3.7%	1	0.04	1	0.04	3	0.11
Implementability	7.9%	3	0.24	3	0.24	1	0.08
Health & Safety	8.8%	1	0.09	3	0.26	1	0.09
Status in the Industry / Record of Performance	14.6%	3	0.44	2	0.29	4	0.58
Public Acceptability	2.3%	4	0.09	2	0.05	2	0.05
TOTAL	**100%**	**23**	**2.78**	**21**	**2.51**	**18**	**1.96**
Overall Ranking		**1**				**2**	

4.3. RECOMMENDATIONS

The previous RRWTP raw water system zebra mussel infestation and recent heavy juvenile zebra mussel settlement in Lewisville Lake lead to the recommendation that the COD proceed proactively with actions to better prepare for future zebra mussel infestations of the LLWTP raw water system. As the LLWTP raw water system is susceptible to fouling, and zebra mussel infestations would pose significant risk to COD operations, a proactive program to manage risk is recommended for implementation. Key recommendations include:

- Applying monitoring and inspection techniques to input information into the decision-making process;
- Developing and implementing a multi-barrier approach to zebra mussel management; and
- Optimizing O&M activities, which can significantly reduce future impacts with minimal capital investment.

COD can either select to implement a preventative or reactive approach to zebra mussel management. Preventative strategies prevent attachment on surfaces or prevent settlement of veligers while reactive strategies are aimed at removing an existing infestation. A preventative approach is recommended to minimize future capacity reductions to the water treatment plants. However, some scale of physical removal and disposal will be required even with the most proactive strategies.

Recommendations considered local raw water quality, local zebra mussel biology and ecology, downstream water quality goals, potential operational impacts, current and potential future regulations, and future changes to the raw water system and downstream treatment plants. The source-to-tap approach considered potential dual-benefits and mitigation strategies for potential downstream unintended consequences. Capital, operations and maintenance recommendations for the LLWTP raw water system including risk management recommendations (e.g. monitoring and inspection guidelines and interim chemical feed recommendations) are summarized in Section 4.3.1. Lastly, recommended next steps are provided in Section 4.3.2.

4.3.1. Capital, Operations and Maintenance Recommendations

Long-term recommendations for managing future potential zebra mussel infestations in the LLWTP raw water system include capital improvements (e.g. installation of two chemical feed systems and installation of new copper alloy bar screens), maintenance improvements (e.g. manway installations), and operational enhancements (e.g. operating pumps and valves frequently). Two-chemical systems using common piping and feed system components provide redundancy without a significant increase in cost, and are common in zebra mussel management strategies employed in the Great Lakes region. The ability to utilize an alternate system in lieu of the primary system to reduce the impact of system limitations (e.g., increase effectiveness, mitigate a potential downstream consequence) or when the primary system is not operating due to maintenance, will provide the LLWTP with a robust preventative zebra mussel management strategy. Table 4-9 summarizes recommended capital improvements and O&M strategies for the LLWTP Intake. These improvements should be implemented based upon an established response plan (i.e., trigger for implementing interim and permanent systems) and the results of monitoring. The primary recommendation for COD is to pursue a proactive approach to zebra mussel management (i.e., preventative strategy) to minimize the volume of zebra mussels requiring disposal. Additional information on the recommendations in Table 4-9 is provided within this chapter.

Table 4-9: LLWTP Intake Recommended Capital Improvements, O&M Strategies and Associated Costs for Zebra Mussel Management

	Probable Costs[1]	Recommendations
Capital Improvements	Probable Capital Improvement Cost: $2,360,000 Probable Engineering and Construction Administration Fee: $ 480,000	▪ Rebuild bar screens a copper alloy; include a redesign to make the bar openings 4 to 6-inches and the bar screen removable for future cleaning ▪ Install a copper ion system (based upon plant design flow rate of 30 MGD) ▪ Install a sodium permanganate storage and feed system (based on a design dose of 5.5 mg/L) ▪ Minor manway improvements for physical removal and disposal access, especially at pipeline low points ▪ See Section 4.2 for more information
General O&M Enhancements	Probable annual O&M cost: $99,000 - $147,000	▪ Light physical removal and disposal, as required (e.g. bar screen power washing), to include regular pipeline inspections ▪ Operate pumps, gates and valves frequently ▪ Isolate and dewater structures (e.g. wet well) during plant shutdowns (lower water level if complete dewatering is not possible) ▪ Alternate pipeline use, when possible ▪ See Section 3.2.1 and 4.2 for more information
Dosing Strategies		▪ Dosing strategies (including the dose applied, frequency, duration and time of year) should be optimized after startup. The recommended initial dosing strategy includes: Copper Ion Systems: ▪ Dose: 5 parts per billion (ppb) copper and 0.05 ppb aluminum during settlement season; 2 ppb copper and 0.02 ppb aluminum during non-settlement seasons ▪ Frequency/Duration: continuous operation Sodium Permanganate: ▪ Dose: 3.5 mg/L average (likely range of 1.5 – 5.5 mg/L) ▪ Frequency/Duration: on/off every 30 minutes ▪ Timing: based upon monitoring, when settlement occurs in the spring and fall (alternatively, when temperatures are above 16°C and below 32°C) ▪ See Sections 3.1.23.1.2.1 and 3.2.2 for more information
Risk Management Approaches		▪ Increase monitoring to include additional water quality, substrate sampler and veliger monitoring at minimum (see Section 4.3.1.1 for details) ▪ Visually inspect debris from the bar screen(s). Also visually inspect any dewatered surfaces during maintenance activities (see Section 4.3.1.1 for details) ▪ Develop a plan for interim chemical feed using the existing potassium permanganate system (see Section 4.3.1.2 for details) ▪ See Section 4.3.2 for a summary of recommended next steps to minimize risk including development of on-call contracts, regulatory coordination and new standard operating procedures

1 – Probable costs are based upon the recommended line items shown and are Class 4 Association for the Advancement of Cost Engineering International (AACE). Annual O&M costs assume settlement monitoring will be conducted to reduce chemical feed doses during nonsettlement seasons. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.

4.3.1.1. Recommended Monitoring and Inspection Guidelines

Currently, there is a localized population of zebra mussels near the Lewisville Lake Dam and a recent settlement of adult and juvenile mussels in the Elm Fork arm of Lewisville Lake due to recent flooding. Thus, the focus of the proposed monitoring program is to develop a timeline for implementation of zebra mussel management approaches and optimize future management strategies. COD does not have a current zebra mussel monitoring program, but does measure temperature, pH, calcium and hardness 4 to 6 times per year and TOC, DOC and alkalinity monthly. In addition, USGS is monitoring Lewisville Lake for veligers, settled juveniles and adult zebra mussels. Besides continuing the water quality monitoring currently performed, the Arcadis team recommends the COD perform the additional monitoring outlined in Table 4-10. After infestation of the LLWTP Intake, the monitoring program should be modified to:

- Determine seasonal and annual variability in zebra mussel settlement timing, density and growth; and
- Optimize the zebra mussel management approach including:
    - Frequency of physical cleanings;
    - Dose and chemical applied;
    - Continuous versus intermittent dosing; and
    - Seasons when dosing is required.

Table 4-10: Recommended COD Zebra Mussel Monitoring at the LLWTP Intake

Monitoring Method	Frequency
Information Gathering: Develop a network to disseminate and collect information among all interested and potentially impacted parties including TPWD and other utilities in Texas. Consider designating one staff member to serve as a "zebra mussel point of contact" who is familiar with the issues to participate in all information sharing.	Monthly
Water Quality Monitoring: Establish continuous temperature recorders (in interim could be measured manually) in source water at the elevation of each intake line that is in use and measure at least daily to identify when the water temperature at the intake is favorable for settlement.	Year-round
Direct Site Inspections: Institute an in-house direct inspection program which includes: ▪ Training of facility personnel in adult zebra mussel identification ▪ Establishment of procedures to verify any possible zebra mussel sighting (contract lab, USGS, university) including collection, preservation, and photo-documentation. ▪ Inspection of any dewatered hard surfaces including screens, wet well, pipes, gates during maintenance activities ▪ Inspection of debris (e.g. vegetation) pulled off bar screens or from the wet well. ▪ Diligently observe plant operation for impacts of zebra mussels such as reduced hydraulic capacity. Consider conducting additional pipeline assessments following each settlement season (or at least every 2 years). ▪ Additionally, regularly inspect the rapid mix basins for zebra mussel shells The in-house direct inspection program should continue with increased monitoring during the reproduction season when surface water temperatures are above 16°C (i.e., when settlement is likely to occur). Focus on presence/absence, initially. Following an infestation, focus on densities and control validation within the system.	During routine maintenance activities (e.g. cleaning of bar screens) and plant shutdowns with regular inspections when temperatures are above 16°C

Monitoring Method	Frequency
Veliger Monitoring: Sampling should be modified to determine the density of veligers and settled mussels (i.e., not presence/absence). Sampling should occur at the intake upstream of any control when water temperature is above 12°C (to assure detection of spawning/settlement soon after it occurs around 16°C).	Monthly; Increase to weekly after an established population is detected at the LLWTP Intake
Substrate Samplers: Sampling should be conducted weekly when veligers are present. Initiate when spring ambient water temperatures reach 12°C (to assure detection of spawning/settlement soon after it occurs around 16°C). Consider less frequent monitoring during other times. Sampling should occur at the intake upstream of any control.	Monthly; Increase to weekly after an established population is detected at the LLWTP Intake
Control Validation: For monitoring within a facility, a side-stream technique, using a water tap to provide flow to a sampler, called a biobox is recommended. Biobox monitors should be established in the facility raw water system with the following guidelines: ▪ Place at farthest point where control needs to be effective (i.e., just prior to the rapid mix process at the WTP) ▪ Place near any critical points in the system (e.g. just upstream of raw water fire protection systems, sensitive equipment) ▪ Establish only in areas where continuous flow is present ▪ Following start-up of chemical feed, monitor the permanganate residual through the system. Any components or pipeline lengths not protected by a chemical residual of approximately 0.25 mg/L will be susceptible to fouling. Online permanganate monitors should be installed immediately prior to rapid mix at the WTP (furthest point requiring protection) and at the chemical valve vault (where backup chemical could be added if the demand is higher than expected). Grab sample residual measurements may also be helpful along the raw water pipelines wherever access is available to understand how far the applied dose is protecting. ▪ Bioboxes should include the same substrates used in at the intake and have the capability to conduct veliger sampling (veliger sampling may not be necessary depending on control strategy) ▪ Include the capability to introduce test adult mussels to monitor the efficacy of control	TBD based upon sensitivity to fouling and control approach selected. Monitor at the same frequency and time as monitoring at the intake
Manganese Monitoring*: Following start-up of permanganate feed (or increased chemical feed using the existing permanganate system), monitor the total and dissolved manganese, pH, DO and oxidative-reductive potential (ORP) at multiple points in the raw water system, before and after each treatment process, and in recycle streams. Shifts in pH or ORP, changes in the permanganate dose, anoxic conditions or operational changes at the WTPs could result in resolubilization of manganese and manganese spikes leading to staining of equipment, exceedance of the manganese SMCL of 0.05 mg/L, increased turbidity or colored water. Conduct total manganese monitoring of the finished water daily and conduct manganese profiling regularly and after any of the previously mentioned changes. Consider measuring pH and ORP daily at the LLWTP Intake chemical vault (downstream of chemical addition). Additionally, monitor the manganese removal performance of the biofilters through the ongoing Innovation Fund Project with Arcadis. During this study, the COD performed a trial run by increasing the dose of potassium permanganate at the intake and monitoring the manganese profile across the WTP. The results and recommendations for troubleshooting downstream consequences (e.g., increased turbidity or colored water) are provided in Appendix G. * *Not required if only copper ion system is in use*	Total and dissolved manganese entering the plant and in the finished water daily. Manganese profiles regularly (e.g. once per month) or any time process changes are made (including changes in chemical doses).

The Arcadis team recommends that COD develop site-specific monitoring programs (i.e. regularly update at the frequencies suggested in the table above) dependent on the sensitivity of each facility to fouling and the type of control(s) that are implemented. If an on-staff biologist is not available to oversee and perform biological monitoring techniques, additional monitoring contracts can be established with labs or agencies, such as USGS.

4.3.1.2. Recommendations for Interim Chemical Feed

During an inspection on July 16th, 2015, Chris Churchill with USGS observed a very heavy settlement of juvenile zebra mussels on the passive sampler at the Cantrell Slough site (near US 380 and the Elm Fork of the Trinity River from Ray Roberts). Further, during the spring of 2016, mussels were observed in DWU raw water lines downstream. As mussels were not previously observed at this site in May, this settlement is likely due to the recent flooding in North Texas. High lake levels and cooler water temperatures greatly enhance the likelihood of juvenile settlement at the LLWTP Intake. Based upon ongoing research conducted by Dr. McMahon in Lake Ray Roberts and Lake Texoma, these veligers could grow to reproductive size as early as this fall. Thus, it is essential that City of Denton (COD) begin measures to protect the LLWTP Intake and raw water pipelines from a severe zebra mussel infestation.

The best temporary option to provide protection from a severe zebra mussel infestation to the LLWTP Intake and raw water lines is to use the existing potassium permanganate system at the LLWTP Intake. The existing system will provide up to a 1.6 mg/L potassium permanganate dose at maximum flow for minor taste and odor control, algae control, and pipeline maintenance at the chemical valve vault downstream of the RWPS. The installed pumps have a slightly greater capacity than was required, and a standby pump was installed which could be used in parallel with the duty pump to provide a greater overall capacity. There is also a backup chemical feed point at the RWPS wet well. Depending on the flow rate and water demand, the existing system may not always be capable of delivering the required dose for complete protection of the system. However, use of the existing system at the maximum dose, in these cases, should significantly reduce mussel infestation of the LLWTP Intake and raw water lines. The COD should make arrangements for additional staff presence at the intake as the system will become significantly more labor/maintenance intensive at the higher dose as the dry chemical is loaded manually into the system hopper. It is also recommended the COD check contract dates and scheduled deliveries to ensure adequate chemical is available on site to accommodate the higher dose. The table below outlines recommended start-up operational criteria. Table 4-12 shows the maximum dose that could be fed with the existing potassium permanganate system based upon five different flow rates. An electronic calculation spreadsheet was provided to the COD to allow calculation of doses based upon additional flow rates, as necessary (see Appendix E).

Table 4-13 shows the approximate potassium permanganate dose that would be required at a range of temperatures, based on extrapolating data collected during oxidant demand testing for this project. Demand and required dose are affected by multiple factors, so doses and dose change as a function of temperature are specific to the water quality conditions present at the time of demand testing and may vary significantly from those shown in the table.

Table 4-11: Start-Up Operational Criteria

Criteria	Recommendation	Basis
Permanganate Dose*	On average, 3.5 mg/L (if flow rate is too high to reach this dose, the maximum dose allowed by the existing system)	Estimated annual average chemical dose based upon demand testing was 3.5 mg/L. The dose will need to be adjusted seasonally as demand changes.
Dosing Frequency	Continuous**	Previous project experience suggests that 30 min on 90 min off can be effective at doses above the background water demand; however, the lower dose may be more effective if provided continuously.
Application Point	Primary: Wet Well Backup: Chemical Valve Vault	Existing chemical feed locations (note this will not protect the intake screens or pipelines).
Application Seasons	When temperatures are above 16°C and below 30°C	Research conducted by Dr. McMahon suggests that local spawning / settlement occurs above 16°C and below 30°C. Based on historical data, the water temperature is likely favorable March – July and August – December. Settlement monitoring at the LLWTP Intake would likely narrow the number of months requiring chemical treatment. Settlement monitoring has not been recently conducted by Dr. McMahon in Lewisville Lake.

*A sudden application of an oxidant at a high dose may result in biofilm and solids release from the pipeline. Operational plans should be in place to monitor for and treat a potential spike in influent organics and solids following initial startup.
**Recommend continuous in place of pulse-dosing as the maximum dose of the existing system is below the dose required to maintain a residual through the pipeline based upon chemical demand testing.

Table 4-12: Existing Potassium Permanganate Dosing Capacity

Plant Flow Rate (MGD)	Maximum Potassium Permanganate Dosage Based on Pump Capacity (mg/L)
5.0	10.6
8.4	6.3
10.0	5.3
15.0	3.5
32.5	1.6

Table 4-13: Potassium Permanganate Dose versus Temperature

Temperature (°C)	Potassium Permanganate Dosage (mg/L)
10	0.75
15	1.7
20	2.5
25	4.0
30	5.5

It is critical the COD increase manganese monitoring at the LLWTP following the recommendations in Table 4-10 as soon as the permanganate dose is increased. Note that, at the maximum dose of the existing chemical feed system, some veliger settlement may be observed but long-term application of chemical should significantly lessen any infestations. Nevertheless, the start-up operational criteria in the above table should be optimized by monitoring:

- Settlement of veligers at the LLWTP Intake to optimize the application timing
- Effectiveness of the treatment strategy to optimize the dose and dosing frequency
- Manganese in the raw water system and through the treatment plant to predict and troubleshoot any potential downstream unintended consequences of a higher raw water permanganate dose

In addition to optimizing the operating criteria for permanganate dosing at the LLWTP Intake, monitoring will provide data which will help to optimize the future design of permanent facilities. Data collected over several years should be trended to determine seasonal operating practices specific to the LLWTP Intake and raw water system.

4.3.2. Recommended Next Steps

The recommended capital improvements do not necessarily need to be constructed immediately. There are a number of proactive actions COD can initiate to prepare for potential future infestations of the LLWTP Intake without spending capital funds prematurely. Develop a response plan to initiate further steps to provide zebra mussel protection (e.g. confirm the trigger for constructing interim and permanent improvements). Recommended triggers include:

Short –Term/No Trigger:

- Implement the next steps recommended in this section including but not limited to standard operating procedure development, regulatory coordination and monitoring.
- Revise budgets in the Capital Improvements Plan (CIP) based upon the selected alternative and adjust annual operating budgets to account for increased annual costs to manage zebra mussels.
- Establish third party physical removal contracts.
- Begin designs of permanent systems and develop plans for interim potassium permanganate use.

Long-Term/Zebra Mussel Observed:

- Begin to increase the potassium permanganate dose (existing system) when there is settlement.
- Begin construction of permanent improvements.

Other Considerations:

- During future projects to dredge the lower intake or construct a mid-intake, implement zebra mussel management approaches (e.g. new intake bar screen and chemical feed lines) to protect the intakes.

- Update the response or strategic plan annually based upon updated data from monitoring.

Figure 4-9 summarizes an implementation timeline highlighting recommended short-term actions and actions that can be initiated upon mussel observance. LLWTP raw water system action items recommended for short-term implementation are summarized herein.

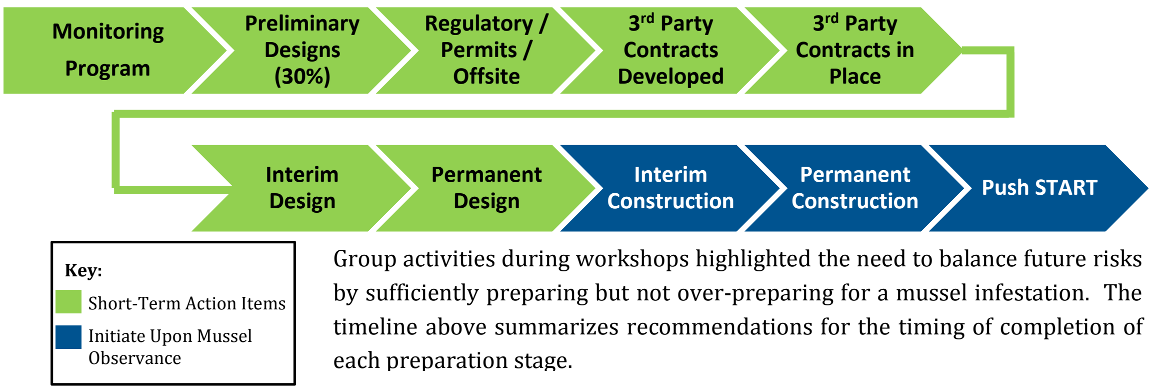


Figure 4-9: Recommendations Timeline

4.3.2.1. Develop a Zebra Mussel Monitoring Standard Operating Procedure (SOP)

Increased biological monitoring should begin immediately to maximize the amount of time to respond and prevent future potential infestations following the recommendations in Section 4.3.1.1. Consider hiring and/or training staff members to perform zebra mussel monitoring (i.e., veliger, settlement and adult identification) at both intake locations. Update the monitoring plan annually based upon a review of trended data collected through the monitoring effort. Following implementation of any molluscicides, the SOP should provide procedures for modifying the site's monitoring program for chemical feed optimization including the use of chemical residual monitors and bioboxes in the intake and at the point farthest downstream in the system where protection is required.

4.3.2.2. Begin Regulatory Coordination

Zebra mussel management will require coordination with multiple regulatory agencies throughout the planning, design, and construction phases of the project as summarized in Section 2.6. Which agencies are involved depends on the selected zebra mussel management approach and the application, but the following regulatory focus items should be addressed in the near term:

- Send 60% and 100% design documents for new chemical improvements to TCEQ for review and approval. Include computational fluid dynamics (CFD) modelling and design chemical feed pumps to interlock with the raw water flow to demonstrate that safety measures are in place to prevent chemical flow into the water source.

- Coordinate with USACE once conceptual designs are complete to confirm whether any permits will be required (especially for new chemical feed systems) and follow up on the new easement agreement.

- Coordinate for USFWS and TPWD to determine whether reviews are required based upon 60% designs. If presence/absence surveys are required, begin coordination of surveys prior to construction bidding.

4.3.2.3. Develop On-Call Contracts for Physical Removal and Disposal

It is recommended that COD proactively develop an on-call contract (see Section 3.2.3.4 for additional information) for cleaning and disposal of mussels. On-call contracts generally require the contractor to coordinate disposal in accordance with all regulations. Develop on-call contracts (or price agreements) for inspecting facilities for zebra mussels and cleaning mussel infestations from facilities. On-call contracts should include detailed drawings and specifications and consider the lessons learned from the RRWTP zebra mussel cleaning event (Section 2.4).

4.3.2.4. Assess Acceptable Impacts and Evaluate Access

Consider potential hydraulic losses due to zebra mussels and/or Asian clams, potential disposal efforts associated with physical removal, and evaluate access points for physical removal of shells.

- Use hydraulic analysis to determine the level of acceptable infestation and allowable reduced hydraulic capacity before cleaning is necessary. Consider each plant individually and the system as a whole. See Section 2 and Appendix E for hydraulic calculations.
- Especially for longer pipelines, consider the maximum volume of mussels that should be allowed to accumulate before removal. If pipe capacities are larger than the current flows, hydraulic impacts may not be noticed before large volumes of mussels accumulate in pipelines and potentially slough off and travel to the head of the plant (i.e., rapid mix). Consider executing an inspection on-call contract to monitor mussel accumulations or conduct regular CCTV assessments of all pipelines.
- Evaluate locations for maintenance access points for zebra mussels and/or Asian clams throughout raw water pipelines, especially at low points. Consider the implementation timeline for access improvements in coordination with potential planned projects. Manway access points could also include mechanical systems to insert cameras for inspections. Include access points in future designs of new raw water lines.

4.3.2.5. Coordinate Disposal

Based on a review of the alternatives, landfilling is recommended to minimize capital costs and future risks associated with alternative disposal approaches. It is assumed that the COD landfill, which was used to dispose of mussels from the RRWTP raw water system, will be used for the LLWTP. If a different landfill is used, there may be additional testing and regulatory requirements.

- Verify that testing completed previously with mussel samples from Lake Ray Roberts is sufficient for approval of future mussels removed from the LLWTP raw water system. If not, complete any required TCLP testing in advance of a major mussel cleaning project to acquire acceptance from the COD landfill. Prior experience from Lake Ray Roberts involving zebra mussel disposal suggests that toxicity should not be an issue. Disposal requirements should be included in on-call contracts or used by COD if cleaning and disposal will be self-performed. Even the best zebra mussel management approaches may require small amounts of zebra mussel disposal at times.

- Review easement and access agreements to ensure ability to access all raw water lines in the case that physical removal is required. The first mile of pipeline and all low points and pipe bends are most critical to access.

4.3.2.6. Develop an Interim Chemical Feed Plan

Develop a plan for using the existing potassium permanganate system to provide some level of zebra mussel management in the case that an infestation occurs before a permanent system is constructed. Detailed recommendations for increasing the permanganate feed are provided in Section 4.3.1.2 and recommendations for increased monitoring and inspections are provided in Section 4.3.1.1. The interim design should include the necessary monitoring equipment (e.g. residual monitors and bioboxes) to optimize the chemical dose and frequency required. Consider completing a trial run of a higher chemical dose in coordination with the recommended increased monitoring (i.e., manganese, ORP and pH profiles) prior to an infestation to troubleshoot any downstream consequences (e.g. increased turbidity or colored water).

4.3.2.7. Develop New Chemical System Design Documents

As settled zebra mussels have been identified in Lewisville Lake, begin development of design documents for the selected alternative. If construction will be completed immediately, complete 100% design documents. Otherwise, 60 or 90% design documents could be developed to minimize the time to complete design prior to future construction without sacrificing the value of designs decreasing as they sit on the shelf. The design should consider and balance dual-water quality benefits (i.e., pre-oxidation of manganese, taste and odor compounds and organics and cyanobacteria and algae control) with downstream treatment challenges (e.g. continuous chemical feed may be preferred over pulse dosing to provide continuous pre-oxidation of manganese and minimize changes in the downstream ozone dose). Design should include developing chemical dosing SOPs and may require more extensive demand testing and/or pre-oxidation jar testing to understand how to respond to water quality changes (e.g. seasonal changes in demand or zebra mussel settlement). Consideration should be given to ensure small diameter lines, including the water supply lines for the potassium permanganate, the raw water turbidimeter and the by-pass valve, are fully protected during settlement season as they will have much lower tolerances than the large diameter transmission lines. The permanent design should also include redundancy of equipment (multiple metering pumps), and a central storage area for permanganate totes.

4.3.2.8. Sodium Permanganate Implemention for Zebra Mussel Management, Develop a Manganese SOP

In conjunction with sodium permanganate (and potassium permanganate for interim feed) implementation for zebra mussel management, a manganese standard operating procedure (SOP) should be developed. If not properly monitored and managed, permanganate can result in increased manganese concentrations (potentially above the 0.05 mg/L MCL) in the treatment stream, which in turn can lead to colored water events. It should be noted that although development of a manganese management procedure is recommended, many utilities (e.g. City of Oregon, OH, City of Toledo, OH and City of Raleigh, NC) have used permanganate doses of 2-4 mg/L without any noticeable resulting manganese water quality impacts. A summary of recommended manganese monitoring is provided in Table 4-10, and a summary of the trial run of increased permanganate performed by the COD is provided in Appendix G.

- The manganese SOP should include increased monitoring of total and dissolved manganese, pH and ORP before and after each treatment process and each oxidant feed location. These parameters should be monitored on a regular basis, and especially after any major water quality or treatment process changes.
- Treatment process optimization strategies (including guidelines for pre-oxidation of manganese) should be outlined and triggers (i.e., manganese concentrations) for implementing operational changes identified. Treatment process optimization strategies should include: optimization of the permanganate dose by monitoring the residual and using bioboxes, increasing the sedimentation basin sludge blowdown frequency to prevent anoxic conditions resulting in resolubilization of manganese, adjusting the ozone dose to prevent over-ozonation and formation of permanganate or colloidal manganese oxides, and improving solids handling and recycle streams to prevent manganese from being recycled to the head of the plant.

4.3.2.9. Copper Ion Generation Implementation for Zebra Mussel Management, Implement Additional Copper and Aluminum Monitoring

The COD should observe the upcoming installation and performance of this system at the City of Lewisville Intake. A copper monitoring plan would be recommended including an initial assessment of background copper levels. Copper removal via downstream treatment processes should be verified to ensure compliance with existing and potential future regulations and assess impacts on copper and lead control in the distribution system, understanding that existing regulations generally become more stringent over time. Aluminum should also be monitored and assessed.

Due to the limited information available and limited full-scale municipal installations for zebra mussel control, a sidestream biobox pilot study could be performed prior to full-scale installation of a copper ion alternative to verify efficacy in COD source waters and systems. Additionally, a performance guarantee of zebra mussel settlement prevention could be requested from the manufacturer.

5. RAY ROBERTS WATER TREATMENT PLANT

The RRWTP provides drinking water to customers in the area of the City of Denton, Texas. The RRWTP is the smaller of the two COD water treatment plants. The plant was constructed in 2002, the raw water infrastructure was completed in 1983 and the second valve vault added in 1997. Most recently, in 2014, manways were installed in the raw water line to allow access for cleaning and disposal of zebra mussels. The plant has a current capacity of 20 MGD, average flows of approximately 9.9 MGD (based upon flow data from 2012-2015) and minimum flows of approximately 5 MGD. If future demands increase, the capacity of the RRWTP will be increased to 50 and ultimately 100 MGD. The existing main treatment processes include:

- Pre-ozone contactors for pre-oxidation and microflocculation
- Pumped diffusion vault followed by flocculation and sedimentation with cationic polymer and ferric sulfate for particle and organics removal
- Intermediate ozonation primarily for *virus* and *Giardia* inactivation and taste and odor control
- Biologically active filtration for turbidity removal, organics removal and trace contaminant removal
- Caustic addition to increase pH of finished water for corrosion control, maintenance of disinfection residual and increased chemical stability
- Disinfection with chloramines (chlorine combined with ammonia) through the clearwell and through the distribution system
- Fluoride addition prior to the clearwells for dental hygiene

The RRWTP has one intake (i.e., the RRWTP Intake) on Lake Ray Roberts. Raw water flows by gravity from the USACE outlet structure on the lake through a 60-inch and 42-inch concrete pipeline to the plant. The site survey results, including a detailed description of the existing raw water system, an assessment of the risk of a future zebra mussel infestation and an evaluation of future improvements, are provided in Section 5.1. The results from the site survey (Section 5.1) facilitated the development of site-specific zebra mussel management approaches and recommendations (Sections 5.2 and 5.3).

5.1. SITE SURVEY RESULTS

Site surveys were comprised of desktop design document review of as-built drawings, treatment plant process schematics, raw water quality data, plant operational data and local zebra mussel data as well as site visits (conducted March 23, 2015) with operations staff from both water treatment plants. In addition to explaining the physical characteristics of each site, operations staff provided insight into how the facilities are currently operated and any operational constraints that may exist. Considering all the information collected and reviewed, a risk assessment was conducted (Section 5.1.2) to evaluate the level of risk of a future zebra mussel infestation at the RRWTP Intake. Lastly, a list of planned future improvements to the raw water system, including identification of potential implications to future zebra mussel management, was developed (Section 5.1.3). The results from the site surveys aided in the development of site-specific zebra mussel management approaches and recommendations (Sections 5.2 and 5.3).

5.1.1. Description of Existing Raw Water System

The raw water system consists of the USACE dam outlet structure (i.e., the RRWTP Intake), a 60-inch raw water pipeline to the raw water pump station (RWPS) which is currently bypassed, and a 42-inch concrete pipeline to the plant. The COD also owns a hydroelectric power plant which is connected to the raw water system but is no longer in use. An overview of the RRWTP raw water system is shown in Figure 5-1, and the raw water system components are shown schematically in Figure 5-2. The total raw water pipeline distance from Lake Ray Roberts to the RRWTP is approximately 0.8 miles.

Figure 5-1: RRWTP Raw Water System

The USACE outlet structure and the first 0.15 miles of the 60-inch raw water conduit, including valve vault 1 (Figure 5-3), is owned and operated by the USACE. The USACE outlet consists of gates which have recently been coated by the USACE with the Sher-Release® silicon based coating for zebra mussel control after mitigation of existing zebra mussel fouling (Figure 2-7). During site visits, extensive fouling of rock and riprap was observed in the USACE Trinity River Stilling Basin (Figure 5-4). Water flows through a 60-inch raw water conduit to valve vault 1, which contains a wye providing way for discharge to the Trinity River's Stilling Basin or to COD's RWPS and WTP farther downstream.

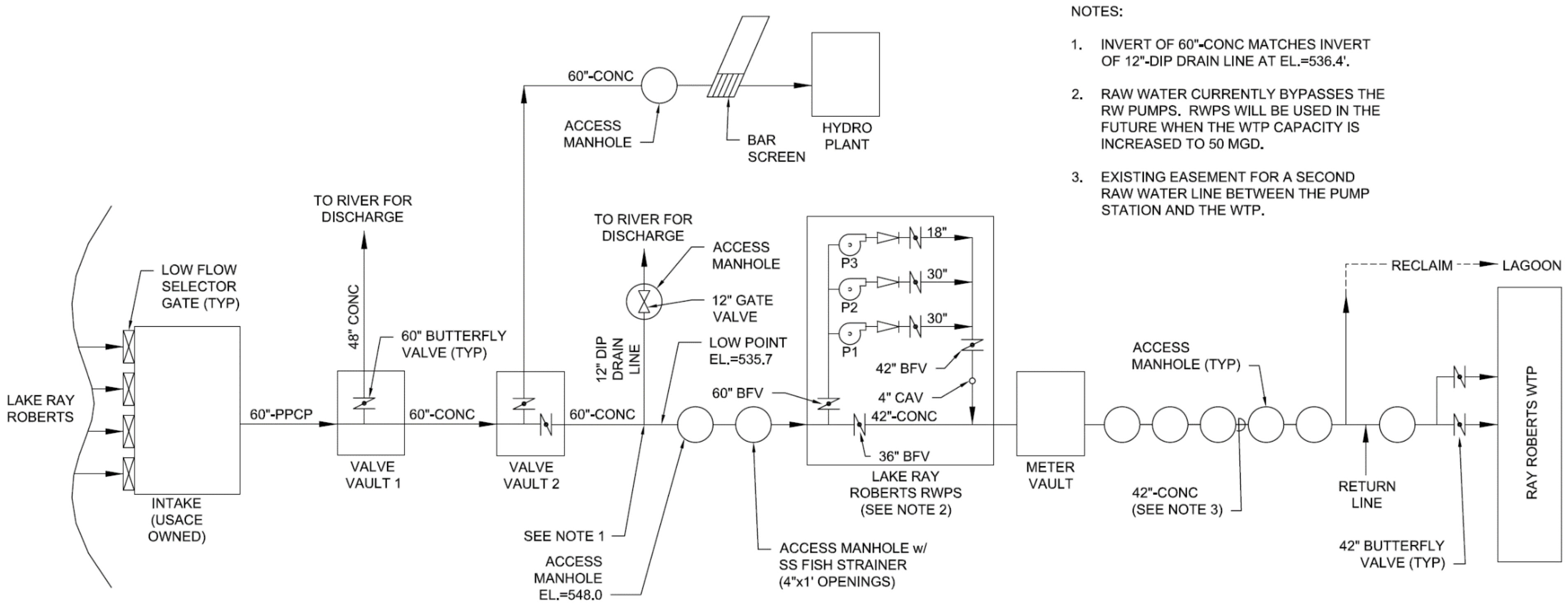


Figure 5-2: Lake Ray Roberts WTP Overall Flow Schematic

Figure 5-3: RRWTP Raw Water Valve Vault 1

Figure 5-4: Zebra Mussels in the USACE Trinity River Stilling Basin

COD facilities, which are the focus of the raw water system improvements for zebra mussel control, begin with the 60-inch pipeline immediately downstream of valve vault 1. There is a second valve vault (i.e., valve vault 2) downstream of valve vault 1 containing another wye which routes the water to the hydroelectric power plant or alternatively to the RWPS. A photo of valve vault 2 taken during site visits is shown in Figure 5-5. The 60-inch pipeline connection to the hydroelectric power plant can be accessed via a manhole and contains a fish strainer (i.e., bar screen). The hydroelectric power plant is no longer in use, but may be repurposed in the future to house a new pump station. The 60-inch pipeline connection to the RWPS is marked by a critical low point, which will be a problem area for zebra mussel shell accumulation. Just upstream of the RWPS is another access manhole and fish strainer. The pipeline distance from valve vault 1 to the RWPS is approximately 265 ft.

Figure 5-5: RRWTP Raw Water Valve Vault 2

The RWPS, illustrated in Figure 5-6, is equipped with three pumps inside the main pump building, and an adjacent electrical building. The RWPS was designed for use at low lake levels, and in the future, when the RRWTP is upgraded to 100 MGD. During site visits, it was noted that USACE road improvements may be required for any future tote/bulk chemical delivery to the site. As the USACE owns the road to the RWPS, roadway improvements would require coordination with the USACE, and could potentially be partially funded by them. Water currently bypasses the pumps through the 42-inch line connected to the remaining single 42-inch raw water line to the RRWTP. The lagoon recycle line connects to the raw water line ahead of the plant. There is an existing easement for a second pipeline between the RWPS and the RRWTP. The distance from the RWPS to the RRWTP is approximately 0.6 miles. Typically, the 42-inch raw water line enters the RRWTP at the pre-ozone contactors, however, the pre-ozone contactors can be bypassed. Zebra mussel shells have been found as far downstream as inside the pre-ozone contactors (see Section 2.4 for additional information on the zebra mussel infestation in the RRWTP raw water system).

Figure 5-6: Lake Ray Roberts Electrical Building (Left) and RWPS (Right)

5.1.2. Risk Assessment

A risk assessment was conducted to rank the overall relative risk to the RRWTP raw water system and to provide information/notification of potential impacts. In addition to the operational and physical characteristics of the site (Section 5.1.1), the risk assessment considered zebra mussel biology and ecology, local zebra mussel occurrences and local water quality as summarized in Section 2 The assessment considered the likelihood of infestation and potential impact to the COD as summarized below.

- **High Likelihood of Infestation** – The RRWTP raw water system was classified as high likelihood of infestation as they have previously been infested with zebra mussels.

- **High Potential Impact to the COD** – The RRWTP raw water system was classified as high potential impact, meaning that it is susceptible to fouling due to the presence of many hard surfaces with small openings (i.e., bar screens, pipelines) and would pose a significant risk to COD operations if flow was constricted. Hydraulic capacity reductions were observed during the prior infestation of the RRWTP raw water system. Additionally, due to the USACE outlet structure upstream, the RRWTP raw water system will continue to receive volumes of dead mussel shells following die-off events as chemical cannot be fed at the USACE outlet.

- **Extremely High Overall Risk** – Due to the high likelihood of an infestation and the high potential impact, the RRWTP raw water system was classified as extremely high overall risk.

During site surveys, key components of the raw water system were identified, key considerations were recorded and the potential impacts of fouling to each component were evaluated (Table 5-1). The immediate potential impact to all components includes hydraulic capacity reductions due to fouling (Section 2). The low point on the 60-inch raw water line downstream of valve vault 2 is at greatest risk for fouling due to the volume of mussel shells that will accumulate at this point following die-off events in the lake and in the USACE outlet structure. The small diameter lagoon recycle line is also very susceptible at the connection point with the raw water line ahead of the RRWTP. The valves and the fish strainers are also particularly susceptible to zebra mussel fouling and accumulated zebra mussel shells in the pipelines could clog the pumps if operated in the future. In addition, mussels could lead to degradation of pipelines due to corrosion and pitting following physical removal. Shells within the raw water pipelines could be carried all the way to the ozone contactors at the plant. Additionally, mussels may result in an increase in taste and odor compounds in the water entering the treatment plant.

Table 5-1: RRWTP Raw Water System Evaluation of Major Components

Component	Considerations	Impacts
USACE Intake Structure & Intake Pipelines	▪ Owned and operated by the USACE ▪ 4 Low flow gate selectors ▪ Wet well ▪ 5' Dia. Conduit ▪ 60" Dia. Penstock ▪ Valve Vault 1 with butterfly valve	Although USACE has recently coated the gates and may also coat the wet wells, live and dead mussels will continue to flow through the USACE structure into the COD raw water lines. Physical removal of mussel shells, from downstream infrastructure, especially at low points, will be required long-term.
60" Raw Water Pipeline	▪ Single 60" Dia. CCP ▪ Valve Vault 2 ▪ New manhole for access	Mussels may foul the pipelines and constrict flow to the plant; long-term impacts may include accelerated degradation of pipelines due to corrosion and pitting from mussel attachment and removal. Mussel shells will continue to collect in the low point on this line.
Fish Strainer	▪ Stainless Steel with 4" x 1' Openings ▪ Existing manhole for access ▪ Existing tap on both sides for headloss measurement	Zebra mussels may build up on the strainer and constrict flow. Manhole access will ease physical removal of mussel shells that accumulate at this point.
Raw Water Pump Station	▪ Currently bypassed, but will be used in the future ▪ 3 Pumps with check, air release and butterfly valves	Zebra mussels may foul the pumps and support infrastructure in the future. Valves are particularly susceptible to mussel fouling.
42" Raw Water Pipeline	▪ Single 42" Dia. CCP ▪ Easement for a second pipeline ▪ New manholes for access ▪ Lagoon recycle line connection	Mussels may foul the pipelines and constrict flow to the plant; long-term impacts may include accelerated degradation of pipelines due to corrosion and pitting from mussel attachment and removal. The connection with the lagoon recycle line may be extremely susceptible to fouling due to the small diameter of the pipeline.
Hydroelectric power plant	▪ No longer in use; will be decommissioned ▪ Manhole and fish strainer (bar screen) ▪ Butterfly Valve ▪ May be repurposed as a future pump station	While not in use, there are no impacts. However, if the plant was converted to a pump station in the future, zebra mussels may foul the piping and infrastructure. Valves are particularly susceptible to fouling.

5.1.3. Implications of Future Improvements

Future improvements to the RRWTP raw water system could potentially both positively and negatively impact management of zebra mussels. Table 5-2 summarizes the planned improvements to RRWTP raw water system and their potential implications. The table was developed during site visits and the Alternatives Analysis Workshop.

Table 5-2: Implications of Future Improvements to the RRWTP Raw Water System

Planned Improvements	Benefits to Zebra Mussel Control	Risks to Zebra Mussel Control
100 MGD WTP plant upgrades: 100 MGD flow rates will require the use of the RWPS, which is currently bypassed and would only be used under low lake level conditions.	▪ Zebra mussel management improvements (including duplicate raw water lines) could be incorporated into future projects.	▪ If demand for water increases and the existing raw water system remains as-is (no redundancy), the risk for COD will be considerably higher in the case of ZM fouling. ▪ If RWPS is used it can pose a greater risk to COD's assets (pumps, valves, etc.) in case of ZM fouling.
RW Easement: There is an existing easement for a second RW pipeline from the RWPS to WTP for the expansion to 100 MGD.	▪ If constructed, would allow alternating the use of raw water pipelines and reduce the risk due to fouling. Pipeline cleaning would be facilitated if there is redundancy in the RW pipelines. ▪ If allowed, could route chemical or potable water from the plant through the easement.	▪ If unprotected, the additional pipeline may be fouled with zebra mussels as well.
Hydroelectric Power Plant: The hydropower plant is to be decommissioned; it could be repurposed as a future PS.	▪ Pipeline leading to the hydroelectric power plant could be repurposed to provide a bypass during cleaning of the 60" raw water line at the low point. ▪ Could evaluate repurposing the plant as a chemical storage and feed facility.	▪ If repurposed in the future, pumps, pipes and appurtenances may become fouled with mussels.
USACE Plan of Coating Intake Gates: USACE has applied an anti-fouling (silicon based) coating to intake racks and may apply the coating to the inside of the wet well also.	▪ Reduction in the amount of time the USACE intake (and thus RRWTP) must be offline for zebra mussel cleaning events.	▪ Silicon coatings will not prevent infestations. COD facilities will continue to be at risk of clogging due to dead mussel shells. ▪ Flakes / sheets of coatings may be released into the COD raw water system.

5.2. MANAGEMENT APPROACH ALTERNATIVES

Considering the preventative, control, and reactive strategies for zebra mussel management identified and evaluated in Section 1.2.3, one reactive strategy and two preventative strategy alternatives were selected to be evaluated in detail including development of descriptions and conceptual layouts (Section 5.2.1) and both quantitative (Section 5.2.2) and qualitative evaluation criteria established with the COD (Section 5.2.3). O&M enhancements that require capital improvements are included within each of the management approaches. Management approach recommendations and all other O&M recommendations not requiring capital improvements are summarized in Section 5.3.

5.2.1. Description of Management Approach Alternatives

Zebra mussel management approaches focus on only the raw water system components owned and operated by the COD (i.e., the outlet through valve vault 1 were not considered, as management approaches will be determined and implemented by the USACE). Consideration was given to the impacts of USACE management approaches upstream (i.e., molluscicides cannot be applied upstream of valve vault 1 as they would pose a threat to aquatic wildlife downstream through the environmental release in valve vault 1). Three alternatives were selected to be further evaluated. These alternatives assume that basic maintenance improvements to the raw water lines will be implemented regardless of the primary alternative selected to address the continued volume of shells anticipated to enter the COD raw water lines through the USACE structures. An optional addition to these base alternatives is the construction of a bypass line or duplicate raw water line as described in Section 5.2.1.4. A site plan showing the proposed improvements is displayed with an aerial view in Figure 5-7 and schematically in Figure 5-8. Proposed modifications to the valve vaults are shown schematically in Figure 5-9 and Figure 5-10. Alternatives A1 and A2 are shown schematically and in cost estimates as Alternative A as the same chemical feed system would be used for either alternative. Should only one of the two chemicals be selected, then the chemical building size could be reduced and would only include the respective chemical storage or skid system.

5.2.1.1. Alternative A1 – Sodium Permanganate System

A preventative strategy to zebra mussel management would include capital improvements that prevent or minimize zebra mussel fouling to infrastructure. One preventative strategy would include raw water pipeline improvements and the addition of sodium permanganate in valve vault 1 to protect the pump station and raw water lines. This alternative would include:

- **Raw Water Pipeline Improvements** – Several manholes would be added to improve ease of access near the low points in the raw water pipeline: one 60-inch manway is to be added inside valve vault 1, one 60-inch manway in valve vault 2 and one 42-inch manhole downstream of the raw water pump station. In order to be able to isolate the pipeline section of concern for cleaning, a 60-inch butterfly valve needs to be installed in valve vault 1. An extension stem at the 12-inch drain line would optimize manual operation of the valve. Additionally, because of the addition of chemicals, a new raw water sampling point needs to be provided in valve vault 1, upstream of the proposed chemical feed point. The raw water sampling line would extend to the RWPS or new chemical building for ease of access. The sample line pump should maintain a high velocity to prevent settlement of veligers or mussels within the unprotected line.

- **Addition of a new sodium permanganate chemical system and feed points –** A new chemical building would be constructed to the north-west of the RWPS to house the new chemical storage and feed system. Sodium permanganate would be delivered in a 40% aqueous solution in 4-foot by 4-foot totes. A truck lift would be required to replace the totes. The system would also include two peristaltic metering pumps, and instrumentation and controls to operate the chemical feed system. The totes would be installed in a chemical containment area, surrounded by a concrete barrier. Stainless steel 3/4-inch diameter chemical pipes (double-walled in PVC pipe) would feed permanganate from the chemical building to primary and backup chemical feed points in the raw water line valve vaults. The new double wall chemical feed line would be buried along with the sample line. Chemical injection quills would be attached to the downstream side of the valves. The chemical feed pumps will be interlocked with the raw water pumps to prevent chemical from spilling into the lake or into the river through the environmental release. This alternative assumes an annual average sodium permanganate dose of 1.5 mg/L pulse-fed (i.e., 30 minutes on and 30 minutes off). Costs for both 8 months of chemical feed (i.e., based upon favorable temperatures for settlement) and five months of chemical feed only during settlement season (i.e., an annual monitoring cost is included) were calculated to understand the potential savings from monitoring for settlement (see Section 3.2.2).

- **Potable Water** – A potable water line that extends from the RRWTP to the RWPS along with connections (hose bibs, fire hydrant, etc.) would be installed to provide connections for emergency showers and future zebra mussel cleaning events. This would reduce the cost of the future contract for cleaning. If desired, this line could also be extended to provide solution/chase water for the chemical system, as well. However, use of potable water would add to annual operating costs.

- **Light physical removal and disposal –** This alternative also accounts for some degree of physical removal and disposal which will likely be required due to shells accumulating through the USACE outlet following die-off events. Closed-circuit television (CCTV) inspections should be conducted at least every two years to determine if cleaning is required.

5.2.1.2. Alternative A2 – Copper Ion Generation System

A second preventative strategy would include the addition of a copper and aluminum ion solution at the end of valve vault 1 to protect the downstream COD facilities. Although some degree of physical removal and disposal may be required, the level of effort and time offline would be minimal. This alternative would include:

- **Raw Water Pipeline Improvements** – The raw water pipeline would be improved as described in Section 5.2.1.1.

- **Addition of a new copper ion generation system and feed points –** A new chemical building would be constructed to the north-west of the RWPS to house the new chemical storage and feed system. During detailed design, the option of locating the copper ion system within the RRWTP pump station could be evaluated to reduce construction costs. The generation system would consist primarily of three to four cells containing copper and aluminum anodes, piping and a PLC unit. These components could either be fastened to the RWPS wall or provided on a skid (or the PLC could be fastened to the wall while the remaining components are provided on a skid). Plan and section views of the skid in these different configurations are provided in Appendix F. The cells have a one-year warranty, and are expected to be replaced annually. A spare cell is recommended to minimize any downtime when replacement is required. Chemical containment is not required. Pressurized raw water would be provided to the system by tapping the 42-inch pump discharge header and installing a transfer pump (as the pumps are currently not operated). A backwashable strainer should be installed on the raw water feed line to minimize settlement and fouling of the cells. Potable water could also be used in lieu of raw water, if desired. The system would also include ancillary piping and valving, water quality monitors and instrumentation and controls to operate the system. PVC or cross-linked polyethylene (PEX) 2-inch diameter chemical pipes would feed the copper and aluminum ion solution from the chemical building to primary and backup chemical feed points in the valve vaults. The new double wall chemical feed line would be routed through a chemical trench. Chemical injection quills would be attached to the downstream side of the valves. The chemical feed pumps will be interlocked with the raw water pumps to prevent chemical from spilling into the lake or into the river through the environmental release. This alternative assumes the copper and aluminum ion solution will be fed continuously throughout the year (although at a lower dose during non-settlement seasons) based upon manufacturer recommendations. Since the dose is based upon the amount of current directed at the anodes, only minor savings in power costs would be observed by monitoring for settlement, and thus the higher power cost was assumed.

- **Potable Water** – A potable water line would be installed as described in Section 5.2.1.1.

- **Light physical removal and disposal –** This alternative also accounts for some small degree of physical removal and disposal which may be required as described in Section 5.2.1.1.

5.2.1.3. Alternative B – Physical Removal and Maintenance Improvements

A reactive strategy to zebra mussel management would include minimal capital improvements to ease future physical removal and disposal efforts. This alternative would include:

- **Raw Water Pipeline Improvements** – The raw water pipeline would be improved as described in Section 5.2.1.1 except that the new raw water sample line would not be required.

- **Physical Removal and Disposal** – As this reactive strategy would allow for a significant infestation of the intake, pump station and raw water lines, physical removal and disposal would be required at least every two years (depending on the allowable reduction in hydraulic capacity). Since the COD recently completed a project to install manways for cleaning access, no additional manways would be required except those noted with the raw water pipeline improvements. It is assumed mussels would be transported to the RRWTP lagoons, as they were during the previous cleaning project, for storage, and periodically transported to the COD landfill for disposal. An on-call contract for cleaning would accelerate the physical removal process to allow for removal before a severe infestation occurs. There are no anticipated variable costs (e.g. maintenance access to manways) as the COD recently accessed all the manways installed along this line.

- **Potable Water** – A potable water line would be installed as described in Section 5.2.1.1.

5.2.1.4. Optional Additions

There are several variations to the alternatives listed in the previous sections. The list below consists of alternative additional selections or substitutions to any of the proposed alternatives represented above.

- **Addition 1: Bypass Line** – One additional item that could to be added to the alternatives involves constructing a bypass line that connects the 60-inch raw water pipeline that extends from valve vault 1 to the hydroelectric power plant, to the 60-inch raw water pipeline that extends from valve vault 1 to the raw water pump station. This option would involve the reversal of the existing butterfly valve and the proposed manhole inside valve vault 2. By constructing the bypass line, the plant could remain online during cleaning of the low point in the 60-inch raw water line. However, as there would only be one point of isolation to the confined space requiring cleaning, there are safety risks that must be considered. This additional item is represented in the capital cost estimate as a line item in addition to the base cost.

- **Addition 2: Duplicate Raw Water Line** – There is an existing easement for a second raw water line between the RWPS and WTP which was planned for the future plant expansions. A second raw water line would allow for alternating pipeline use as an O&M strategy for zebra mussel management and would also minimize plant shutdown time during cleaning events. A second 42” line was assumed for cost estimating purposes including the installation of manways and valves.

- **Potable Water Line –** The alternatives described all include installation of a potable water line to the intake site for use during future zebra mussel cleaning events of the raw water line. This line could also be connected to the chemical feed system to use potable water instead of raw water for chemical carrier water. Although potable water would have a lower background demand and potentially result in a slightly lower required chemical cost, the additional water usage cost would add to the annual operating cost.

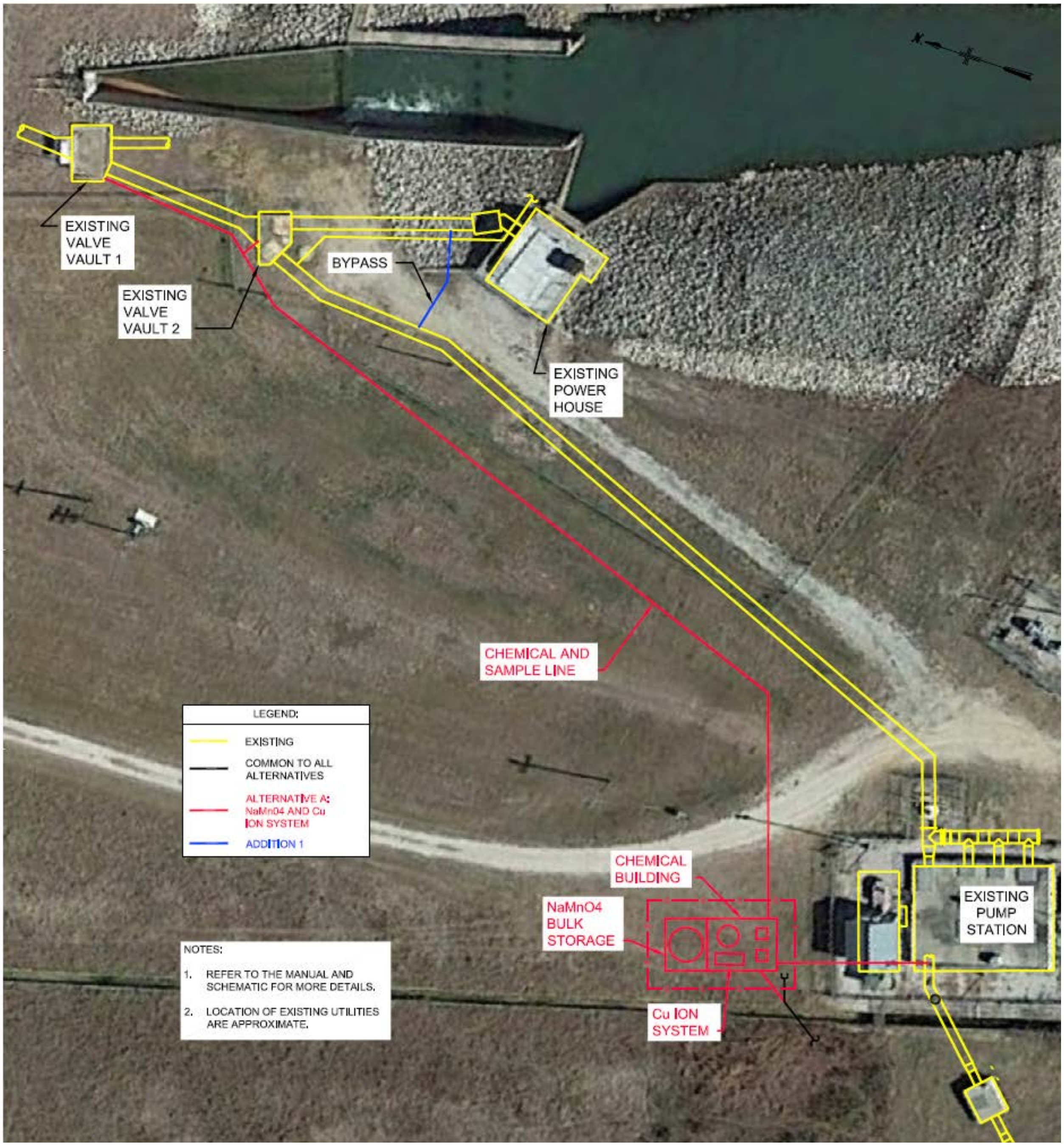


Figure 5-7: RRWTP Raw Water System Aerial of Proposed Improvements

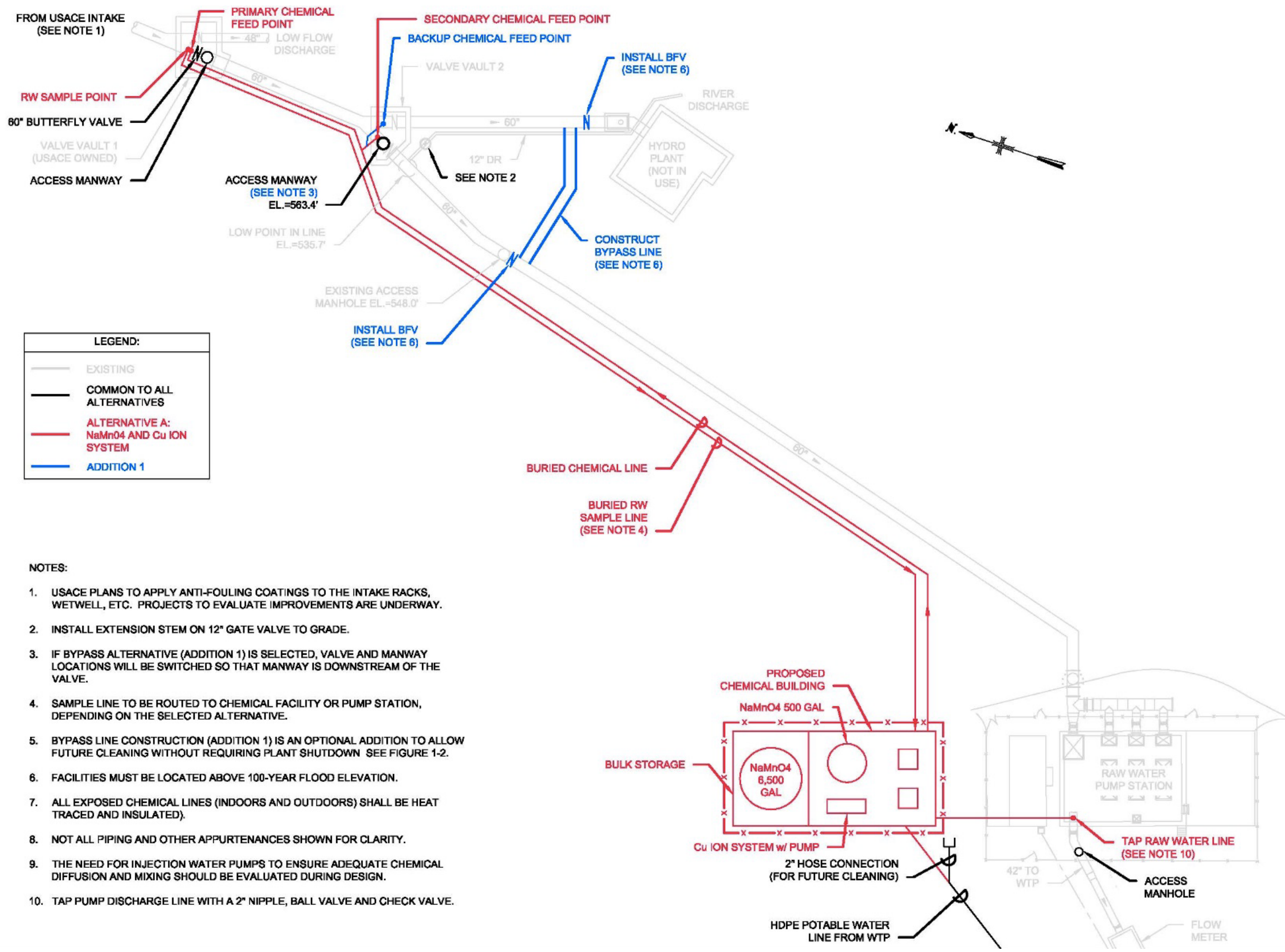


Figure 5-8: RRWTP Raw Water System Schematic of Proposed Improvements

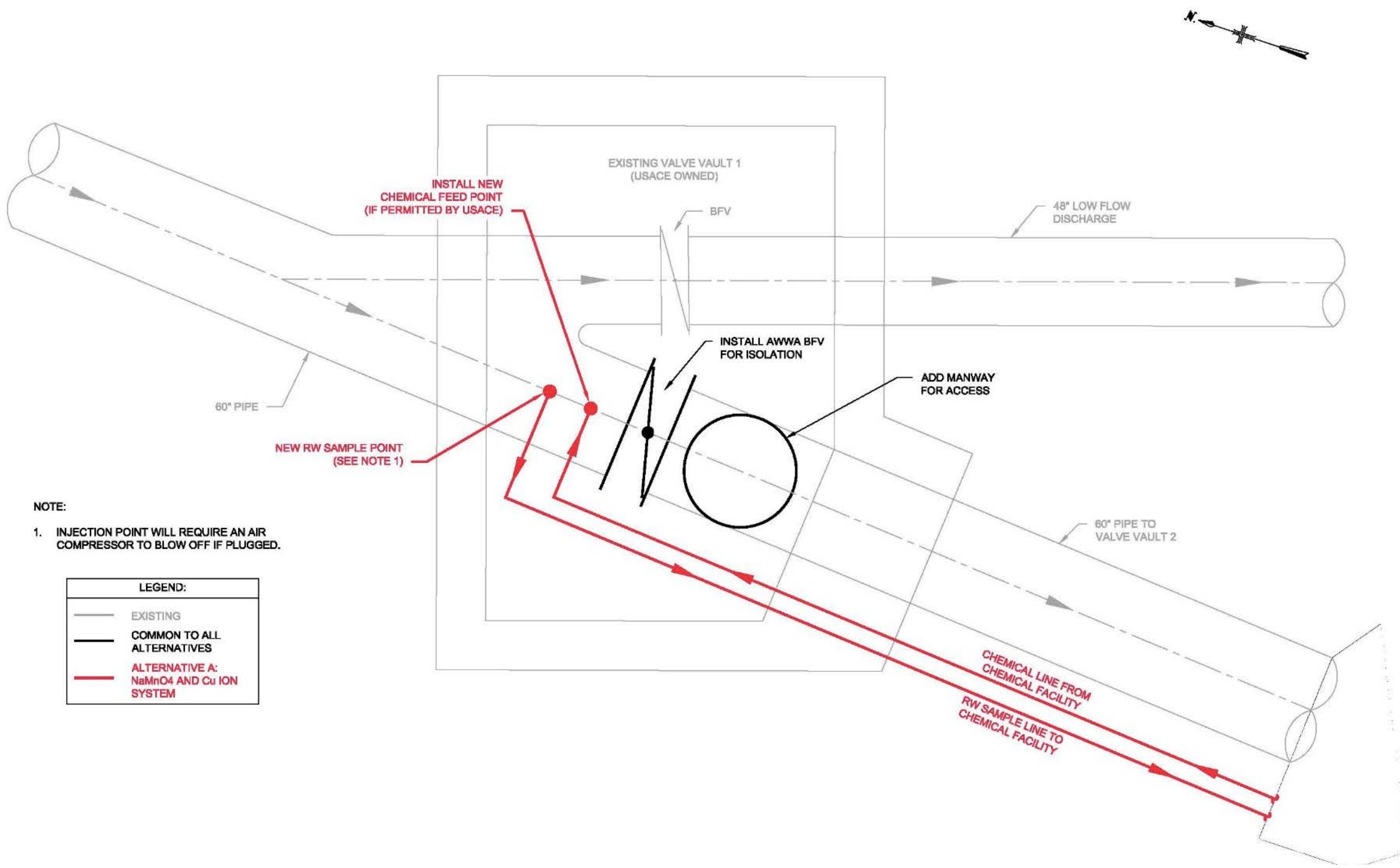


Figure 5-9: RRWTP Modifications at Valve Vault 1

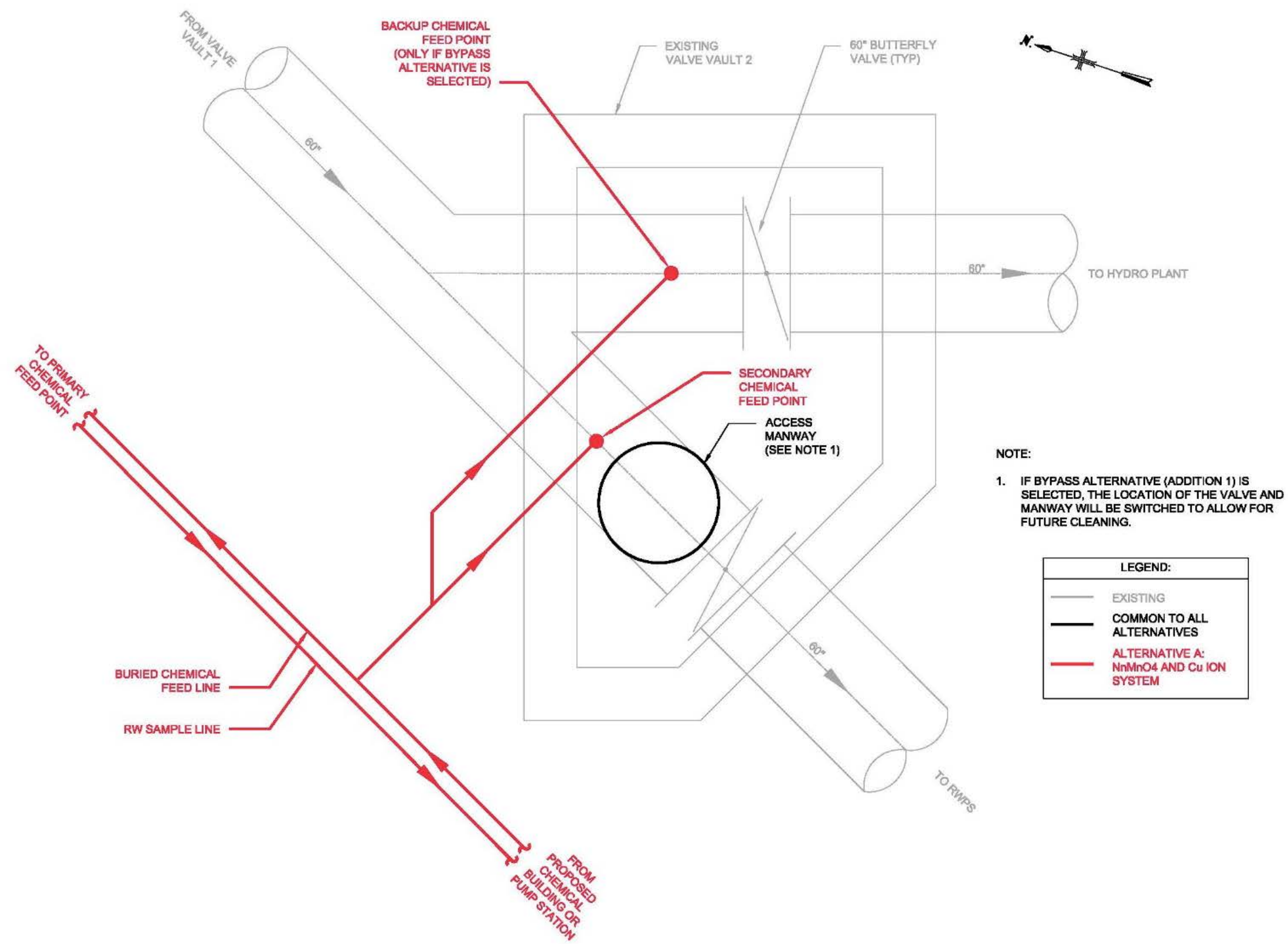


Figure 5-10: RRWTP Modifications at Valve Vault 2

5.2.2. Cost Estimates

Design criteria for the chemical feed layouts and costs based upon expert knowledge and literature are summarized in Table 5-3. Table 5-4 summarizes the approximate capital costs, yearly operation and maintenance costs, and 20-year lifecycle costs for the zebra mussel management alternatives described in 5.2. These costs were based on manufacturer proposals and quotes, TxDOT low bid tabs, as well as construction costs from previous projects. Detailed probable cost estimates can be found in Appendix E.

Table 5-3: RRWTP Intake Design Criteria and Assumptions

Category	Unit Cost or Assumption			Basis
FLOW	Minimum Flow	5	MGD	Plant RW Flow Data from 2012-2015
	Average Flow	9.9	MGD	
	Maximum Flow	20	MGD	
CHEMICAL DOSE	Sodium Permanganate Design Dose	2.5	ppm	Chemical Demand Testing Summarized in Appendix C
	Sodium Permanganate Annual Average Dose	1.5	ppm	
	Copper Dose (During Settlement)	5.0	ppb	Mfr Recommendations
	Copper Dose (No Settlement)	2	ppb	
	Aluminum Dose (During Settlement)	0.5	ppb	
	Aluminum Dose (No Settlement)	0.2	ppb	
CHEMICAL COST	Cost of Cu/Al Anode Cell	5,500	$/year	Mfr Cost Estimate
	Cost of Sodium Permanganate	1.65	$/lb	Costs Provided by COD
	Delivery Cost	500	$/delivery	Estimate
CHEMICAL PROPERTIES	Sodium Permanganate %	40%		Mfr Specifications
CHEMICAL DOSING FREQUENCY	Sodium Permanganate Dosing Frequency	12	hours/day	Estimate from Previous Project Experience
	Copper Ion Dosing Frequency	24	hours/day	Mfr Recommendations
	Months of Chemical Feed	8	months/year	Estimate from Previous Project Experience
	Months of Chemical Feed (Monitoring)	5	months/year	
ZM CLEANING	Mussel Coverage Without Management	50%		Estimate from Previous Project Experience
	Mussel Coverage With Management	10%		
	Average Thickness of Mussel Coverage Without Management across Pipeline	1	inch	
	Average Thickness of Mussel Coverage With Management across Pipeline	0.5	inch	
	Mussel Density	76	lb/cy	
	Linear feet of pipe cleaned	200	lf/day	
	Frequency of cleaning	2	every ...years	
	Cost of Physical Cleaning	10000	$/day	
	Dumpster fee	150	EA (30 CY)	
	Minimum Cost for Short Distance Hauling	350	$	
	Mussel Transport to landfill	9	$/mile	
	Mussel Disposal Fee	26	$/ton	
LIFECYCLE COST	Escalation Factor	3.50%		Estimate
	Interest Rate	3%		
	Lifecycle	20	years	
O&M COST	Energy Cost	0.09	$/kWh	Current Industry Rates
	Water Cost	0.0027	$/day	

Category	Unit Cost or Assumption			Basis
	Ion Generator Power (Maximum)	0.64	kW	
	Ion Generator Power (Minimum)	0.08	kW	
	Operator Chemical Rate	50	$/hr	
	Instrument Technician Rate	60	$/hr	
	Mechanical Technician Rate	55	$/hr	
CAPITAL COST	Mobilization and Demobilization	3%		Estimate
	General Requirements	5%		
	Bonds and Insurance	2%		
	Contractor's Profit	15%		
	Contingency	30%		
	Labor and Installation	30%		
ENGINEERING & CONSTRUCTION ADMINISTRATION	Fee Percentage of Capital Cost	20%		Estimate

Table 5-4: RRWTP Intake Proposed Improvements Cost Estimate

	Alternative	Capital Cost[1]	Annual O&M Cost[1]	Annual Cleaning and Removal Cost[2]	20-Year Lifecycle Cost	Engineering and Construction Administration
A	Sodium Permanganate and Copper Ion Systems[4]	$2,180,000				$440,000
A1	Sodium Permanganate 8 Month Chemical Feed		$61,000	$58,000	$4,707,000	
	Sodium Permanganate 5 Month Chemical Feed (with Monitoring)		$56,000	$58,000	$4,597,000	
	Sodium Permanganate Potential Savings from Monitoring		$5,000	-	$110,000	
A2	Copper Ion Generation System		$40,000	$58,000	$4,594,000	
B	Physical Removal and Maintenance Improvements	$930,000	$26,000	$121,000	$4,032,000	$190,000
Optional Additions and Substitutions:						
Addition 1: Bypass Line		$109,000	$12,000	$12,000	$1,219,000	$70,000
Addition 2: Duplicate Raw Water Line		$3,053,000	$25,000	$90,000	$3,456,000	$300,000
Addition 3: Potable Water for Chemical Feed		$0	$24,000	$0	$847,000	$0

[1] Probable costs are based upon the recommended line items shown and rounded up to two significant figures as cost estimates are Class 4 Association for the Advancement of Cost Engineering International (AACE). Annual O&M costs assume settlement monitoring will be conducted to reduce chemical feed to 5 months of the year. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.

[2] Physical Cleaning and Removal not included.

[3] Physical Cleaning and Removal Cost is represented on annual basis for budgetary purposes, although in reality would occur every 2 years.

[4] The capital cost provided for Alternative A assumes both the copper ion and sodium permanganate systems are constructed to provide a redundant approach to zebra mussel management. If only one of the two chemical systems was implemented, the capital cost would likely be reduced by approximately $300,000-$350,000.

5.2.3. Comparison of Alternatives

An alternative comparison matrix was developed to compare each of the alternatives based upon the evaluation criteria summarized in Section 3.1.1. Each of the three alternatives described previously is listed in a matrix column in Table 5-6. Each row in the matrices compares alternatives relative to each criterion. Following the alternative comparison matrix is a one-page summary matrix (Table 5-7) that highlights each matrix cell (each criterion per alternative) in one of the following four categories as summarized in Table 5-5. Lastly, Table 4-8 ranks the alternatives based upon the evaluation criteria weighting factors established during the Alternatives Analysis Workshop and summarized in Section 3.1.1. **Based upon the results of the ranking, sodium permanganate and copper ion systems were ranked the highest.**

Table 5-5: Ranking Categories

Description of Category	Highlight Color	Score
Not Favorable	Red	1
Many Limitations	Orange	2
Some Limitations	Yellow	3
Favorable	Green	4

Table 5-6: RRWTP Intake Alternative Comparison Matrix

Approaches	Prevention Approach: Chemical Alternatives		Reaction Approach
Improvement	Alternative A1: Sodium permanganate[3]	Alternative A2: Copper ion generation	Alternative B: Physical removal and maintenance improvements[4]
Life Cycle Cost[1] **[Capital Costs]**	**$4,707,000 - $4,597,000** [$2,180,000]	**$4,594,000** [$2,180,000]	**$4,032,000** [$930,000]
Effectiveness for Prevention of Zebra Mussel Fouling	• Effectively prevents settlement with a 0.25 mg/L residual • Based on oxidant demand, may be effective at an average dose of 1.5 mg/L. Based on water quality the required dose may range between 0.5 – 2.5 mg/L	• Limited lab studies suggest a 0.01 – 5 ppm copper dose may be effective at preventing settlement • Manufacturers recommend a dose 0.005 ppm copper above background concentrations • Effectiveness is also due to formation of aluminum hydroxide flocs • Water quality (e.g. total suspended solids, DOC, temperature) impacts toxicity of the copper ion	• Will not prevent fouling but addition of new valves and manways will ease future cleaning efforts
Ease of O&M and Operational Flexibility	• Simple application equipment (chemical feed system and storage for one liquid chemical) • Available in concentrations up to 40% • Will require maintenance	• Impending lawsuit of Fortress MC system by MacroTech • Alum flocs may settle in raw water pipelines • Requires pressurized raw water • Anode cells require annual replacement • Generation equipment, cells and PLC come on a skid or can be wall mounted. No bulk chemicals required • Electrodes will degrade and may foul over time requiring greater power to generate the same copper concentrations and resulting in varied copper concentrations	• Physical removal is labor intensive • May require extended shutdowns • Damage to pipelines (i.e., pitting) may occur with repeated removal activities
Impact to Downstream Water Quality and Water Treatment Plant	• Oxidizes iron/manganese • May improve aesthetic quality of water • No regulated DBP formation • May result in increased manganese concentrations, color tinting or turbidity if not properly managed • Manganese SMCL of 0.05 mg/L must be considered	• Addition of copper must consider the copper SMCL of 1.0 ppm and Lead and Copper Rule Action Level of 1.3 ppm • Addition of aluminum ions must consider the SMCL of 0.2 ppm • No known DBP formation	• Taste and odor compounds may be generated by decaying mussels • Headloss across fish strainers may result as mussels build up

Approaches	Prevention Approach: Chemical Alternatives		Reaction Approach
Improvement	Alternative A1: Sodium permanganate[3]	Alternative A2: Copper ion generation	Alternative B: Physical removal and maintenance improvements[4]
Impact to Environment / Ecology	• Nonselective and highly toxic to non-target organisms • Requires application point that would prevent flow into source water • Would require construction of new tanks/pumps above the 100-yr flood elevation	• Nonselective and highly toxic to non-target organisms • Requires application point that would prevent flow into source water	• None if mussels are removed and disposed of in a landfill
Implementability	• Minimal equipment (bulk and day tanks and feed pumps/piping) required • Chemicals should be stored in a cool, dry area in closed containers. May require a new chemical building • Requires regulatory coordination	• Impending lawsuit of Fortress MC system by MacroTech • Requires on-site generation • Minimal equipment fits on a small skid • Requires tapping of pump discharge lines • Requires regulatory coordination	• Requires construction of manways along the pipeline for access • Requires extended plant shutdowns • Regulatory coordination was completed for prior cleaning event • Requires potable water
Health & Safety	• NFPA 430 Class II oxidizer • NFPA Ratings: Health = 2, Flammability = 0, Reactivity = 1, Special = OX • Strong (20-40%) concentration	• Copper NFPA Ratings: Health = 2, Flammability = 1, Reactivity = 0 • Al NFPA Ratings: Health =1, Flammability = 0, Reactivity = 0	• Safety concerns with entry into confined spaces (i.e., pipelines) • Safety concerns due to sharp shells

Status in the Industry / Record of Performance	• Potassium permanganate has been used extensively for zebra mussel control by municipalities.
	• Sodium permanganate has been used less frequently but is gaining popularity. For example:
	  ◦ City of Findlay, OH (including pilot study that proved effectiveness)
	  ◦ Neenah Water Utility Water Treatment Plant, WU
	  ◦ Keokik Municipal Waterworks, IA
		• Proprietary system and programming.
		• Limited research studies or municipal installations for zebra mussel control.
		• Complete list for the MacroTech system includes:
		  ◦ City of Wichita (80 MGD)
		  ◦ City of Emporia (15 MGD)
		  ◦ RWD#3 – Kansas (5 MGD)
		  ◦ Milford Utilities (5 MGD)
		• Fortress MC system Commissioned by City of Wahpeton, IA (0.4 MGD) in May 2015.
			• Widely-used for trash racks and small diameter pipelines
			• Supplemental maintenance to most zebra mussel management approaches
			• Less commonly used as a primary management approach due to labor intensiveness and long shutdowns

Approaches	Prevention Approach: Chemical Alternatives		Reaction Approach
Improvement	Alternative A1: Sodium permanganate[3]	Alternative A2: Copper ion generation	Alternative B: Physical removal and maintenance improvements[4]
Public Acceptability	• Widely used in water treatment for pre-oxidation • Familiar technology	• Potential for unknown consequences due to limited information and installations available • Proprietary technology • Potential for increased copper or aluminum concentrations in the distribution system	• Potential for reduced consumer confidence if reduced hydraulic capacity cannot meet water demands

1 – Probable costs are based on the Class 4 Association for the Advancement of Cost Engineering International (AACE).
2 – Chemical alternative costs include the cost for raw water pipeline improvements and light physical removal and disposal.
3 – Lifecycle costs for sodium permanganate is presented as a range based on chemical feed of 8 – 5 months per year. Based upon favorable water temperatures for zebra mussel settlement, 8 months of chemical feed per year is required. However, incorporation of settlement monitoring may reduce chemical feed to less than 5 months of the year. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.
4 – Physical removal and maintenance improvements costs include raw water pipeline improvements.

Table 5-7: RRWTP Intake Summary of Alternatives

Approaches	Prevention Approach		Reaction Approach
Improvement	**Alternative A1: Sodium permanganate[3]**	**Alternative A2: Copper ion generation**	**Alternative B: Physical removal and maintenance improvements[4]**
Life Cycle Cost **[Capital Costs]**	**$4,707,000 - $4,597,000** [$2,180,000]	**$4,594,000** [$2,180,000]	**$4,032,000** [$930,000]
Effectiveness for Prevention of Zebra Mussel Fouling	• Effective	• Effective, but dose required varies across studies	• Will not prevent fouling
Ease of O&M and Operational Flexibility	• Simple application equipment	• Impending lawsuit of Fortress MC system • Electrodes may degrade and foul over time • Settlement of alum flocs	• Labor intensive • May require extended shutdowns • Damage to pipelines
Impact to Downstream Water Quality and Water Treatment Plant	• May result in increased manganese, turbidity or color tinting of the water	• Addition of copper and aluminum ions may result in Lead and Copper Rule or SMCL violations	• Potential for increased taste and odor • May result in increased manganese, turbidity or color tinting of the water
Impact to Environment / Ecology	• Toxic to non-target organisms	• Toxic to non-target organisms	• Minimal
Implementability	• Minimal equipment	• Impending lawsuit of Fortress MC system • Minimal equipment fits on a small ski	• Requires extended plant shutdowns
Health & Safety	• Strong oxidizer	• Copper and aluminum ions	• Confined spaces
Status in the Industry / Record of Performance	• Proven technology but limited installations	• Proprietary • Few municipal installations for zebra mussel control	• Proven technology
Public Acceptability	• Widely-used in water treatment	• Proprietary technology • Increased copper and aluminum ions	• Potential to not meet water demands

Key:

Not Favorable	Many Limitations	Some Limitations	Favorable

Table 5-8: RRWTP Intake Ranking of Alternatives

Criteria	Criteria Weighting Factor	Alternative A1: Sodium permanganate		Alternative A2: Copper ion generation		Alternative B: Physical removal and maintenance improvements	
		Raw Score	Weighted Score[1]	Raw Score	Weighted Score	Raw Score	Weighted Score
Capital and Lifecycle Costs	14.1%	3	0.42	3	0.42	3	0.42
Effectiveness for Prevention of Zebra Mussel Fouling	21.6%	4	0.86	3	0.65	1	0.22
Ease of O&M and Operational Flexibility	16.4%	3	0.49	2	0.33	1	0.16
Impact to Downstream Water Quality and Water Treatment Plant	10.6%	1	0.11	3	0.32	3	0.32
Impact to Environment / Ecology	3.7%	1	0.04	1	0.04	3	0.11
Implementability	7.9%	3	0.24	3	0.24	2	0.16
Health & Safety	8.8%	1	0.09	2	0.18	1	0.09
Status in the Industry / Record of Performance	14.6%	3	0.44	2	0.29	4	0.58
Public Acceptability	2.3%	4	0.09	2	0.05	2	0.05
TOTAL	**100%**	**23**	**2.78**	**21**	**2.51**	**20**	**2.11**
	Overall Ranking	**1**				**2**	

5.3. RECOMMENDATIONS

Lessons learned from the previous RRWTP raw water system zebra mussel infestation lead to the recommendation that the COD proceed proactively with actions to better prepare for future zebra mussel infestations of the RRWTP raw water system. As the RRWTP raw water system is susceptible to fouling, and zebra mussel infestations would pose significant risk to COD operations, a proactive program to manage risk is recommended for immediate implementation. Key recommendations include:

- Applying monitoring and inspection techniques to input information into the decision-making process;
- Developing a multi-barrier approach to zebra mussel management; and
- Optimizing O&M activities, which can significantly reduce future impacts with minimal capital investment.

COD can either elect to implement a preventative or reactive approach to zebra mussel management. Preventative strategies prevent attachment on surfaces or prevent settlement of veligers while reactive strategies are aimed at removing an existing infestation. A preventative approach is recommended to minimize future capacity reductions to the water treatment plants. However, some scale of physical removal and disposal will be required, even with the most proactive strategies.

Recommendations considered local raw water quality, local zebra mussel biology and ecology, downstream water quality goals, potential operational impacts, current and potential future regulations, and future changes to the raw water system and downstream treatment plants. The source-to-tap approach considered potential dual-benefits and mitigation strategies for potential downstream unintended consequences. Capital, operations and maintenance recommendations for the RRWTP raw water system including risk management recommendations (e.g. monitoring and inspection guidelines and interim chemical feed recommendations) are summarized in Section 5.3.1. Lastly, recommended next steps are provided in Section 5.3.3.

5.3.1. Capital, Operations and Maintenance Recommendations

Long-term recommendations for managing future potential zebra mussel infestations in the RRWTP raw water system include capital improvements (e.g. installation of two chemical feed systems), maintenance improvements (e.g. raw water pipeline improvements), and operational enhancements (e.g. operating pumps and valves frequently). Two-chemical systems provide redundancy and flexibility, and are common in zebra mussel management strategies employed in the Great Lakes region. The ability to utilize an alternate system in lieu of the primary system to reduce the impact of system limitations (e.g., increase effectiveness, mitigate a potential downstream consequence) or when the primary system is not operating due to maintenance, will provide the RRWTP with a robust preventative zebra mussel management strategy. Table 5-9 summarizes recommended capital improvements and O&M strategies for the RRWTP Intake. These improvements should be implemented based upon an established response plan (i.e., trigger for implementing interim and permanent systems) and the results of monitoring. The primary recommendation for COD is to pursue a proactive approach to zebra mussel management (i.e., preventative strategy) to minimize the volume of zebra mussels requiring disposal. Additional information on the recommendations in Table 5-9 are provided within this chapter.

Table 5-9: RRWTP Intake Recommended Capital Improvements, O&M Strategies and Associated Costs for Zebra Mussel Management

	Probable Costs[1]	Recommendations
Capital Improvements	Probable Capital Improvement Cost: $ 2,180,000 Probable Engineering and Construction Administration Fee: $ 440,000	▪ Improve the raw water pipelines with additional ▪ Install a copper ion system (based upon plant design flow rate of 20 MGD) ▪ Install a sodium permanganate storage and feed system (based on a design dose of 2.5 mg/L) ▪ Minor manway improvements for physical removal and disposal access especially at pipeline low points ▪ See Section 5-9 for more information
General O&M Enhancements	Probable annual O&M cost: $ 98,000 – $ 119,000	▪ Light physical removal and disposal, as required especially at the low point downstream from the USACE outlet, to include regular pipeline inspections ▪ Operate valves frequently (and pumps if in operation) ▪ Isolate and dewater structures (e.g. pipelines) during plant shutdowns (lower water level if complete dewatering is not possible) ▪ See Section 3.2.1 and 5-9 for more information
Dosing Strategies		▪ Dosing strategies (including the dose applied, frequency, duration and time of year) should be optimized after startup. The recommended initial dosing strategy includes: Copper Ion Systems: ▪ Dose: 5 parts per billion (ppb) copper and 0.05 ppb aluminum during settlement season; 2 ppb copper and 0.02 ppb aluminum during non-settlement seasons ▪ Frequency/Duration: continuous operation Sodium Permanganate: ▪ Dose: 1.5 mg/L average (likely range of 0.5 – 2.5 mg/L) ▪ Frequency/Duration: on/off every 30 minutes ▪ Timing: based upon monitoring, when settlement occurs in the spring and fall (alternatively, when temperatures are above 16°C and below 32°C) ▪ See Sections 3.1.2.1 and 3.2.2.2 for more information
Risk Management Approaches		▪ Increase monitoring to include additional water quality, substrate sampler and veliger monitoring at minimum (see Section 5.3.1.1 for details) ▪ Visually inspect debris from the pipelines or USACE outlet. Also visually inspect any dewatered surfaces during maintenance activities (see Section 5.3.1.1 for details) ▪ Develop a plan for interim chemical feed using sodium permanganate totes (see Section 0 for details) ▪ See Section 5.3.3 for a summary of recommended next steps to minimize risk including development of on-call contracts, regulatory coordination and new standard operating procedures

1 – Probable costs are based upon the recommended line items shown and rounded up to two significant figures as cost estimates are Class 4 Association for the Advancement of Cost Engineering International (AACE). Annual O&M costs assume settlement monitoring will be conducted to reduce chemical feed to 5 months of the year. Control validation monitoring (e.g. the use of bioboxes) would likely further reduce annual chemical costs.

5.3.1.1. Recommended Monitoring and Inspection Guidelines

As the RRWTP raw water system has already been infested with zebra mussels, the focus of the proposed monitoring program is to optimize future management strategies. COD does not have a current zebra mussel monitoring program, but does measure temperature, pH, calcium and hardness 4-6 times per year and TOC, DOC and alkalinity monthly. Furthermore, USGS is monitoring Lake Ray Roberts for veligers and settled juvenile and adult zebra mussels. In addition to continuing the water quality monitoring currently performed, the Arcadis team recommends the COD perform the additional monitoring outlined in Table 5-10 to:

- Determine seasonal and annual variability in zebra mussel settlement timing, density and growth
- Optimize the zebra mussel management approach including:
    - Frequency of physical cleanings
    - Dose and chemical applied
    - Continuous versus intermittent dosing
    - Seasons when dosing is required

Table 5-10: Recommended COD Zebra Mussel Monitoring at the RRWTP Intake

Monitoring Method	Frequency
Information Gathering: Develop a network to disseminate and collect information among all interested and potentially impacted parties including TPWD and other utilities in Texas. Consider designating one staff member to serve as a “zebra mussel point of contact” who is familiar with the issues to participate in all information sharing.	Monthly
Water Quality Monitoring: Establish continuous temperature recorders (in interim could be measured manually) in source water approximately 1.5 - 2 meters from the surface and measure at least daily to identify when the water temperature at the intake is favorable for settlement.	Year-round
Direct Site Inspections: Institute an in-house direct inspection program which includes: ▪ Training of facility personnel in adult zebra mussel identification. ▪ Establishment of procedures to verify any possible zebra mussel sighting (contract lab, USGS, university) including collection, preservation, and photo-documentation. ▪ Inspection of any dewatered hard surfaces including pipes, valves, and the fish strainers during maintenance activities ▪ Inspection of debris (e.g. vegetation) pulled from the system or the USACE outlet. ▪ Diligently observe plant operation for impacts of zebra mussels such as reduced hydraulic capacity. Consider conducting additional pipeline assessments following each settlement season (or at least every 2 years). ▪ Additionally, regularly inspect the pre-ozone contactors for zebra mussel shells. The in-house direct inspection program should continue with increased monitoring during the reproduction season when surface water temperatures are above 16°C (i.e. when settlement is likely to occur). Focus on densities and control validation within the system.	During routine maintenance activities and plant shutdowns with regular inspections when temperatures are above 16°C
Veliger Monitoring: Sampling should be modified to determine the density of veligers and settled mussels (i.e., not presence/absence). Sampling should occur at the intake upstream of any control when water temperature is above 12°C (to assure detection of spawning/settlement soon after it occurs around 16°C).	Weekly

<table>
<tr><th>Monitoring Method</th><th>Frequency</th></tr>
<tr><td>Substrate Samplers: Sampling should be conducted weekly when veligers are present. Initiate when spring ambient water temperatures reach 12°C (to assure detection of spawning/settlement soon after it occurs around 16°C). Consider less frequent monitoring during other times. Sampling should occur at the intake upstream of any control.</td><td>Weekly</td></tr>
<tr><td>Control Validation: For monitoring within a facility, a side-stream technique, using a water tap to provide flow to a sampler, called a biobox is recommended. Biobox monitors should be established in the facility raw water system with the following guidelines:
Place at furthest point where control needs to be effective (i.e., just prior to the pre-ozone contactors at the WTP).
Place near any critical points in the system (e.g. just upstream of raw water fire protection systems, sensitive equipment).
Establish bioboxes only in areas where continuous flow is present.
Following start-up of chemical feed, monitor the permanganate residual through the system. Any components or pipeline lengths not protected by a chemical residual of approximately 0.25 mg/L will be susceptible to fouling. Online permanganate monitors should be installed immediately prior to the pre-ozone contactors at the WTP (furthest point requiring protection) and at the chemical valve vault (where backup chemical could be added if the demand is higher than expected). Grab sample residual measurements may also be helpful along the raw water pipelines wherever access is available to understand how far the applied dose is protecting.
Bioboxes should include the same substrates used in at the intake and have the capability to conduct veliger sampling (veliger sampling may not be necessary depending on control strategy).
Include the capability to introduce test adult mussels to monitor the efficacy of control.</td><td>TBD based upon sensitivity to fouling and control approach selected. Monitor at the same frequency and time as monitoring at the intake</td></tr>
<tr><td>Manganese Monitoring*: Following start-up of chemical feed, monitor the total and dissolved manganese, pH, DO and ORP (manganese profiling) at multiple points in the raw water system, before and after each treatment process, and in recycle streams. Shifts in pH or ORP, changes in the permanganate dose, anoxic conditions or operational changes at the WTPs could result in resolubilization of manganese and manganese spikes leading to staining of equipment, exceedance of the manganese SMCL of 0.05 mg/L, increased turbidity or colored water. Conduct total manganese monitoring of the finished water daily and conduct manganese profiling regularly and after any of the previously mentioned changes. Consider measuring pH and ORP daily at the RRWTP raw water valve vault (downstream of chemical addition if selected). Additionally, monitor the manganese removal performance of the biofilters through the ongoing Innovation Fund Project with Arcadis.
* Not required if only copper ion systems in use</td><td>Total and dissolved manganese entering the plant and in the finished water daily; Manganese profiles regularly (e.g. once per month) or anytime process changes are made (including changes in chemical doses)</td></tr>
</table>

The Arcadis team recommends that COD develop site-specific monitoring programs (i.e., regularly updated the frequencies suggested in the table above) dependent on the sensitivity of each facility to fouling and the type of control(s) that are implemented. If an on-staff biologist is not available to oversee and perform biological monitoring techniques, additional monitoring contracts can be established with labs or agencies, such as USGS.

5.3.1.2. Recommendations for Interim Chemical Feed

As the COD had to undergo a major cleaning effort following the 2014 zebra mussel settlement season(s), the COD asked for recommendations on the best interim chemical feed system to minimize future infestations of the RRWTP raw water system until a permanent management strategy can be implemented. The best temporary chemical feed system would be the use of sodium permanganate. Based upon initial discussions between the COD and USACE, it was determined that it would not be allowed to apply chemical upstream of the RWPS without obtaining a permit (which would likely be a lengthy process). Thus, it was determined that chemical could be fed at the fish strainer immediately upstream of the RWPS. As there is already a penetration in the access manway to the fish strainer for pressure measurements, it would be feasible to add a chemical feed line at the same location. Chemical would be injected from the open end of the pipe pointing upstream of the main flow to encourage diffusion following the criteria in Table 5-11. The interim feed system would consist of the following equipment housed within the existing RWPS fencing to minimize security concerns. COD has already received approval from TCEQ for use of the interim chemical system as described herein and shown in Figure 5-11.

- Sodium permanganate totes or drums with temporary containment (40% solution)
- 2-inch feed piping (no diffusers or piping split into two 1-inch lines for a simple diffuser) with a temporary enclosure or within an existing building
- Feed pump (at least 50 gpm capacity needed based on 5 ft/sec velocity in the feed pipe for mixing) using raw water

Table 5-11: Start-Up Operational Criteria

Criteria	Recommendation	Basis
Permanganate Dose*	1.5 mg/L (0.5-2.5 mg/L may be required) @ 5 MGD , 0.01 gpm @ 20 MGD , 0.03 gpm	Dose was based upon chemical demand testing and raw water flow data.
Dosing Frequency	30 minutes on / 30 minutes off	Previous project experience suggests that 30 min on 90 min off can be effective at doses above the background water demand; however, it is recommended to begin more conservatively.
Application Point	Fish Strainer	There is an existing access point to the pipeline (note this will not protect the valves and 60" pipeline upstream).
Application Seasons	When temperatures are above 16°C and below 30°C	Research conducted by Dr. McMahon suggests that local spawning / settlement occurs above 16°C and below 30°C. Based on historical data, the water temperature is likely favorable March – July and August – December. Settlement monitoring at the RRWTP Intake would likely narrow the number of months requiring chemical treatment.

*A sudden application of an oxidant at a high dose may result in biofilm and solids release from the pipeline. Operational plans should be in place to monitor for and treat a potential spike in influent organics and solids following initial startup.

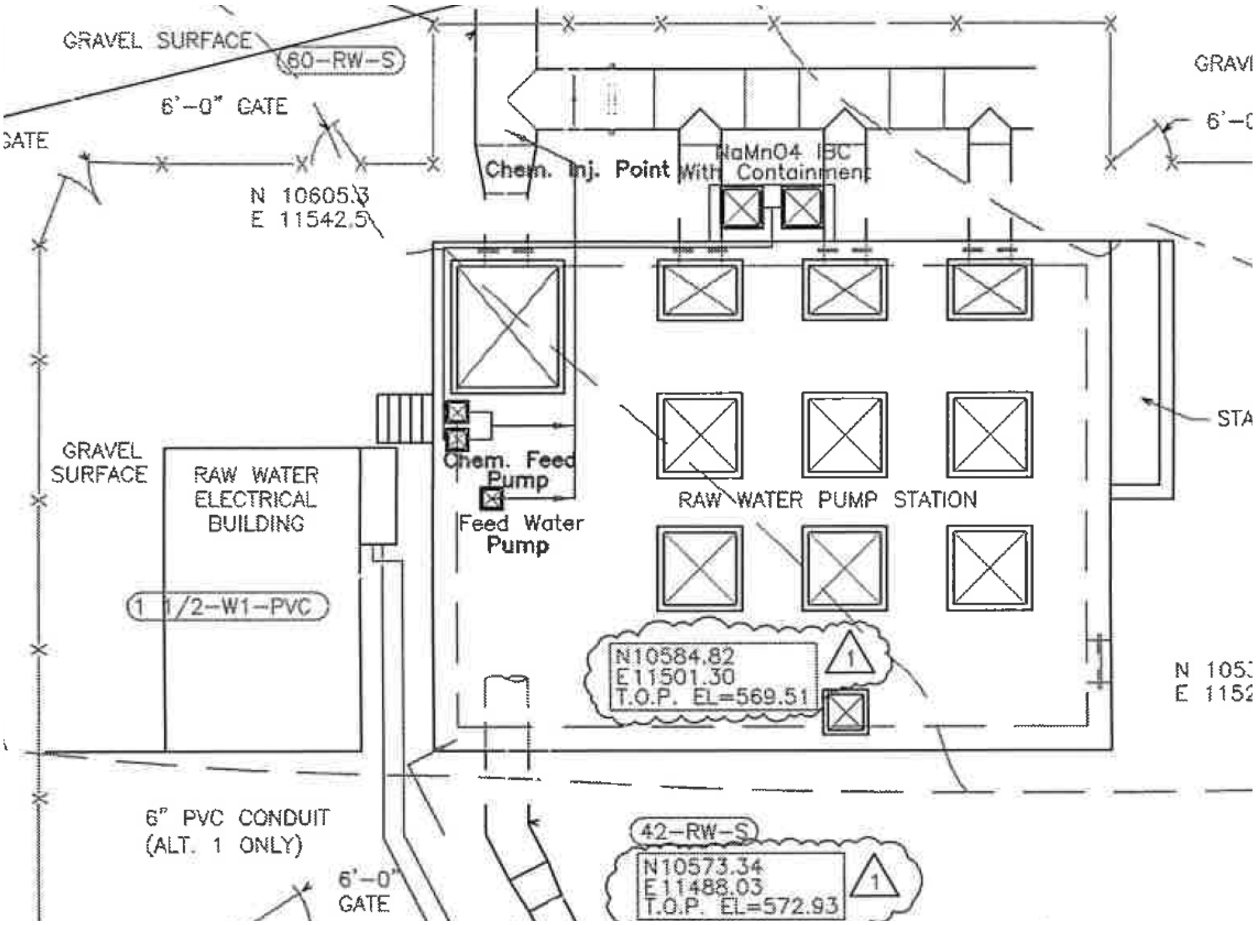


Figure 5-11: RRWPT Schematic of Interim Sodium Permanganate Feed System (Developed by Mamun Yusuf, COD)

It is critical the COD increase monitoring at the RRWTP immediately following the recommendations in Table 5-10 as soon as the permanganate dose is increased. Nevertheless, the start-up operational criteria in the above table should be optimized by monitoring:

1. Settlement of veligers at the RRWTP Intake to optimize the application timing
2. Effectiveness of the treatment strategy to optimize the dose and dosing frequency
3. Manganese in the raw water system and through the treatment plant to predict and troubleshoot any potential downstream unintended consequences of a higher raw water permanganate dose

In addition to optimizing the operating criteria for permanganate dosing at the RRWTP Intake, monitoring will provide data that will help to optimize the future design of permanent facilities. Data collected over several years should be trended to determine seasonal operating practices specific to the RRWTP Intake and raw water system.

5.3.2. Pre-Ozone Contactor Recommendations

Given the discovery of zebra mussel shells in the pre-ozone contactors, COD has concerns about the zebra mussel shells clogging up the pre-ozone contactors drains, mainly because they have no way to clean them (no manholes). COD's main concerns are with the pre-ozone contactor drains and the splitter box drains (if pre-ozone is bypassed). The drains go down from 24" in size to as little as about 8". Below is a summary of items to consider:

- Once the chemical addition has started there will be far fewer mussels accumulating in the pre-ozone contactors that would require cleaning. This is because there will be fewer mussels settling on and attaching on upstream piping. Those mussels that attach and grow in the piping drop off in clumps over time and get washed into the contactors. The chemical control will prevent settlement and attachment in the upstream piping and cause mortality of the veligers who will not be able to grow and form new colonies in the contactor. The access points the Team is suggesting to install inside the valve chambers will also allow COD to do more frequent manual cleaning to prevent accumulation in the low spot critical areas of the pipeline. Frequent (e.g. every other year) cleaning will minimize the volume of larger clumps of mussels from being flushed downstream into the contactor, which is a likely the cause of mussels in the contactor that have recently been observed. Nevertheless, Lake Ray Roberts WTP may still get some adult mussels flushed into the contactors, which could potentially clog the drains. More than likely mussels would not be attaching or growing in the drains because they are stagnant most of the time and any live mussels would desiccate and die.

- Arcadis could provide means or a plan to drain the contactor without using the drains until they observe the impact of chemical addition to the raw water pipeline and annual cleanings of the intake has on mussel accumulation in the pre-ozone contactors. If a plan is desired, the Team suggests it involve temporary portable pumps that would be set up to pump down the tanks most of the way using hoses to get the water to the sedimentation tanks followed by hiring a contractor with a vactor truck (or perhaps the City of Denton sewer department has a vactor) that could suck up the debris at the bottom of the tank. The ozone contactor does have exterior access hatches that could be used.

- If permanent means to drain the contactor without using the drains is desired, it would involve either:

    - Core drilling the walls and placing a pump on a slab on the outside wall and pumping the contents to a lined lagoon area. This could also be done by gravity, depending where it is draining to and using quick connect hosing rather than permanent discharge piping; or

    - Installing a pump on the top of the tanks and penetrating the roof to allow pumping out of the tanks in the same manner as for the previous alternative.

- Another way to protect the drains could involve standpipes above the drains. Since the mussels in the contactor should all be dead and the shells settled on the bottom of the tank, "standpipes" could be added above the drains; essentially a 12 to 18 inch extension of the drain opening with small weep holes drilled into the extension. When draining the tank, water would flow into the open standpipe above the drain until it got to the elevation of the top of the standpipe. Then the remaining 18 inches of water would flow out gradually through the weep holes leaving the mussels on the tank floor. Similarly, this could be accomplished with a slotted well screen inserted into the drain opening.

5.3.3. Recommended Next Steps

In addition to designing and constructing the selected capital improvements ASAP, there are a number of proactive actions COD can initiate to prepare for potential future infestations of the RRWTP Intake. Develop a response plan to initiate further steps to provide zebra mussel protection (e.g. confirm the trigger for constructing interim and permanent improvements). The response plan should include:

Short-Term/No Trigger:

- Implement the next steps recommended in this section including but not limited to standard operating procedure development, regulatory coordination and monitoring.
- Revise budgets in the Capital Improvements Plan (CIP) based upon the selected alternative and adjust annual operating budgets to account for increased annual costs to manage zebra mussels.
- Begin designs and subsequent construction of permanent systems.
- Begin implementation of the interim sodium permanganate system to minimize future infestation of 42" pipeline.

Longer-Term/Zebra Mussel Observed:

- Plan for physical removal and disposal from the 60" pipeline at least once before the new systems are constructed in 2017.
- Plan for annual inspections of the 60" (particularly at the low point downstream of the USACE outlet) to determine whether additional cleanings are required.

Other Considerations:

- During future projects (e.g. the construction of the second pipeline from the RWPS to the plant), include zebra mussel management approaches (e.g. manways for cleaning access) during design and construction.
- Update the response or strategic plan annually based upon updated data from monitoring.

5.3.3.1. Develop a Zebra Mussel Monitoring Standard Operating Procedure (SOP)

Increased biological monitoring should begin immediately to maximize the amount of time to respond and prevent future potential infestations following the recommendations in Section 5.3.1.1. Consider hiring and/or training staff members to perform zebra mussel monitoring (i.e., veliger, settlement and adult identification) at both intake locations. Update the monitoring plan annually based upon a review of trended data collected through the monitoring effort. Following implementation of any molluscicides, the SOP should provide procedures for modifying the site's monitoring program for chemical feed optimization including the use of chemical residual monitors and bioboxes in the intake and at the point farthest downstream in the system where protection is required.

5.3.3.2. Begin Regulatory Coordination

Zebra mussel management will require coordination with multiple regulatory agencies throughout the planning, design, and construction phases of the project as summarized in Section 2.6. Which agencies are involved depends on the selected zebra mussel management approach and the application, but the following regulatory focus items should be addressed in the near term:

- Submit 60/100% design documents to TCEQ for review and approval. Include computational fluid dynamics (CFD) modelling and design chemical feed pumps to interlock with the raw water flow to demonstrate that safety measures are in place to prevent chemical flow into the water source.
- Coordinate with USACE once conceptual designs are complete to begin the permitting process to add chemical in the valve vaults.
- Coordinate with USFWS and TPWD to determine whether reviews are required.

5.3.3.3. Develop On-Call Contracts for Physical Removal and Disposal

It is recommended that COD proactively develop an on-call contract (see Section 3.2.3.4 for additional information) for cleaning and disposal of mussels. On-call contracts generally require the contractor to coordinate disposal in accordance with all regulations. Develop on-call contracts (or price agreements) for inspecting facilities for zebra mussels and cleaning mussel infestations from facilities. On-call contracts should include detailed drawings and specifications consider the lessons learned from the RRWTP zebra mussel cleaning event (Section 2.4).

5.3.3.4. Assess Acceptable Impacts

Consider potential hydraulic losses due to zebra mussels and/or Asian clams, potential disposal efforts associated with physical removal, and evaluate access points for physical removal of shells.

- Use hydraulic analysis to determine the level of acceptable infestation and allowable reduced hydraulic capacity before cleaning is necessary. Consider each plant individually and the system as a whole. See Section 2 and Appendix E for hydraulic calculations.

- Especially for longer pipelines, consider the maximum volume of mussels that should be allowed to accumulate before removal. If pipe capacities are larger than the current flows, hydraulic impacts may not be noticed before large volumes of mussels accumulate in pipelines and potentially slough off and travel to the head of the plant (i.e., pre-ozone contactors). Consider executing an inspection on-call contract to monitor mussel accumulations or conduct regular CCTV assessments of all pipelines.

5.3.3.5. Implement the Interim Chemical Feed Plan

Implement the interim chemical feed system as described in Section 0. Concurrently, implement the recommendations for increased monitoring and inspections are provided in Section 5.3.1.1. The interim design should include the necessary monitoring equipment (e.g. residual monitors and bioboxes) to optimize the chemical dose and frequency required. Prior to long-term application, perform a trial run of permanganate application with full manganese profile monitoring (i.e., similar to the study completed at the LLWTP summarized in Appendix G) to troubleshoot any unanticipated downstream consequences.

5.3.3.6. Develop New Chemical System Design Documents

Complete development of design documents for the selected alternative. The design should consider and balance dual-water quality benefits (i.e., pre-oxidation of manganese, taste and odor compounds and organics and cyanobacteria and algae control) with downstream treatment challenges (e.g. continuous chemical feed may be preferred over pulse dosing to provide continuous pre-oxidation of manganese and minimize changes in the downstream ozone dose). Design should include developing chemical dosing SOPs and may require more extensive demand testing and/or pre-oxidation jar testing to understand how to respond to water quality changes (e.g. seasonal changes in demand or zebra mussel settlement). Consideration should be given to ensure small diameter pump seal water lines are fully protected during settlement season as they will have much lower tolerances than the large diameter transmission lines. The permanent design should also include redundancy of equipment (multiple metering pumps), and a central storage area for permanganate totes/tanks.

5.3.3.7. Sodium Permanganate Implementation for Zebra Mussel Management, Develop a Manganese SOP

In conjunction with sodium permanganate implementation for zebra mussel management, a manganese standard operating procedure (SOP) should be developed. If not properly monitored and managed, permanganate can result in increased manganese concentrations (potentially above the 0.05 mg/L SMCL) in the treatment stream, which in turn can lead to colored water events. It should be noted that although development of a manganese management procedure is recommended, many utilities (e.g. City of Oregon, OH, City of Toledo, OH and City of Raleigh, NC) have used permanganate doses of 2-4 mg/L without any noticeable resulting manganese water quality impacts. A summary of recommended manganese monitoring is provided in Table 5-10.

- The manganese SOP should include increased monitoring of total and dissolved manganese, pH and ORP before and after each treatment process and each oxidant feed location. These parameters should be monitored on a regular basis, and especially after any major water quality or treatment process changes.

- Treatment process optimization strategies (including guidelines for pre-oxidation of permanganate) should be outlined and triggers (i.e., manganese concentrations) for implementing operational changes identified. Treatment process optimization strategies should include: optimization of the permanganate dose by monitoring the residual and using bioboxes, increasing the sedimentation basin sludge blowdown frequency to prevent anoxic conditions resulting in resolubilization of manganese, adjusting the ozone dose to prevent over-ozonation and formation of permanganate or colloidal manganese oxides, and improving solids handling and recycle streams to prevent manganese from being recycled to the head of the plant.

5.3.3.8. Copper Ion Generation Implementation for Zebra Mussel Management, Implement Additional Copper and Aluminum Monitoring

The COD should observe the upcoming installation and performance of this system at the City of Lewisville Intake. A copper monitoring plan would be recommended including an initial assessment of background copper levels. Copper removal via downstream treatment processes should be verified to ensure compliance with existing and potential future regulations and assess impacts on copper and lead control in the distribution system, understanding that existing regulations generally become more stringent over time. Aluminum should also be monitored and assessed.

Due to the limited information available and limited full-scale municipal installations for zebra mussel control, a sidestream biobox pilot study could be performed prior to full-scale installation of a copper ion alternative to verify efficacy in COD source waters and systems. Additionally, a performance guarantee of zebra mussel settlement prevention could be requested from the manufacturer.

APPENDICES

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APPENDIX A: REFERENCES

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APPENDIX B: WATER QUALITY DATA

Temperature (°C) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	12	9
April-13	17	20
June-13	26	21.3
August-13	31	25
October-13	23	21
February-14	7	9.2
April-14	16	10
June-14	28	24
August-14	29	27.4
October-14	25	24.7
December-14	14	16.3

pH (mg/L) Data Provided by City of Denton (Lab)		
Date	Lewisville Lake	Ray Roberts Lake
February-13	8.43	8.13
April-13	8.42	7.99
June-13	8.49	8.1
August-13	8.6	7.2
October-13	8.3	7.8
February-14	8.08	7.99
April-14	8.15	8.05
June-14	8.35	7.96
August-14	8.75	7.76
October-14	8.34	7.69
December-14	8.2	8.19

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
January 1, 2014	7.27	7.87
January 2, 2014	7.27	7.91
January 3, 2014	7.27	7.89
January 4, 2014	7.27	7.87
January 5, 2014	7.28	7.8
January 6, 2014	7.28	7.76
January 7, 2014	7.27	7.95
January 8, 2014	7.28	7.97
January 9, 2014	7.27	7.96
January 10, 2014	7.27	7.97
January 11, 2014	7.28	8.02
January 12, 2014	7.28	8.03
January 13, 2014	7.28	8.05
January 14, 2014	7.27	7.93
January 15, 2014	7.27	7.95
January 16, 2014	7.27	8.01
January 17, 2014	7.28	7.92
January 18, 2014	7.27	7.81
January 19, 2014	7.28	7.89
January 20, 2014	7.28	7.94
January 21, 2014	7.27	7.88
January 22, 2014	7.28	7.84
January 23, 2014	7.28	7.88
January 24, 2014	7.27	7.9
January 25, 2014	7.28	7.87
January 26, 2014	7.28	7.82
January 27, 2014	7.27	7.66
January 28, 2014	7.28	7.72
January 29, 2014	7.28	7.99
January 30, 2014	7.28	7.86
January 31, 2014	7.27	7.79
February 1, 2014	7.27	7.73
February 2, 2014	7.28	7.66
February 3, 2014	7.28	7.81
February 4, 2014	7.27	7.73
February 5, 2014	7.27	7.59

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
February 6, 2014	7.27	7.8
February 7, 2014	7.27	7.65
February 8, 2014	7.27	7.76
February 9, 2014	7.27	7.75
February 10, 2014	7.27	7.54
February 11, 2014	7.28	7.84
February 12, 2014	7.28	7.85
February 13, 2014	7.28	7.97
February 14, 2014	7.27	7.93
February 15, 2014	7.28	7.79
February 16, 2014	7.28	7.9
February 17, 2014	7.27	7.94
February 18, 2014	7.28	7.88
February 19, 2014	7.28	8.01
February 20, 2014	7.27	7.91
February 21, 2014	7.28	7.98
February 22, 2014	7.27	8
February 23, 2014	7.27	7.98
February 24, 2014	7.28	7.85
February 25, 2014	7.28	7.72
February 26, 2014	7.27	7.75
February 27, 2014	7.28	7.87
February 28, 2014	7.28	7.78
March 1, 2014	7.27	7.79
March 2, 2014	7.28	7.73
March 3, 2014	7.28	7.74
March 4, 2014	7.28	7.82
March 5, 2014	7.28	7.91
March 6, 2014	7.27	7.94
March 7, 2014	7.27	8.01
March 8, 2014	7.28	7.94
March 9, 2014	7.27	7.93
March 10, 2014	7.28	7.82
March 11, 2014	7.28	7.82
March 12, 2014	7.28	7.81
March 13, 2014	7.28	7.79

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
March 14, 2014	7.28	7.68
March 15, 2014	7.27	7.62
March 16, 2014	7.27	7.66
March 17, 2014	7.28	7.66
March 18, 2014	7.27	7.54
March 19, 2014	7.28	7.53
March 20, 2014	7.28	7.64
March 21, 2014	7.27	7.54
March 22, 2014	7.28	7.8
March 23, 2014	7.27	7.64
March 24, 2014	7.27	7.63
March 25, 2014	7.27	7.59
March 26, 2014	7.28	7.54
March 27, 2014	7.27	7.59
March 28, 2014	7.28	7.55
March 29, 2014	7.27	7.72
March 30, 2014	7.27	7.77
March 31, 2014	7.28	7.67
April 1, 2014	7.27	7.86
April 2, 2014	7.27	7.89
April 3, 2014	7.28	7.86
April 4, 2014	7.27	7.6
April 5, 2014	7.27	7.8
April 6, 2014	7.28	7.83
April 7, 2014	7.28	7.73
April 8, 2014	7.27	7.72
April 9, 2014	7.28	7.94
April 10, 2014	7.27	7.86
April 11, 2014	7.28	7.9
April 12, 2014	7.27	7.82
April 13, 2014	7.28	7.8
April 14, 2014	7.28	7.69
April 15, 2014	7.27	7.78
April 16, 2014	7.27	7.9
April 17, 2014	7.27	7.92
April 18, 2014	7.28	7.83

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
April 19, 2014	7.27	7.87
April 20, 2014	7.28	7.95
April 21, 2014	7.27	7.92
April 22, 2014	7.27	7.83
April 23, 2014	7.27	8.08
April 24, 2014	7.27	8.03
April 25, 2014	7.28	7.92
April 26, 2014	7.27	7.97
April 27, 2014	7.27	7.92
April 28, 2014	7.27	7.96
April 29, 2014	7.28	7.82
April 30, 2014	7.27	7.76
May 1, 2014	7.28	7.8
May 2, 2014	7.27	7.99
May 3, 2014	7.27	8.17
May 4, 2014	7.27	8.17
May 5, 2014	7.27	8.11
May 6, 2014	7.28	8.05
May 7, 2014	7.28	8.02
May 8, 2014	7.27	7.91
May 9, 2014	7.28	7.84
May 10, 2014	7.28	7.94
May 11, 2014	7.27	7.96
May 12, 2014	7.27	7.66
May 13, 2014	7.28	7.66
May 14, 2014	7.28	7.63
May 15, 2014	7.27	8.21
May 16, 2014	7.27	7.71
May 17, 2014	7.28	7.86
May 18, 2014	7.28	7.83
May 19, 2014	7.28	7.9
May 20, 2014	7.27	7.45
May 21, 2014	7.28	7.95
May 22, 2014	7.28	7.88
May 23, 2014	7.27	7.77
May 24, 2014	7.28	7.7

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
May 25, 2014	7.28	7.51
May 26, 2014	7.27	7.35
May 27, 2014	7.28	7.41
May 28, 2014	7.28	7.4
May 29, 2014	7.27	7.45
May 30, 2014	7.27	7.52
May 31, 2014	7.27	7.33
June 1, 2014	7.28	7.51
June 2, 2014	7.27	7.64
June 3, 2014	7.28	7.67
June 4, 2014	7.27	7.66
June 5, 2014	7.28	7.55
June 6, 2014	7.28	7.54
June 7, 2014	7.27	7.49
June 8, 2014	7.27	7.47
June 9, 2014	7.27	7.38
June 10, 2014	7.28	7.37
June 11, 2014	7.27	7.53
June 12, 2014	7.28	7.47
June 13, 2014	7.28	7.5
June 14, 2014	7.27	7.68
June 15, 2014	7.28	7.66
June 16, 2014	7.27	7.86
June 17, 2014	7.27	7.77
June 18, 2014	7.27	7.94
June 19, 2014	7.27	7.92
June 20, 2014	7.28	7.76
June 21, 2014	7.27	7.64
June 22, 2014	7.27	7.44
June 23, 2014	7.28	7.36
June 24, 2014	7.27	7.41
June 25, 2014	7.27	7.47
June 26, 2014	7.27	7.43
June 27, 2014	7.27	7.66
June 28, 2014	7.28	7.68
June 29, 2014	7.28	8.06

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
June 30, 2014	7.27	7.83
July 1, 2014	7.28	7.98
July 2, 2014	7.27	7.83
July 3, 2014	7.28	7.55
July 4, 2014	7.28	7.94
July 5, 2014	7.28	7.82
July 6, 2014	7.28	7.83
July 7, 2014	7.27	7.81
July 8, 2014	7.27	7.76
July 9, 2014	7.27	7.64
July 10, 2014	7.28	7.72
July 11, 2014	7.27	7.7
July 12, 2014	7.27	7.7
July 13, 2014	7.28	7.68
July 14, 2014	7.27	7.85
July 15, 2014	7.28	7.54
July 16, 2014	7.28	7.52
July 17, 2014	7.28	7.4
July 18, 2014	7.28	7.42
July 19, 2014	7.27	7.37
July 20, 2014	7.28	7.66
July 21, 2014	7.27	7.68
July 22, 2014	7.28	7.85
July 23, 2014	7.27	7.79
July 24, 2014	7.28	7.66
July 25, 2014	7.27	7.74
July 26, 2014	7.28	8.14
July 27, 2014	7.28	7.91
July 28, 2014	7.27	7.42
July 29, 2014	7.27	7.56
July 30, 2014	7.28	7.5
July 31, 2014	7.28	7.41
August 1, 2014	7.28	7.46
August 2, 2014	7.28	7.37
August 3, 2014	7.27	7.56
August 4, 2014	7.27	7.92

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
August 5, 2014	7.28	7.76
August 6, 2014	7.27	7.9
August 7, 2014	7.28	7.72
August 8, 2014	7.28	7.81
August 9, 2014	7.27	7.89
August 10, 2014	7.27	7.59
August 11, 2014	7.27	7.47
August 12, 2014	7.27	7.62
August 13, 2014	7.28	7.88
August 14, 2014	7.28	7.87
August 15, 2014	7.28	7.76
August 16, 2014	7.28	7.78
August 17, 2014	7.28	7.48
August 18, 2014	7.27	7.67
August 19, 2014	7.28	7.77
August 20, 2014	7.28	7.88
August 21, 2014	7.27	6.97
August 22, 2014	7.27	7.61
August 23, 2014	7.27	7.76
August 24, 2014	7.28	7.62
August 25, 2014	7.28	7.44
August 26, 2014	7.28	7.49
August 27, 2014	7.27	7.45
August 28, 2014	7.28	7.74
August 29, 2014	7.27	7.4
August 30, 2014	7.28	7.51
August 31, 2014	7.28	7.66
September 1, 2014	7.28	7.39
September 2, 2014	7.28	7.44
September 3, 2014	7.27	7.45
September 4, 2014	7.28	7.61
September 5, 2014	7.27	7.65
September 6, 2014	7.27	7
September 7, 2014	7.27	7.06
September 8, 2014	7.28	7.82
September 9, 2014	7.28	7.77

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
September 10, 2014	7.28	7.55
September 11, 2014	7.28	7.19
September 12, 2014	7.27	7.2
September 13, 2014	7.27	7.13
September 14, 2014	7.28	7.07
September 15, 2014	7.27	7.56
September 16, 2014	7.28	7.75
September 17, 2014	7.28	7.79
September 18, 2014	7.27	7.42
September 19, 2014	7.28	7.58
September 20, 2014	7.28	7.53
September 21, 2014	7.28	7.33
September 22, 2014	7.27	7.37
September 23, 2014	7.28	7.53
September 24, 2014	7.27	7.51
September 25, 2014	7.28	7.1
September 26, 2014	7.28	7.44
September 27, 2014	7.28	7.46
September 28, 2014	7.27	7.5
September 29, 2014	7.28	7.49
September 30, 2014	7.28	7.8
October 1, 2014	7.27	7.73
October 2, 2014	7.27	7.33
October 3, 2014	7.27	7.04
October 4, 2014	7.28	7.57
October 5, 2014	7.28	7.5
October 6, 2014	7.27	7.54
October 7, 2014	7.27	7.69
October 8, 2014	7.28	7.78
October 9, 2014	7.27	7.53
October 10, 2014	7.28	7.71
October 11, 2014	7.28	7.05
October 12, 2014	7.27	7.4
October 13, 2014	7.27	7.2
October 14, 2014	7.28	7.16
October 15, 2014	7.28	7.41

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
October 16, 2014	7.27	7.91
October 17, 2014	7.28	7.54
October 18, 2014	7.27	7.57
October 19, 2014	7.27	7.65
October 20, 2014	7.28	7.93
October 21, 2014	7.27	8.03
October 22, 2014	7.27	7.89
October 23, 2014	7.28	7.92
October 24, 2014	7.27	7.91
October 25, 2014	7.28	7.98
October 26, 2014	7.27	7.99
October 27, 2014	7.27	7.56
October 28, 2014	7.27	7.24
October 29, 2014	7.28	7.51
October 30, 2014	7.27	7.28
October 31, 2014	7.27	7.2
November 1, 2014	7.28	7.41
November 2, 2014	7.28	7.52
November 3, 2014	7.28	7.6
November 4, 2014	7.28	7.4
November 5, 2014	7.27	6.35
November 6, 2014	7.28	6.71
November 7, 2014	7.27	7.19
November 8, 2014	7.28	7.34
November 9, 2014	7.28	7.73
November 10, 2014	7.27	7.94
November 11, 2014	7.28	7.62
November 12, 2014	7.27	7.6
November 13, 2014	7.28	7.75
November 14, 2014	7.28	7.85
November 15, 2014	7.28	7.48
November 16, 2014	7.27	7.84
November 17, 2014	7.28	7.64
November 18, 2014	7.28	7.84
November 19, 2014	7.28	7.74
November 20, 2014	7.27	7.92

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
November 21, 2014	7.28	7.84
November 22, 2014	7.27	7.69
November 23, 2014	7.27	7.48
November 24, 2014	7.27	7.44
November 25, 2014	7.28	7.6
November 26, 2014	7.27	7.41
November 27, 2014	7.27	7.62
November 28, 2014	7.27	7.49
November 29, 2014	7.28	7.56
November 30, 2014	7.27	7.45
December 1, 2014	7.28	7.42
December 2, 2014	7.28	7.49
December 3, 2014	7.28	7.67
December 4, 2014	7.27	7.62
December 5, 2014	7.28	7.52
December 6, 2014	7.28	7.57
December 7, 2014	7.28	7.44
December 8, 2014	7.27	7.73
December 9, 2014	7.27	7.7
December 10, 2014	7.27	7.84
December 11, 2014	7.27	7.88
December 12, 2014	7.28	7.85
December 13, 2014	7.28	7.9
December 14, 2014	7.28	7.65
December 15, 2014	7.28	7.43
December 16, 2014	7.27	7.4
December 17, 2014	7.28	7.52
December 18, 2014	7.27	7.59
December 19, 2014	7.28	7.53
December 20, 2014	7.27	7.43
December 21, 2014	7.28	7.17
December 22, 2014	7.27	7.36
December 23, 2014	7.28	7.4
December 24, 2014	7.28	7.45
December 25, 2014	7.28	7.47
December 26, 2014	7.27	7.51

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
December 27, 2014	7.27	7.53
December 28, 2014	7.27	7.57
December 29, 2014	7.28	7.55
December 30, 2014	7.27	7.58
December 31, 2014	7.27	7.73
January 1, 2015	7.28	7.59
January 2, 2015	7.28	7.76
January 3, 2015	7.28	7.5
January 4, 2015	7.28	7.52
January 5, 2015	7.28	7.74
January 6, 2015	7.28	7.72
January 7, 2015	7.28	7.7
January 8, 2015	7.28	7.62
January 9, 2015	7.27	7.88
January 10, 2015	7.28	7.65
January 11, 2015	7.28	7.56
January 12, 2015	7.27	7.95
January 13, 2015	7.28	7.87
January 14, 2015	7.27	7.8
January 15, 2015	7.28	7.87
January 16, 2015	7.27	7.67
January 17, 2015	7.28	7.79
January 18, 2015	7.27	7.89
January 19, 2015	7.28	7.83
January 20, 2015	7.28	7.48
January 21, 2015	7.28	7.76
January 22, 2015	7.28	7.69
January 23, 2015	7.28	7.66
January 24, 2015	7.27	7.64
January 25, 2015	7.28	7.89
January 26, 2015	7.28	7.72
January 27, 2015	7.27	7.6
January 28, 2015	7.28	7.93
January 29, 2015	7.27	7.73
January 30, 2015	7.27	7.68
January 31, 2015	7.27	7.69

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
February 1, 2015	7.28	7.58
February 2, 2015	7.28	7.73
February 3, 2015	7.27	7.4
February 4, 2015	7.28	7.73
February 5, 2015	7.27	7.7
February 6, 2015	7.28	7.62
February 7, 2015	7.28	7.57
February 8, 2015	7.28	7.49
February 9, 2015	7.28	7.7
February 10, 2015	7.27	7.83
February 11, 2015	7.28	7.59
February 12, 2015	7.28	7.53
February 13, 2015	7.27	7.64
February 14, 2015	7.27	7.74
February 15, 2015	7.27	7.67
February 16, 2015	7.28	7.52
February 17, 2015	7.27	7.66
February 18, 2015	7.27	7.66
February 19, 2015		7.59
February 20, 2015		7.78
February 21, 2015		7.58
February 22, 2015		7.24
February 23, 2015		7.83
February 24, 2015		7.68
February 25, 2015		7.31
February 26, 2015		7.41
February 27, 2015		7.77
February 28, 2015		7.72
March 1, 2015		7.71
March 2, 2015		7.82
March 3, 2015		7.86
March 4, 2015		7.81
March 5, 2015		7.73
March 6, 2015		7.94
March 7, 2015		7.54
March 8, 2015		7.65

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
March 9, 2015		7.87
March 10, 2015		7.77
March 11, 2015		7.76
March 12, 2015		7.82
March 13, 2015		7.71
March 14, 2015		7.71
March 15, 2015		7.8
March 16, 2015		8.24
March 17, 2015		7.73
March 18, 2015		8.06
March 19, 2015		7.58
March 20, 2015		7.68
March 21, 2015		7.91
March 22, 2015		7.87
March 23, 2015		8.05
March 24, 2015		8.16
March 25, 2015		7.85
March 26, 2015		7.64
March 27, 2015		7.94
March 28, 2015		8.25
March 29, 2015		8.18
March 30, 2015		8.35
March 31, 2015		8.24
April 1, 2015		8.16
April 2, 2015		8.07
April 3, 2015	7.28	7.76
April 4, 2015	7.28	7.75
April 5, 2015	7.27	7.85
April 6, 2015	7.28	7.97
April 7, 2015	7.27	8.12
April 8, 2015	7.27	8.09
April 9, 2015	7.27	7.93
April 10, 2015	7.27	7.83
April 11, 2015	7.28	7.98
April 12, 2015	7.27	7.9
April 13, 2015	7.27	7.85

pH (mg/L) Data Provided by City of Denton (SCADA)		
Date	Lewisville Lake	Ray Roberts Lake
April 14, 2015	7.27	7.82
April 15, 2015	7.27	7.83
April 16, 2015	7.28	7.89
April 17, 2015	7.27	7.9
April 18, 2015	7.27	7.81
April 19, 2015	7.28	7.73
April 20, 2015	7.27	7.57
April 21, 2015	7.28	7.77
April 22, 2015	7.28	7.72
April 23, 2015	7.28	7.97
April 24, 2015	7.27	7.58
April 25, 2015	7.28	7.52
April 26, 2015	7.27	7.48
April 27, 2015	7.27	7.35
April 28, 2015	7.28	7.48
April 29, 2015	7.28	7.28
April 30, 2015	7.27	7.4

Total Organic Carbon (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
January-02	4.30	
February-02	6.44	
March-02	4.04	
April-02	6.76	
May-02	5.91	
June-02	5.61	
July-02	5.83	
August-02	6.14	
September-02	6.66	
October-02	6.15	
November-02	5.20	
December-02	6.04	
January-03	4.90	
February-03	5.64	
March-03	5.89	
April-03	5.27	
May-03	5.78	
June-03	5.36	5.69
July-03	5.97	5.82
August-03	6.68	6.24
September-03	5.25	5.73
October-03	6.14	5.22
November-03	5.92	4.53
December-03	5.42	4.82
January-04	6.16	5.12
February-04	5.14	4.69
March-04	5.76	4.92
April-04	6.04	5.30
May-04	5.57	5.36
June-04	6.00	4.78
July-04	6.64	5.14
August-04	5.68	5.14
September-04	5.98	5.06
October-04	6.04	4.92
November-04	5.98	
December-04	4.85	4.84

Date	Total Organic Carbon (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-05	5.81	5.81
February-05	5.50	5.84
March-05	4.94	4.42
April-05	5.58	4.96
May-05	7.46	4.96
June-05	5.86	5.52
July-05	5.50	5.10
August-05	5.34	4.89
September-05	6.35	5.44
October-05	6.00	5.38
November-05	5.97	4.96
December-05	5.31	4.49
January-06	6.46	5.04
February-06	6.18	5.09
March-06	7.12	5.28
April-06	6.35	4.94
May-06	6.50	4.76
June-06	7.42	4.86
July-06	7.17	4.98
August-06	6.99	4.92
September-06	6.97	4.61
October-06	6.98	4.46
November-06	6.42	4.60
December-06	6.94	5.70
January-07	5.64	5.18
February-07	6.70	5.44
March-07	6.43	5.20
April-07	6.44	5.54
May-07	5.97	5.24
June-07	6.52	4.85
July-07	7.68	5.74
August-07	7.02	5.31
September-07	6.49	5.68
October-07	6.38	4.86
November-07	6.04	4.87
December-07	5.90	5.37

Date	Total Organic Carbon (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-08	5.36	4.60
February-08	5.83	5.18
March-08	5.96	4.93
April-08	6.00	5.11
May-08	6.22	5.38
June-08	6.76	4.85
July-08	6.12	5.00
August-08	6.56	5.38
September-08	6.34	5.46
October-08	6.42	6.40
November-08	6.08	4.40
December-08	6.16	5.34
January-09	6.06	5.12
February-09	5.91	5.10
March-09	6.00	5.08
April-09	5.88	6.01
May-09	6.22	5.99
June-09	6.38	5.74
July-09	5.58	4.88
August-09	6.16	5.26
September-09	7.62	6.20
October-09	6.86	5.40
November-09	6.00	4.80
December-09	4.60	4.20
January-10	5.92	5.10
February-10	6.88	5.40
March-10	6.92	4.85
April-10	6.62	5.24
May-10	6.21	5.51
June-10	6.54	5.20
July-10	5.54	4.76
August-10	6.30	5.50
September-10	5.60	4.30
October-10	4.90	3.92
November-10	4.70	4.13
December-10	4.90	4.06

Date	Total Organic Carbon (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-11	6.33	4.70
February-11	4.98	4.44
March-11	4.98	4.36
April-11	4.95	4.29
May-11	5.36	4.24
June-11	6.36	4.07
July-11	6.09	4.36
August-11	6.88	4.33
September-11	7.59	4.92
October-11	5.95	4.71
November-11	6.77	5.30
December-11	6.13	5.05
January-12	5.00	4.10
February-12	6.54	4.97
March-12	5.90	4.80
April-12	7.19	4.54
May-12	6.28	4.73
June-12	5.96	4.48
July-12	7.85	4.81
August-12	6.63	4.83
September-12	5.85	4.52
October-12	5.92	4.32
November-12	6.88	4.32
December-12	5.98	4.48
January-13	5.79	4.58
February-13	6.77	4.61
March-13	5.71	4.92
April-13	5.95	4.70
May-13	6.00	4.60
June-13	5.93	4.77
July-13	6.54	4.41
August-13	6.78	4.36
September-13	7.45	4.22
October-13	6.49	4.23
November-13	6.22	4.06
December-13	6.14	4.59

Total Organic Carbon (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
January-14	6.35	4.70
February-14	6.09	4.75
March-14	6.33	4.94
April-14	6.28	5.09
May-14	6.50	5.12
June-14	6.84	5.09
July-14	7.33	4.95
August-14	6.96	4.90
September-14	6.29	5.35
October-14	6.53	4.88
November-14	6.48	4.84
December-14	6.16	4.73
January-15	6.04	4.45
February-15	6.16	4.79

Date	Dissolved Organic Carbon (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-02		
February-02	4.26	
March-02		
April-02		
May-02		
June-02	5.44	
July-02	5.32	
August-02	5.26	
September-02	5.76	
October-02	4.77	
November-02	4.71	
December-02		
January-03		
February-03	5.58	
March-03	5.25	
April-03	5.06	
May-03	5.25	4.97
June-03	4.86	5.13
July-03		5.12
August-03	5.07	5.82
September-03	4.84	5.30
October-03	5.00	4.61
November-03	5.08	4.33
December-03	5.39	4.56
January-04	5.31	4.68
February-04	5.02	4.47
March-04	5.54	4.84
April-04	5.70	5.13
May-04	5.14	4.64
June-04	5.45	4.68
July-04	5.91	
August-04		4.80
September-04	5.48	4.76
October-04	5.46	4.52
November-04		
December-04	4.78	4.34

Dissolved Organic Carbon (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
January-05	5.84	4.64
February-05	5.42	5.28
March-05	4.98	4.64
April-05	5.56	4.84
May-05	7.23	5.18
June-05	5.42	5.10
July-05	5.41	4.71
August-05	4.98	5.00
September-05	5.72	5.16
October-05	5.70	5.10
November-05	5.48	4.37
December-05	5.12	4.66
January-06		4.47
February-06	5.64	4.88
March-06	6.81	5.00
April-06	6.04	4.77
May-06	6.09	4.62
June-06	7.24	4.64
July-06	6.60	4.81
August-06	6.63	4.85
September-06	6.37	4.74
October-06	6.24	4.37
November-06	5.98	4.38
December-06	6.38	4.97
January-07	5.52	5.07
February-07	6.00	5.05
March-07	6.15	5.01
April-07	6.10	4.68
May-07	5.75	5.44
June-07	6.29	4.16
July-07	7.04	5.55
August-07	6.86	5.09
September-07	5.75	5.64
October-07	6.33	4.51
November-07	5.66	4.77
December-07	5.32	5.02

Date	Dissolved Organic Carbon (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-08	4.97	4.35
February-08	5.15	4.92
March-08	5.24	4.74
April-08	5.66	4.82
May-08	5.56	4.98
June-08	6.18	4.82
July-08	5.59	5.02
August-08	5.84	4.70
September-08	5.05	4.50
October-08	5.96	5.06
November-08	5.06	3.82
December-08	5.59	4.93
January-09	5.27	4.65
February-09	5.26	4.46
March-09	5.46	4.68
April-09	5.41	4.62
May-09	4.67	5.59
June-09	5.82	4.02
July-09	5.09	4.35
August-09	5.38	4.80
September-09	5.96	5.38
October-09	4.72	4.46
November-09	5.38	3.99
December-09	4.40	3.80
January-10	5.30	4.64
February-10	6.18	4.90
March-10	6.46	4.62
April-10	6.16	4.97
May-10	5.74	5.02
June-10	5.88	4.92
July-10	4.74	4.26
August-10	4.97	4.67
September-10	4.80	4.06
October-10	4.06	3.42
November-10	4.29	3.97
December-10	4.46	3.97

Dissolved Organic Carbon (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
January-11	6.08	4.51
February-11	4.69	4.13
March-11	4.44	4.04
April-11	4.67	4.67
May-11	4.73	3.88
June-11	5.94	3.91
July-11	5.15	4.12
August-11	6.22	4.05
September-11	6.23	4.41
October-11	5.15	4.23
November-11	5.92	5.24
December-11	5.02	4.32
January-12	4.90	4.10
February-12	5.55	4.52
March-12	5.18	4.32
April-12	6.45	4.32
May-12	5.61	4.53
June-12	5.23	4.23
July-12		4.38
August-12		4.63
September-12		4.48
October-12		4.23
November-12		4.20
December-12		4.31
January-13	5.11	4.42
February-13	5.27	4.40
March-13	5.30	
April-13	5.40	4.55
May-13	5.39	4.50
June-13	5.55	4.54
July-13	5.51	4.29
August-13		4.13
September-13		4.09
October-13		4.06
November-13		3.89
December-13		4.13

Dissolved Organic Carbon (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
January-14		4.62
February-14		4.56
March-14		4.60
April-14		4.83
May-14		4.90
June-14		4.75
July-14		4.76
August-14		4.15
September-14		5.12
October-14		4.59
November-14		
December-14		
January-15		3.46
February-15		3.87

Date	Alkalinity (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
January-02	111.44	
February-02	112.90	
March-02	112.44	
April-02	95.27	
May-02	101.50	
June-02	101.50	
July-02	90.77	
August-02	88.56	
September-02	94.52	
October-02	102.00	
November-02	96.00	
December-02	102.00	
January-03	109.00	
February-03	107.50	
March-03	112.00	
April-03	116.00	
May-03	116.00	
June-03	105.50	99.00
July-03	93.50	110.00
August-03	91.00	100.00
September-03	90.00	84.00
October-03	95.00	102.50
November-03	96.00	101.60
December-03	98.70	104.00
January-04	104.00	107.00
February-04	105.00	107.43
March-04	108.20	100.00
April-04	109.80	108.00
May-04	107.00	107.00
June-04	102.50	102.00
July-04	90.00	96.00
August-04	87.00	94.00
September-04	88.50	98.00
October-04	100.00	125.00
November-04	96.96	

Alkalinity (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
December-04	98.48	108.00
January-05	102.00	102.00
February-05	115.00	96.00
March-05	116.00	103.00
April-05	121.00	99.00
May-05	121.00	99.00
June-05	102.00	99.96
July-05	96.96	99.99
August-05	92.92	98.98
September-05	86.86	93.93
October-05	91.54	108.96
November-05	94.52	103.48
December-05	107.46	104.48
January-06	108.46	109.45
February-06	108.46	110.44
March-06	111.44	111.44
April-06	108.00	111.10
May-06	100.00	110.00
June-06	100.99	116.00
July-06	85.57	114.92
August-06	82.60	110.40
September-06	80.00	104.00
October-06	85.00	97.00
November-06	94.00	107.00
December-06	100.00	107.00
January-07	100.00	108.00
February-07	101.00	108.00
March-07	108.00	111.00
April-07	110.00	110.00
May-07	94.00	111.00
June-07	100.00	113.00
July-07	98.00	89.00
August-07	108.00	94.00
September-07	107.00	87.00
October-07	108.46	95.02
November-07	108.05	100.00

Date	Alkalinity (mg/L) Data Provided by City of Denton Lewisville Lake	Ray Roberts Lake
December-07	111.00	103.48
January-08	107.37	97.01
February-08	118.20	106.80
March-08	119.77	97.85
April-08	102.67	105.00
May-08	94.24	105.00
June-08	115.00	108.00
July-08	94.80	110.70
August-08	84.00	114.00
September-08	89.20	112.16
October-08	87.40	105.60
November-08	87.35	106.00
December-08	104.20	95.53
January-09	97.00	103.00
February-09	110.60	111.00
March-09	108.80	112.87
April-09	106.80	121.90
May-09	106.80	121.90
June-09	90.27	88.19
July-09	88.20	
August-09	89.28	117.00
September-09	86.50	112.03
October-09	89.06	104.42
November-09	79.59	88.91
December-09	97.50	100.40
January-10	97.50	100.40
February-10	105.20	105.70
March-10	96.30	100.92
April-10	109.41	98.85
May-10	114.13	99.05
June-10	80.93	94.21
July-10	86.60	114.78
August-10	75.20	117.61
September-10	75.00	95.22
October-10	84.60	92.42
November-10	87.00	97.00

Alkalinity (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
December-10	96.06	97.72
January-11	99.64	100.83
February-11	101.00	104.00
March-11	101.00	91.00
April-11	102.70	92.40
May-11	104.00	95.60
June-11	86.40	104.50
July-11	79.00	108.50
August-11	78.00	113.80
September-11	77.70	108.50
October-11	83.40	105.60
November-11	92.80	106.60
December-11	92.80	104.80
January-12	95.10	104.60
February-12	67.80	99.80
March-12	88.10	101.50
April-12	90.10	101.60
May-12	89.10	103.80
June-12	86.60	105.80
July-12	101.10	80.50
August-12	75.60	100.00
September-12	83.70	98.50
October-12	84.30	102.50
November-12	82.19	104.14
December-12	95.70	104.70
January-13	97.50	108.70
February-13	97.50	102.80
March-13	96.00	103.60
April-13	107.60	110.20
May-13	105.00	112.40
June-13	100.80	107.90
July-13	85.20	104.40
August-13	76.30	99.10
September-13	72.00	99.00
October-13	78.20	105.50
November-13	88.10	102.40

Alkalinity (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
December-13	92.20	101.30
January-14	92.30	101.80
February-14	102.70	104.20
March-14	103.10	104.40
April-14	104.00	105.00
May-14	111.10	107.90
June-14	85.50	112.50
July-14	83.20	108.90
August-14	81.80	102.30
September-14	82.30	97.60
October-14	81.20	99.40
November-14	81.90	97.90
December-14	92.20	97.60
January-15	95.60	98.80
February-15	100.90	97.20

Alkalinity (mg/L) Data Provided by City of Denton (MOR)		
Date	Lewisville Lake	Ray Roberts Lake
February-13	97.52	102.76
April-13	107.62	110.21
June-13	100.80	107.88
August-13	76.29	99.12
October-13	78.25	105.51
February-14	102.68	104.18
April-14	103.96	104.99
June-14	85.49	112.50
August-14	81.81	102.27
October-14	81.15	99.36
December-14	92.23	97.65

Calcium (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	98.65	94.15
April-13	97.1	81.45
June-13	103.55	96.62
August-13	76.36	93.88
October-13	79.24	84.82
February-14	106.09	84.28
April-14	47.48	34.88
June-14	95.45	93.55
August-14	31.16	32.39
October-14	31.65	32.23
December-14	95.6	87.18

Hardness ($CaCO_3$) (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	118.12	112.35
April-13	116.9	98.97
June-13	122.51	113.62
August-13	95.68	113.01
October-13	98.43	102.37
February-14	126.05	101.81
April-14	140.34	105.05
June-14	117.66	112.5
August-14	96.54	97.35
October-14	98.76	97.73
December-14	115.17	104.32

Iron (Fe) (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	0.24	1.098
April-13	0.422	0.198
June-13	0.231	0.153
August-13	0.113	0.175
October-13	0.439	0.411
February-14	0.3548	0.1705
April-14	0.5434	0.1168
June-14	0.1838	0.6754
August-14	0.1245	0.0554
October-14	0.4004	0.0527
December-14	0.2638	0.3996

Manganese (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	0.033	0.132
April-13	0.054	0.005
June-13	0.032	0.162
August-13	0.03	0.023
October-13	0.046	0.026
February-14	0.0284	0.0043
April-14	0.0193	0.0034
June-14	0.0265	0.0449
August-14	0.0191	0.0051
October-14	0.0403	0.0098
December-14	0.0456	0.0214

Ammonia (NH_3) (mg/L) Data Provided by City of Denton		
Date	Lewisville Lake	Ray Roberts Lake
February-13	<0.10	<0.10
April-13	<0.10	<0.10
June-13	<0.10	<0.10
August-13	<0.10	<0.10
October-13	<0.10	<0.10
February-14	<0.10	<0.10
April-14	<0.10	<0.10
June-14	<0.10	<0.10
August-14	<0.10	<0.10
October-14	<0.10	<0.10
December-14	<0.10	<0.10

APPENDIX C: CHEMICAL DEMAND TESTING

CONTENTS:

- City of Denton Chemical Demand Testing Plan for Zebra Mussel Management
- Results of Chemical Demand Testing Conducted by Dr. Dean Gregory
- Carus Laboratory Report
- Chemical Demand Testing Results and Conclusions

CITY OF DENTON CHEMICAL DEMAND TESTING PLAN FOR ZEBRA MUSSEL MANAGEMENT

- Sampling and Testing Plan
- Analysis and Summary of Results
- Quality Assurance and Quality Control Plan

As part of the Manual for the Control, Operation and Maintenance of Zebra Mussels (Manual), the City of Denton (COD) leadership reviewed chemical alternatives for zebra mussel management and selected a short-list of the most feasible molluscicides (i.e. chemicals toxic to mollusks) to further evaluate for implementation in the Lake Lewisville Water Treatment Plant (LLWTP) and Ray Roberts Water Treatment Plant (RRWTP) raw water systems. However, the required residuals and doses found in literature for managing zebra mussels are generally based upon the water quality in the Great Lakes region and do not account for the high source water total organic carbon (TOC) concentrations and long warm water seasons characteristic of North Texas. In order to provide more accurate estimations of chemical doses for preventing zebra mussel veliger settlement, chemical demand testing was planned. The preliminary results from demand testing recently performed by Dallas Water Utilities (DWU) with their five source waters using chlorine dioxide, permanganate, chloramines, ozone and a polyquaternary ammonium compound (Bulab 6002) were also considered in selecting chemicals to test in COD source waters. For example, as ozone demand testing completed by DWU concluded that an ozone residual cannot be maintained through the raw water pipelines at practical doses (i.e. below 8 mg/L), ozone was not further considered by COD. COD selected three chemical oxidants—chlorine dioxide, permanganate, and monochloramine—and one polyquaternary ammonium product (Bulab) for demand testing.

The objective of this testing plan was to develop a more accurate estimate of the expected chemical demand for the short-listed chemicals under consideration for both COD source waters.

SAMPLING AND TESTING PLAN

Dr. Dean Gregory (Denver, CO) performed bench-scale chemical demand tests on both of COD's raw source waters. Dr. Gregory shipped sample kits to the addresses designated in **Table C-1**. Sampling kits included sample containers and sampling instructions. COD staff collected the samples following Dr. Gregory's instructions and shipped the samples back to Dr. Gregory overnight at the address provided in the sample kit instructions. An initial round of sampling (Phase I) was conducted by plant staff on April 21st, 2015 using sampling ktis provided by Dr. Gregory, and a second round of sampling (Phase II) was conducted June 10th, 2015.

Table C-1: Shipping Addresses for Sample Kits

Shipping Address	Number of Sample Kits
Brian Smith Lake Lewisville WTP 1701-B. Spencer Road Denton, TX 76205 940-349-7627	1
David Clark Ray Roberts WTP 9401 Lake Ray Roberts Dam Rd Aubrey, TX 76227 940-349-7522	1

The water sources outlined in Table C-2 were sampled at the locations shown by COD staff using the kits provided by Dr. Dean Gregory. High turbidity events (e.g. storms) were avoided to the extent possible when selecting dates for sampling.

Table C-2: Source Waters to be Sampled

Source Water	Location	Sample Volume[1]	Collected & Shipped By	Shipped To
Lewisville Lake	LLWTP Intake	~ 20 L	COD Staff	Dr. Dean Gregory
Ray Roberts Lake	RRWTP Intake	~ 20 L		

1 – Sample kits will be provided by Dr. Dean Gregory

Dr. Gregory performed bench-scale chemical demand tests on the source waters listed in Table C-2. Dr. Gregory measured pH, alkalinity, turbidity, iron (total and dissolved), total organic carbon (TOC), dissolved organic carbon (DOC), manganese (total and dissolved), oxidation-reduction potential (ORP), and ammonia of each source water at the time of testing. The results of the testing provided an estimate of the chemical demand based upon the average detention times outlined in Table C-3. ARCADIS and Dr. Gregory considered regulatory limits associated with each chemical (e.g. chlorite formation by chlorine dioxide) to aid in determining the appropriate testing doses.

Table C-3: Source Water Detention Times

Source Water	Begin Location	End Location	Detention Time (Hrs) at Average Flow
Lewisville Lake	LLWTP Intake	LLWTP	4.8
Ray Roberts Lake	RRWTP Intake	RRWTP	0.9

PHASE I TESTING DETAILS

Samples from both sources were collected for Phase I testing on April 21st, 2015. Table C-4 outlines the testing procedures for each molluscicide tested during Phase I testing. All experiments were conducted at the temperature at which the samples were collected (approximately 18°C). For both samples, demand/decay testing was conducted using four chemical oxidants—chlorine dioxide, potassium permanganate and monochloramine—and one polyquaternary ammonium product (Bulab).

Table C-4: Source Water Chemical Demand and Decay Test Details – Phase I

Analysis	Doses – Lewisville Lake	Doses – Ray Roberts Lake	Temperature (°C)
Chlorine Dioxide Demand/Decay	1.5 mg/L	1.5, 1.0 and 0.5 mg/L	18°C
Potassium Permanganate Demand/Decay	2.0, 1.5, 1.0 and 0.5 mg/L	0.75, 0.50 and 0.35 mg/L	
Sodium Permanganate Demand/Decay	Calculated based upon potassium permanganate testing		
Monochloramine Demand/Decay	0.5 and 0.3 mg/L	0.5 and 0.3 mg/L	
Bulab Active Polyquat	2.0 and 1.0 mg/L	1.0 and 0.5 mg/L	
Basic Raw Water Quality (TOC/DOC, Turbidity, pH, Alkalinity, Fe/Mn, ammonia)			

Dr. Gregory prepared stock solutions and measured chemical residuals following the procedures outlined below.

- **Potassium permanganate.** A 5000 mg/L stock solution (as $KMnO_4$) was prepared by dissolving reagent-grade potassium permanganate crystals in de-ionized water. Permanganate stock solutions are stable for months when stored in a refrigerator. The concentration was confirmed using the spectrophotometric method (Standard Methods 4500-$KMnO_4$ B). This method was also used to measure $KMnO_4$ residuals during the demand/decay experiments. All $KMnO_4$ residual samples were filtered through a 0.45 µm microfiltration membrane prior to being analyzed.
- **Chlorine dioxide.** A commercially-available, pure 0.3 percent (3000 mg/L) aqueous chlorine dioxide stock solution was used. The concentration of the stock solution was verified using the amperometric titration method (Standard Methods 4500-ClO_2 E). For the demand/decay experiments, the Lissamine Green B method was used to measure ClO_2 residuals (USEPA-approved Method 327.0).
- **Chloramines.** A commercially-available, 6.25 percent sodium hypochlorite solution (bleach) was used as the chlorine source. The free chlorine concentration of the stock solution and the monochloramine (i.e. total chlorine) residuals were measured using the DPD colorimetric method (Standard Methods 4500-Cl G). For the ammonia stock solution, a 5000 mg/L (as $NH4^+$) ammonium chloride stock solution was prepared. During the monochloramine demand/decay experiments, ammonia, when necessary, was dosed immediately prior to the free chlorine injection.
- **Bulab.** A 500-mL sample of Bulab 6002 and the Taylor Quaternary Ammonium Compound / Polyquat Direct Neutralization test kit (# K-9065) was provided by Buckman North America.

PHASE II TESTING DETAILS

Samples were collected for Phase II testing on June 10th, 2015 for both sources. Table C-5 shows that all experiments were conducted at 30°C to simulate high summer water temperatures in the COD source waters. Demand/decay testing was repeated using two of the oxidants tested in Phase I — chlorine dioxide and potassium permanganate. Materials and methods were the same as described under the Phase I procedures.

Table C-5: Source Water Chemical Demand and Decay Test Details – Phase II

Analysis	Doses – Lewisville Lake	Doses – Ray Roberts Lake	Temperature (°C)
Chlorine Dioxide Demand/Decay	1.5 mg/L	1.5 and 1.0 mg/L	30°C
Permanganate Demand/Decay	6.0, 5.0, 3.0 and 2.0 mg/L	2.0, 1.5 and1.0 mg/L	
Basic Raw Water Quality (TOC/DOC, Turbidity, pH, Alkalinity, Fe/Mn, ammonia)			

ANALYSIS AND SUMMARY OF RESULTS

ARCADIS provided data analysis and review for all tests performed. Dr. Gregory compiled the testing results in excel format including graphs of the chemical demand and decay curves. ARCADIS summarized the testing plan and results of the testing, including recommendations for chemical dosages for each source water to be used in cost estimations in the Manual. ARCADIS also compared historical water quality data to the water quality data for the samples collected; and included a summary of the permanganate testing performed by Carus Corporation separately. The Carus testing provided additional quality control with duplicate oxidant demand data for permanganate, and provided a baseline for determining the doses to be tested in this effort.

QUALITY ASSURANCE AND QUALITY CONTROL (QA/QC) PLAN

Bench testing equipment was calibrated in accordance with the manufacturer's instruction and calibration procedures. Dr. Gregory provided sampling instructions with sampling kits to ensure all samples were collected and shipped properly to minimize changes in water quality during shipping. The QA/QC protocols outlined in the methods shown in Table C-6 were followed.

Table C-6: Testing Methods

Analysis	Method
Oxidant Demand/Decay Testing	Standard Methods for the Examination of Water and Wastewater
Active Polyquat Testing	Taylor Kit K-9065

RESULTS OF CHEMICAL DEMAND TESTING CONDUCTED BY DR. DEAN GREGORY

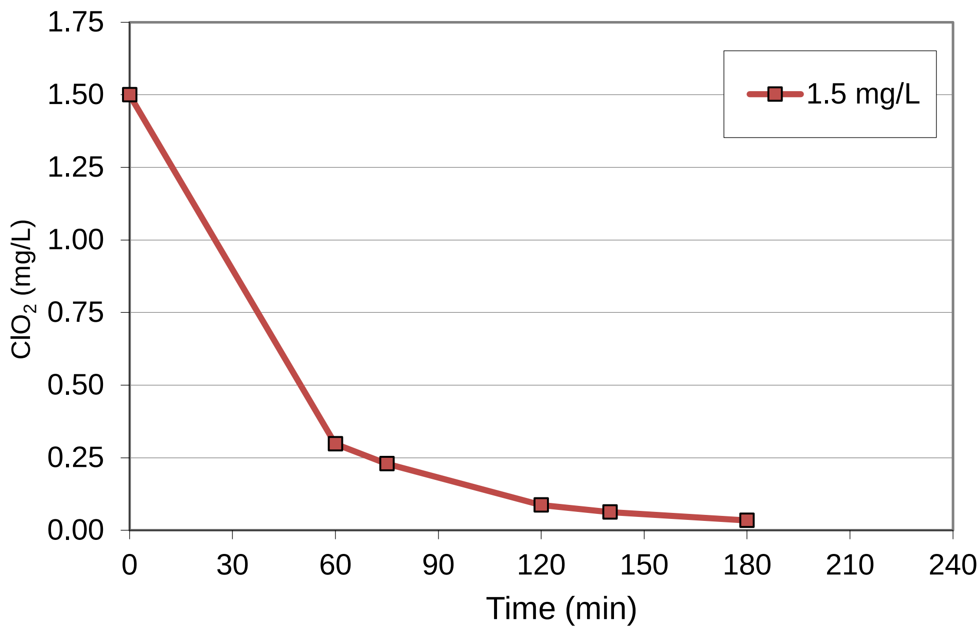
- Lewisville Lake Intake
  - Phase I – Collected April 21, 2015
  - Phase II – Collected June 10, 2015
- Ray Roberts Lake Intake
  - Phase I – Collected April 21, 2015
  - Phase II – Collected June 10, 2015

Lewisville Lake Intake
Phase I Demand Testing
Water Quality

Constituent	Raw Water Quality
TOC (mg/L)	6.05
DOC (mg/L)	5.88
pH (std. units)	7.99
Alkalinity (mg/L as $CaCO_3$)	103
Turbidity (NTU)	11.1
Mn_{tot} (µg/L)	54
Mn^{2+} (µg/L)	12
Fe_{tot} (mg/L)	0.08
Fe^{2+} (mg/L)	0
ORP (mV)	255
Ammonia (mg/L)	0.08

Lewisville Lake Intake
Phase I Demand Testing
Chlorine Dioxide

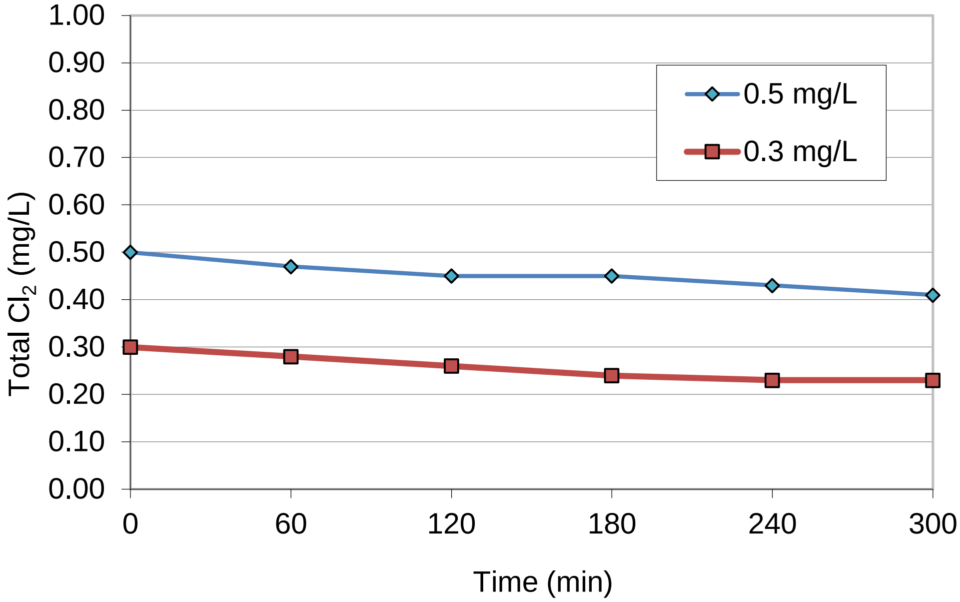
Blanks		1.156
Time	**abs_{614}**	**ClO_2**
(min)		(mg/L)
0		1.50
60	0.999	.30
75	1.035	.23
120	1.110	.09
140	1.123	.06
180	1.138	.03



Chlorine dioxide demand/decay in Lewisville Lake raw water. T = 19 deg. C, pH = 7.91.

Lewisville Lake Intake
Phase I Demand Testing
Chloramines

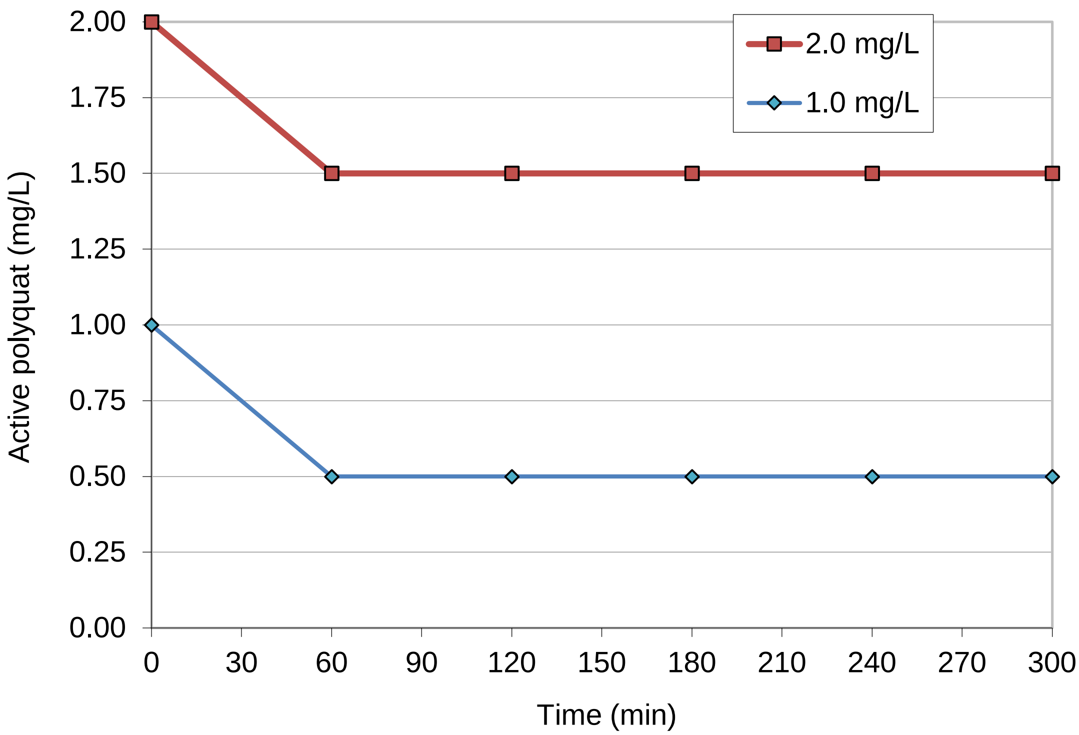
Time (min)	Total Cl_2 (mg/L)	Time (min)	Total Cl_2 (mg/L)
0	0.50	0	0.30
60	0.47	60	0.28
120	0.45	120	0.26
180	0.45	180	0.24
240	0.43	240	0.23
300	0.41	300	0.23



Monochloramine demand/decay in Lewisville Lake raw water. T = 19 deg. C, pH = 7.99. Ammonia added for higher Cl2 dose only.

Lewisville Lake Intake
Phase I Demand Testing
Bulab

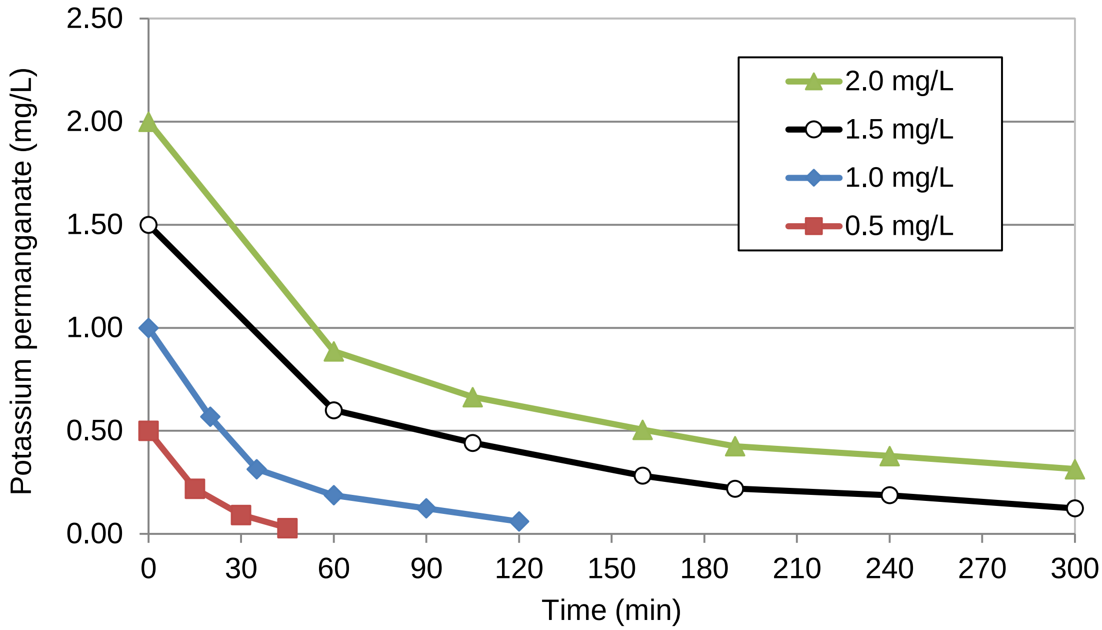
Time	polyquat	Time	polyquat
(min)	(mg/L)	(min)	(mg/L)
0	1.00	0	2.00
60	0.50	60	1.50
120	0.50	120	1.50
180	0.50	180	1.50
240	0.50	240	1.50
300	0.50	300	1.50



Polyquat demand/decay in Lewisville Lake water. T = 19 deg. C, pH = 7.99.

Lewisville Lake Intake
Phase I Demand Testing
Potassium Permanganate

Time (min)	abs_{525}	$KMnO_4$ (mg/L)	Time (min)	abs_{525}	$KMnO_4$ (mg/L)	Time (min)	abs_{525}	$KMnO_4$ (mg/L)	abs_{525}	$KMnO_4$ (mg/L)
0		1.00	0		0.50	0		2.00		1.50
20	0.018	0.57	15	0.007	0.22	60	0.028	0.89	0.019	0.60
35	0.010	0.31	30	0.003	0.09	105	0.021	0.66	0.014	0.44
60	0.006	0.19	45	0.001	0.03	160	0.016	0.51	0.009	0.28
90	0.004	0.12				190	0.014	0.43	0.007	0.22
120	0.002	0.06				240	0.012	0.38	0.006	0.19
						300	0.010	0.31	0.004	0.12

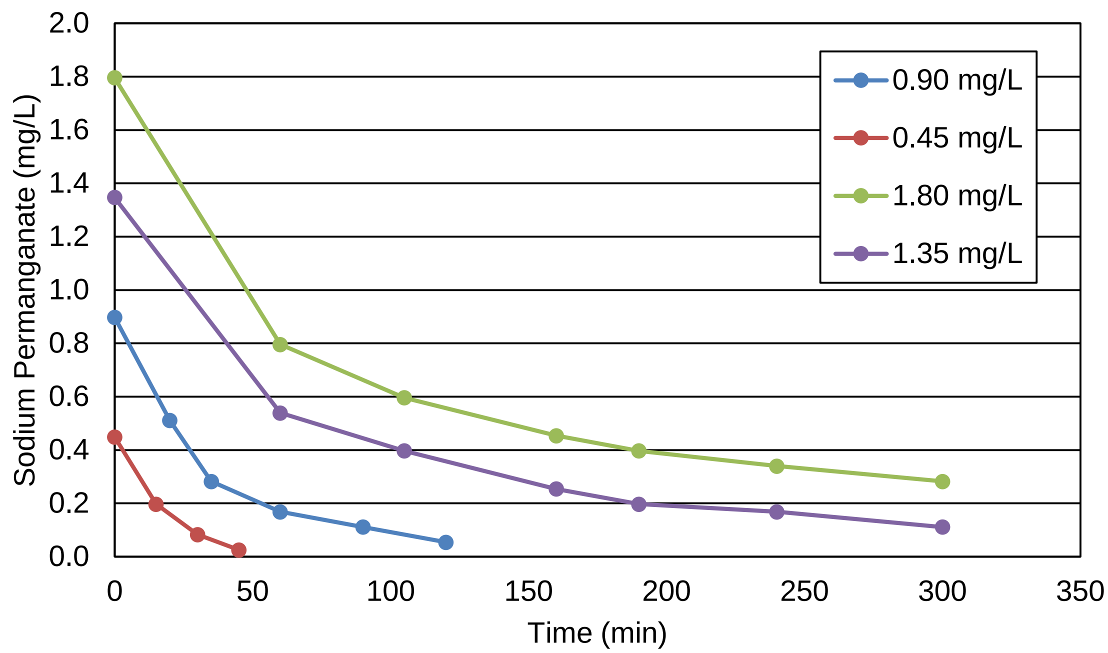


$KMnO_4$ demand/decay in Lewisville Lake raw water. T = 19°C, pH = 7.94.

Lewisville Lake Intake
Phase I Demand Testing
Sodium Permanganate

Permanganate was tested using potassium permanganate. Sodium permanganate would require an equivalent weight of permanganate (the active ingredient). Using molar conversions, the sodium permanganate demand can be estimated as shown below.

Time	abs_{525}	$NaMnO_4$	Time	abs_{525}	$NaMnO_4$	Time	abs_{525}	$NaMnO_4$	abs_{525}	$NaMnO_4$
(min)		(mg/L)	(min)		(mg/L)	(min)		(mg/L)		(mg/L)
0		0.90	0		0.45	0		1.80		1.35
20	0.018	0.51	15	0.007	0.20	60	0.028	0.80	0.019	0.54
35	0.010	0.28	30	0.003	0.08	105	0.021	0.60	0.014	0.40
60	0.006	0.17	45	0.001	0.03	160	0.016	0.45	0.009	0.25
90	0.004	0.11				190	0.014	0.40	0.007	0.20
120	0.002	0.05				240	0.012	0.34	0.006	0.17
						300	0.010	0.28	0.004	0.11



$NaMnO_4$ demand/decay in Lewisville Lake raw water. T=19° C, pH=7.94

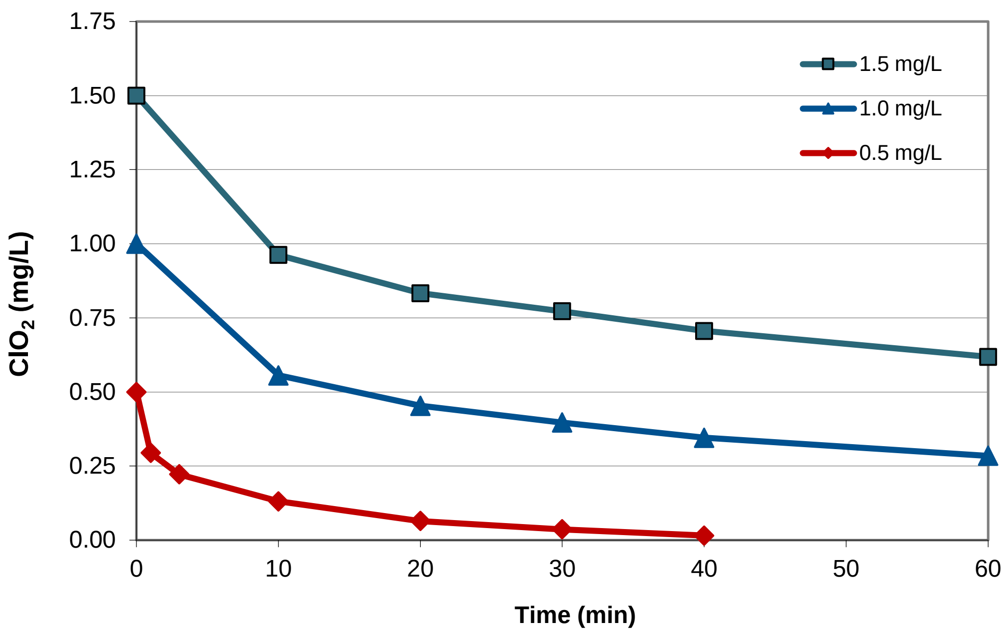
Ray Roberts Intake

Phase I Demand Testing
Water Quality

Constituent	Raw Water Quality
TOC (mg/L)	4.65
DOC (mg/L)	4.51
pH (std. units)	7.77
Alkalinity (mg/L as $CaCO_3$)	89
Turbidity (NTU)	8.7
Mn_{tot} (µg/L)	33
Mn^{2+} (µg/L)	6
Fe_{tot} (mg/L)	0.09
Fe^{2+} (mg/L)	0
ORP (mV)	272
Ammonia (mg/L)	0.12

Ray Roberts Intake
Phase I Demand Testing
Chlorine Dioxide

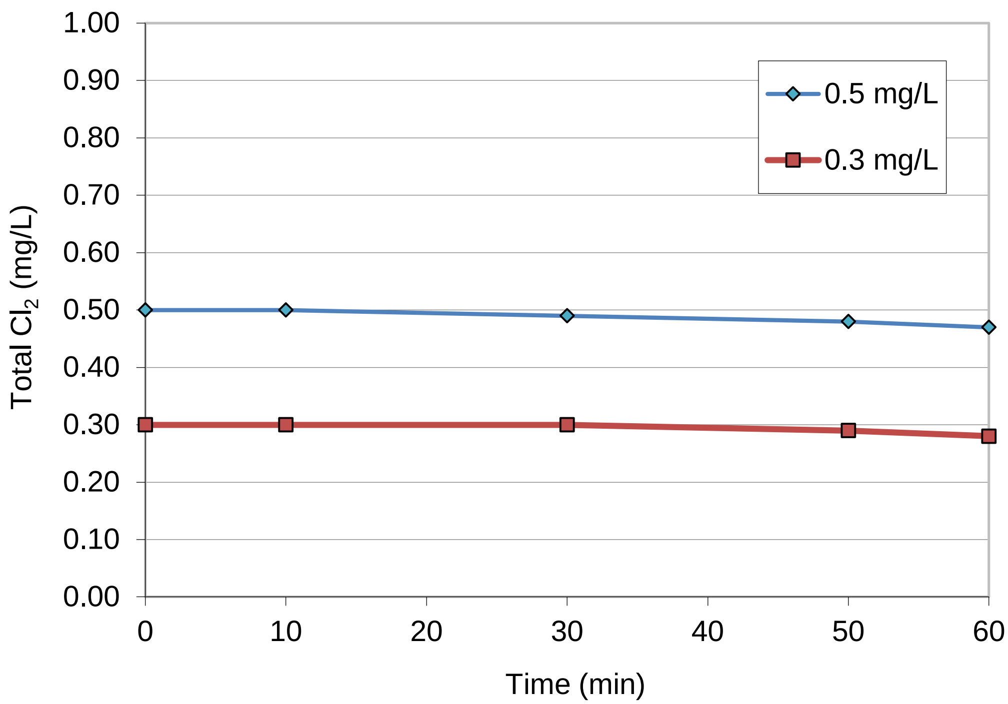
	abs_{614}	ClO_2	abs_{614}	ClO_2	Time	abs_{614}	ClO_2
		(mg/L)		(mg/L)	(min)		(mg/L)
0		1.50		1.00	0		0.50
10	0.633	0.96	0.847	0.56	1	0.985	0.29
20	0.701	0.83	0.901	0.45	3	1.023	0.22
30	0.733	0.77	0.931	0.40	10	1.071	0.13
40	0.768	0.71	0.958	0.35	20	1.106	0.06
60	0.814	0.62	0.990	0.28	30	1.121	0.04
					40	1.132	0.02



Chlorine dioxide demand/decay in Ray Roberts Lake raw water. T = 19 deg. C, pH = 7.75.

Ray Roberts Intake
Phase I Demand Testing
Chloramines

Time	Total Cl_2	Time	Total Cl_2
(min)	(mg/L)	(min)	(mg/L)
0	0.50	0	0.30
10	0.50	10	0.30
30	0.49	30	0.30
50	0.48	50	0.29
60	0.47	60	0.28

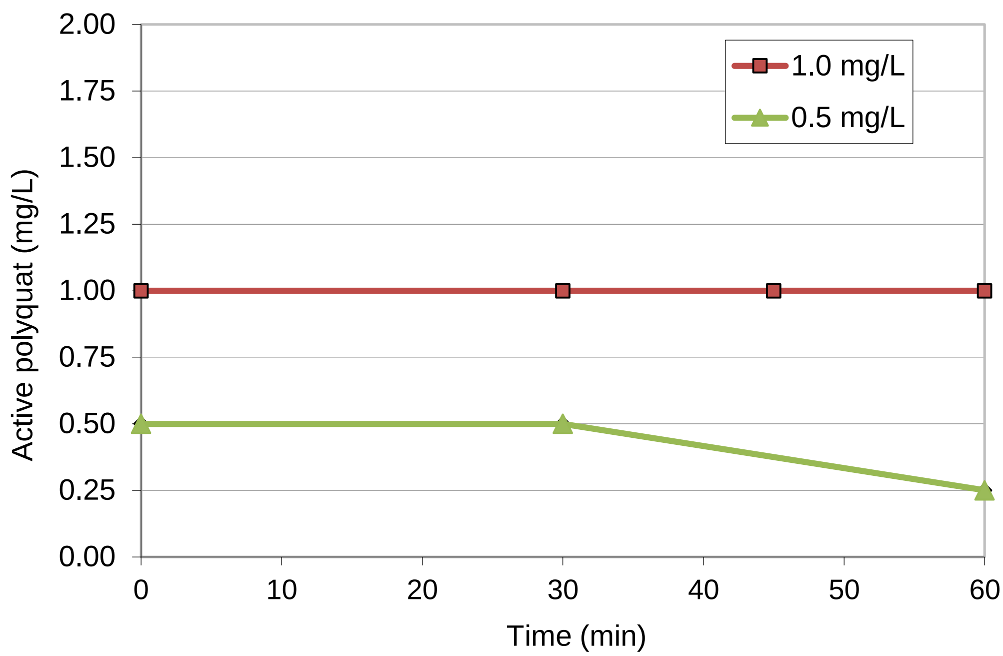


Monochloramine demand/decay in Ray Robets Lake raw water. T = 19 deg. C, pH = 7.74. Ammonia added for higher Cl_2 dose only.

Ray Roberts Intake
Phase I Demand Testing
Bulab

Time	polyquat	Time	polyquat
(min)	(mg/L)	(min)	(mg/L)
0	0.50	0	1.00
30	0.50	30	1.00
60	0.25	45	1.00
		60	1.00

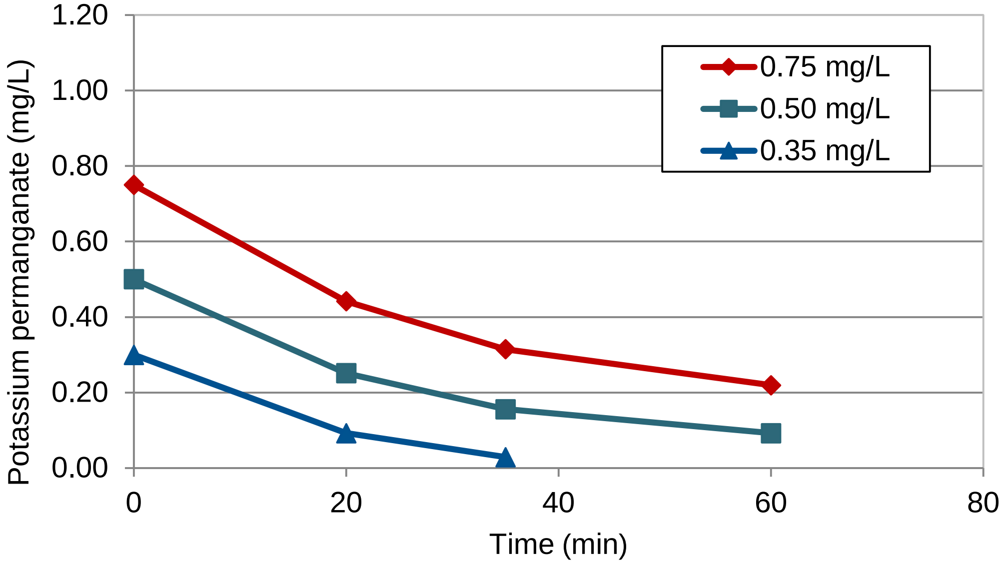
*values in red are estimates



Polyquat demand/decay in Ray Roberts Lake raw water.
T = 19 deg. C, pH = 7.77.

Ray Roberts Intake
Phase I Demand Testing
Potassium Permanganate

Time	abs_{525}	$KMnO_4$	abs_{525}	$KMnO_4$	abs_{525}	$KMnO_4$
(min)		(mg/L)		(mg/L)		(mg/L)
0		0.50		0.30		0.75
20	0.008	0.25	0.003	0.09	0.014	0.44
35	0.005	0.16	0.001	0.03	0.010	0.31
60	0.003	0.09			0.007	0.22

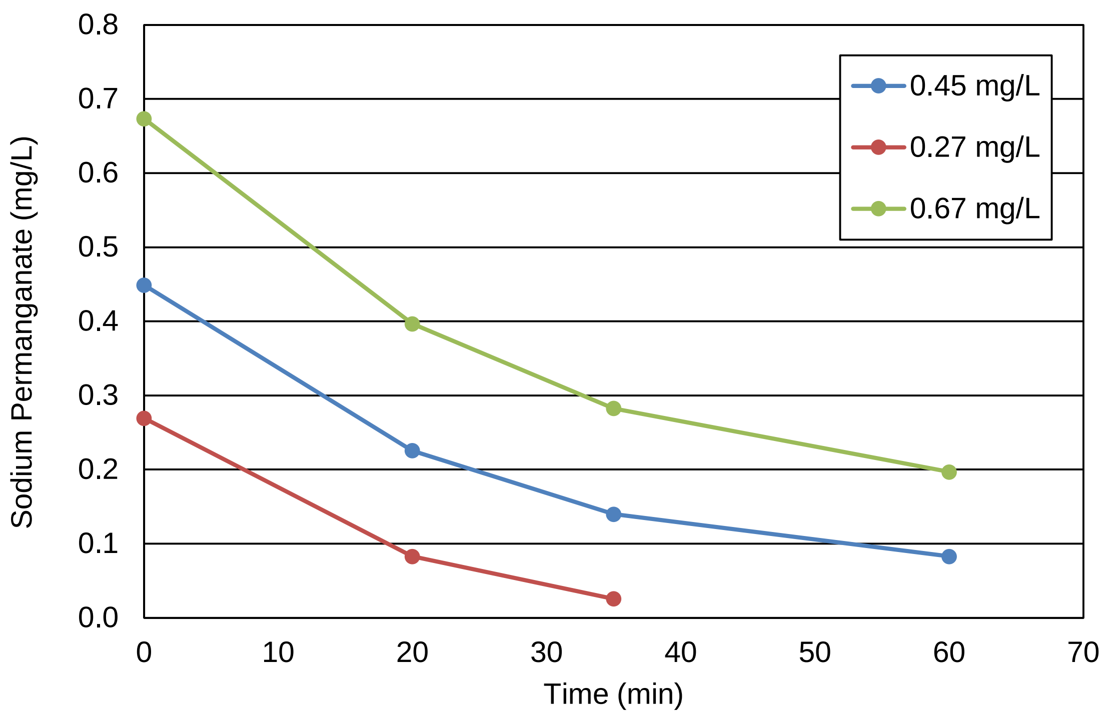


$KMnO_4$ demand/decay in Ray Roberts Lake raw water. T = 19°C, pH = 7.74.

Ray Roberts Intake
Phase I Demand Testing
Sodium Permanganate

Permanganate was tested using potassium permanganate. Sodium permanganate would require an equivalent weight of permanganate (the active ingredient). Using molar conversions, the sodium permanganate demand can be estimated as shown below.

Time (min)	abs_{525}	$NaMnO_4$ (mg/L)	Time (min)	abs_{525}	$NaMnO_4$ (mg/L)	Time (min)	abs_{525}	$NaMnO_4$ (mg/L)
0		0.45	0		0.27	0		0.67
20	0.008	0.23	20	0.003	0.08	20	0.014	0.40
35	0.005	0.14	35	0.001	0.03	35	0.010	0.28
60	0.003	0.08				60	0.007	0.20



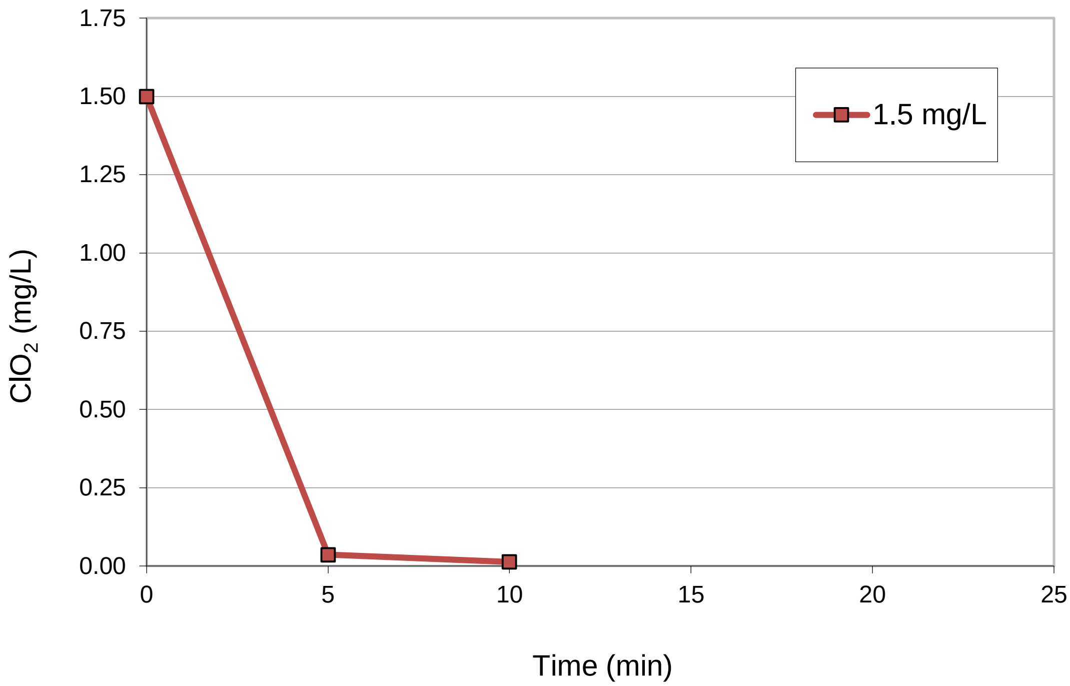
$NaMnO_4$ demand/decay in Ray Roberts Lake raw water. T=19° C, pH=7.74

Lewisville Lake Intake
Phase II Demand Testing
Water Quality

Constituent	Raw Water Quality
TOC (mg/L)	6.39
DOC (mg/L)	6.17
pH (std. units)	8.18
Alkalinity (mg/L as $CaCO_3$)	92
Turbidity (NTU)	9.4
Mn_{tot} (µg/L)	21
Mn^{2+} (µg/L)	6
Fe_{tot} (mg/L)	0.02
Fe^{2+} (mg/L)	0
ORP (mV)	185
Ammonia (mg/L)	0.26

Lewisville Lake Intake
Phase II Demand Testing
Chlorine Dioxide

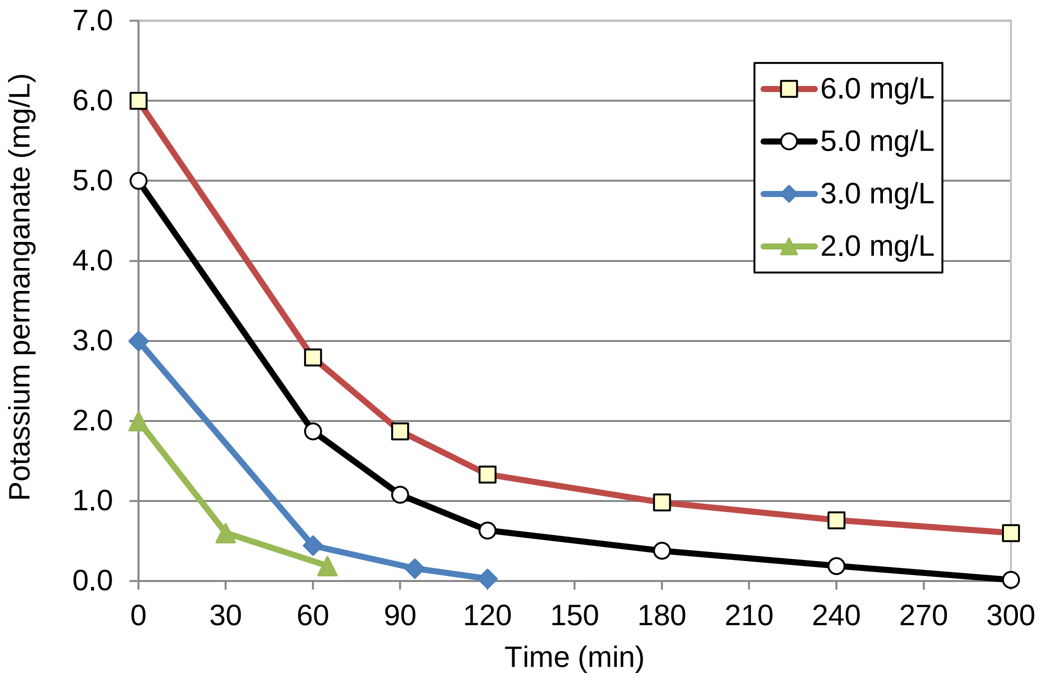
Blank	1.190	
	abs_{614}	**ClO_2**
		(mg/L)
0		1.50
5	1.171	0.04
10	1.183	0.01



Chlorine dioxide demand/decay in Lewisville Lake raw water.
T = 30 deg. C, pH = 8.12.

Lewisville Lake Intake
Phase II Demand Testing
Potassium Permanganate

Time	abs_{525}	$KMnO_4$	Time	abs_{525}	$KMnO_4$	Time	abs_{525}	$KMnO_4$	abs_{525}	$KMnO_4$
(min)		(mg/L)	(min)		(mg/L)	(min)		(mg/L)		(mg/L)
0		3.00	0		2.00	0		5.00		6.00
60	0.014	0.44	30	0.019	0.60	60	0.059	1.87	0.088	2.79
95	0.005	0.16	65	0.006	0.19	90	0.034	1.08	0.059	1.87
120	0.001	0.03				120	0.020	0.63	0.042	1.33
						180	0.012	0.38	0.031	0.98
						240	0.006	0.19	0.024	0.76
						300	0.001	0.01	0.019	0.60

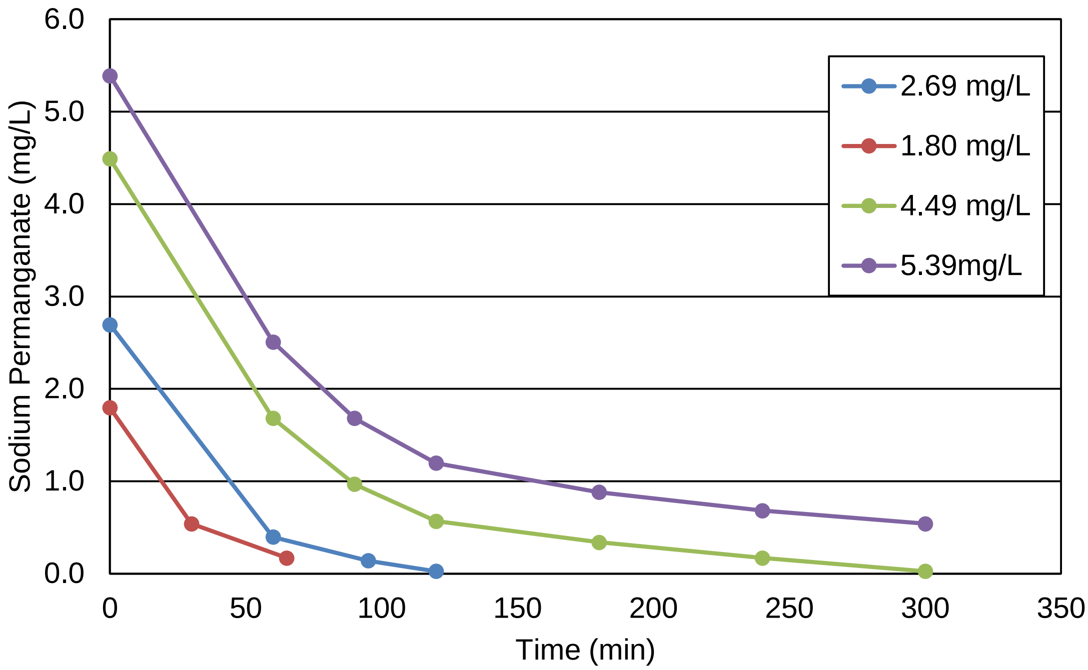


$KMnO_4$ demand/decay in Lewisville Lake raw water. T = 30°C, pH = 8.18.

Lewisville Lake Intake
Phase II Demand Testing
Sodium Permanganate

Permanganate was tested using potassium permanganate. Sodium permanganate would require an equivalent weight of permanganate (the active ingredient). Using molar conversions, the sodium permanganate demand can be estimated as shown below.

Time	abs_{525}	$NaMnO_4$	Time	abs_{525}	$NaMnO_4$	Time	abs_{525}	$NaMnO_4$	abs_{525}	$NaMnO_4$
(min)		(mg/L)	(min)		(mg/L)	(min)		(mg/L)		(mg/L)
0		0.90	0		0.45	0		1.80		1.35
60	0.014	0.40	30	0.019	0.54	60	0.059	1.68	0.088	2.51
95	0.005	0.14	65	0.006	0.17	90	0.034	0.97	0.059	1.68
120	0.001	0.03				120	0.020	0.57	0.042	1.20
						180	0.012	0.34	0.031	0.88
						240	0.006	0.17	0.024	0.68
						300	0.001	0.03	0.019	0.54



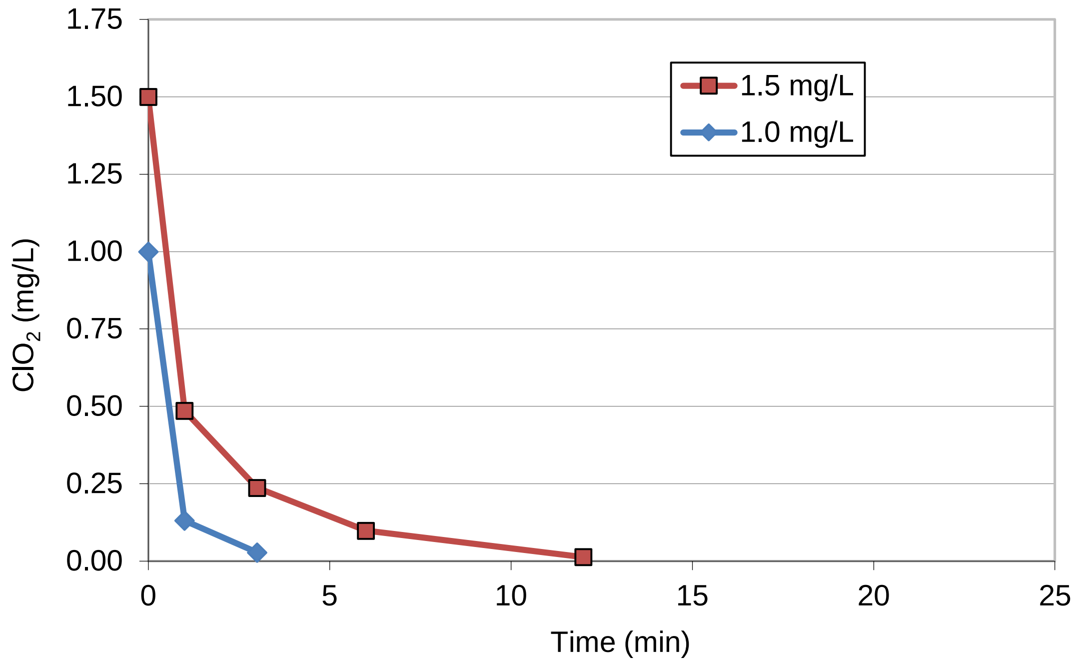
$NaMnO_4$ demand/decay in Lewisville Lake raw water. T=30° C, pH=8.18

Ray Roberts Intake
Phase II Demand Testing
Water Quality

Constituent	Raw Water Quality
TOC (mg/L)	5.22
DOC (mg/L)	5.11
pH (std. units)	7.48
Alkalinity (mg/L as $CaCO_3$)	81
Turbidity (NTU)	33
Mn_{tot} (µg/L)	61
Mn^{2+} (µg/L)	27
Fe_{tot} (mg/L)	0.74
Fe^{2+} (mg/L)	0.02
ORP (mV)	209
Ammonia (mg/L)	0.05

Ray Roberts Intake
Phase II Demand Testing
Chlorine Dioxide

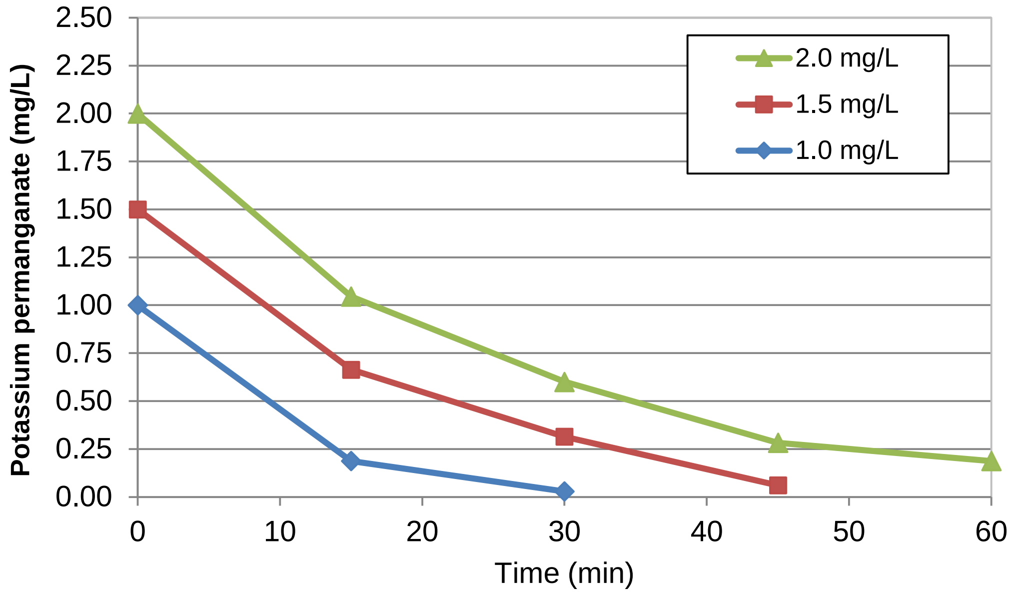
Blanks	1.237			
	abs614	**ClO2**	**abs614**	**ClO2**
		(mg/L)		(mg/L)
0		1.50		1.00
1	0.981	0.49	1.168	0.13
3	1.112	0.24	1.222	0.03
6	1.185	0.10		
12	1.230	0.01		



Chlorine dioxide demand/decay in Ray Roberts Lake raw water. T = 30 deg. C, pH = 7.43.

Ray Roberts Intake
Phase II Demand Testing
Potassium Permanganate

Time	abs_{525}	$KMnO_4$	abs_{525}	$KMnO_4$	abs_{525}	$KMnO_4$
(min)		(mg/L)		(mg/L)		(mg/L)
0		1.50		2.00		1.00
15	0.021	0.66	0.033	1.05	0.006	0.19
30	0.010	0.31	0.019	0.60	0.001	0.03
45	0.002	0.06	0.009	0.28		
60			0.006	0.19		

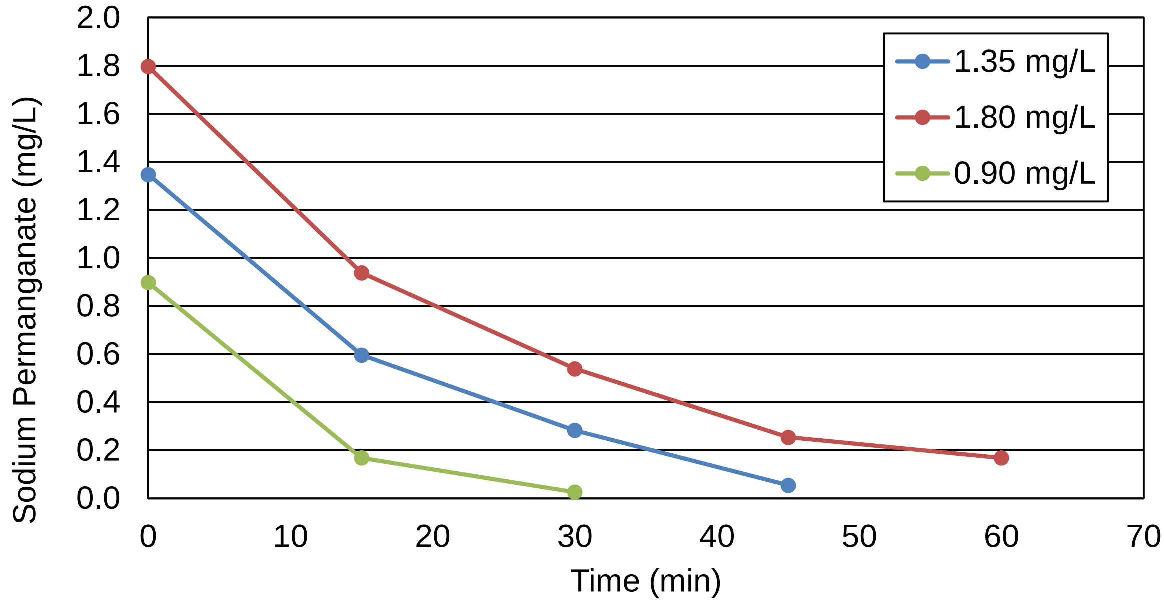


KMnO4 demand/decay in Ray Roberts Lake raw water. T = 30°C, pH = 7.44.

Ray Roberts Intake
Phase II Demand Testing
Sodium Permanganate

Permanganate was tested using potassium permanganate. Sodium permanganate would require an equivalent weight of permanganate (the active ingredient). Using molar conversions, the sodium permanganate demand can be estimated as shown below.

Time	abs_{525}	$NaMnO_4$	abs_{525}	$NaMnO_4$	abs_{525}	$NaMnO_4$
(min)		(mg/L)		(mg/L)		(mg/L)
0		1.35		1.80		0.90
15	0.021	0.60	0.033	0.94	0.006	0.17
30	0.010	0.28	0.019	0.54	0.001	0.03
45	0.002	0.05	0.009	0.25		
60			0.006	0.17		



NaMnO4 demand/decay in Ray Roberts Lake raw water. T=30° C, pH=7.74

CARUS LABORATORY REPORT

CARUS CORPORATION

Technical Service Report

17 December 2014

Firm: City of Denton
Lake Lewisville Water Treatment Plant
1701B Spencer Road
Denton, TX 76205

Writer: Darin Skutt
Product: CAIROX®
Application: Drinking Water
For: Demand Testing

Personnel Contacted: Ken Hurley & Randy Markham with City of Denton
Ashley Evans with Arcadis US

Purpose: Perform Jar Tests to determine the CAIROX® demand for the source waters used by the Lake Lewisville Water Treatment Plant.

Summary:

Carus Corporation was invited to the City of Denton Lake Lewisville Water Treatment Plant to perform jar testing to determine the permanganate demand of the raw water using CAIROX® for pre-treatment at the different facilities. The sources of raw water for the demand testing included Lake Lewisville and Lake Ray Roberts.

In water treatment plants, permanganate is added to the raw water intake to control a number of water treatment concerns. The permanganate demand test (PV)t is used to determine the amount of permanganate that is necessary to maintain a trace residual throughout the entire intake distribution piping. This information may be used to estimate annual usages, as well as, to help size appropriate feed and storage equipment.

Jar testing is typically used to determine potassium permanganate demand. It is important that the jar testing be conducted in a manner that simulates the conditions expected in the field and that the tests are conducted using fresh raw water samples. Additionally, it is important to conduct the jar test for a period of time that is consistent with the detention times expected between the intake and the final destination point.

Detention times for the demand tests conducted for Lake Lewisville WTP and the Lake Ray Roberts WTP were provided by Arcadis US. Detention times were calculated for each application point and were 3 to 5 hours for the Lake Lewisville Intake to the Lake Lewisville WTP and 1 hour for the Lake Ray Roberts Intake to the Ray Robert WTP.

Controlling Water Quality Issues with CAIROX® Potassium Permanganate:

Permanganate has been used for many years in both water & wastewater treatment. Permanganate is a strong oxidizer which can be used to destroy many organic compounds, as well as, oxidize iron, manganese, sulfide compounds, and other taste and odor producing substances. Problems associated with iron and manganese in drinking water prompted the U.S. EPA to set an aesthetic or Secondary Maximum Contaminant Level of 0.3 mg/L and 0.05 mg/L respectively. Iron and manganese above this level can cause water discoloration, staining of laundry and plumbing fixtures, incrustation of piping, clogging of home water softeners and increased turbidity. Elevated levels can also accelerate biological growths in distribution systems and, in general, aggravate color, taste, and odor problems.

The oxidations of reduced iron and manganese by permanganate ion are given by the following equations respectively:

$$3\,Fe^{2+} + MnO_4^{-} + 2\,H_2O \rightarrow MnO_2\downarrow + 3\,Fe^{3+}\downarrow + 4\,OH^{-}$$

$$3\,Mn^{2+} + 2\,MnO_4^{-} + 2\,H_2O \rightarrow 5\,MnO_2\downarrow + 4\,H^{+}$$

According to these equations, 0.71 parts of MnO_4^{-} is required to oxidize 1 part Fe^{+2} and 1.44 parts of MnO_4^{-} is required to oxidize 1 part Mn^{+2}. However, if organic matter is present, dosages higher than these stoichiometric values may be required in order to break the organic complex to expose the Fe^{+2} and Mn^{+2} for oxidation.

Algae have long been documented as a major culprit for producing tastes and odors in storage reservoirs and lakes. This algal activity varies from one water supply to another and from season to season. The major offenders include the blue-green algae (grassy odors), diatoms (aromatic odors), and the green motile algae (fishy odors). Combinations of various organisms can produce any number of peculiar tastes and odors.

Bacteria are another important biological cause of tastes and odors. They are very similar to algae because their metabolic processes produce compounds that can generate tastes and odors, even when present in the parts per billion ranges. Actinomycetes, a causative agent of tastes and odors, are sometimes classified as an aerobic bacteria or imperfect fungus. Actinomycetes produce geosmin. Actinomycetes grow quite rapidly in three to four weeks after a blue-green algae bloom, since they are important nutrients to its growth. Actinomycetes are also important for the decomposition of lignins. They grow on weeds and vegetation, bringing about the slow destruction of plant residues and giving rise to an ever-increasing, persistent taste and odor problem.

CAIROX® potassium permanganate is one of the most versatile and commonly used oxidants in drinking water treatment. Permanganate customers have reported that the fishy, grassy, septic, phenolic, sulfur and cucumber odors are easily controlled by permanganate. Earthy, musty, and some of the “flowery” type odors are more difficult to control using permanganate alone. The combination of permanganate with activated carbon has been reported to be used very successfully to produce an acceptable odor level when MIB and Geosmin are found in raw waters.

The main cause of THMs and haloacetic acids (HAAs) is chlorination of raw water that contains precursors, primarily humic and fulvic acids. The addition of CAIROX® as an alternate pretreatment oxidant is advisable to maintain an oxidizing environment in the raw water. It is used not only to control tastes, odors, iron and manganese but also to assist on the removal of THM and HAA precursors.

Results:

The permanganate demand testing was conducted using CAIROX® potassium permanganate.

Permanganate Stock Solution Preparation:

- 1% (10,000 mg/L) Stock Solution: Place 5 grams of CAIROX® potassium permanganate (KMnO4) into a 500 mL volumetric flask and add approximately 250 ml of distilled water. Agitate the solution to insure all the permanganate is dissolved. When complete, add the remaining distilled water to the proper volume (500 ml). Mix well. This will produce a 1% KMnO4 solution.
- Standard Solution (2000 mg/L): Pipette 20 mL of the 1% stock solution into a 100 ml volumetric flask and dilute with distilled water to volume (100 ml). Mix well.
- For jar testing, 1 ml of this solution added to 2000 ml of a raw water sample is equivalent to 1.0 mg/L CAIROX® potassium permanganate.

Flow Chart 1 below shows the process flow diagram for the laboratory jar tests.

2000 ml Raw Water Sample for Each Jar
↓
Permanganate Addition
Mix for Various Times at 30 RPM
↓
Filter Samples with 0.22 micron Filters
Measure Permanganate Residual

Flow Chart 1

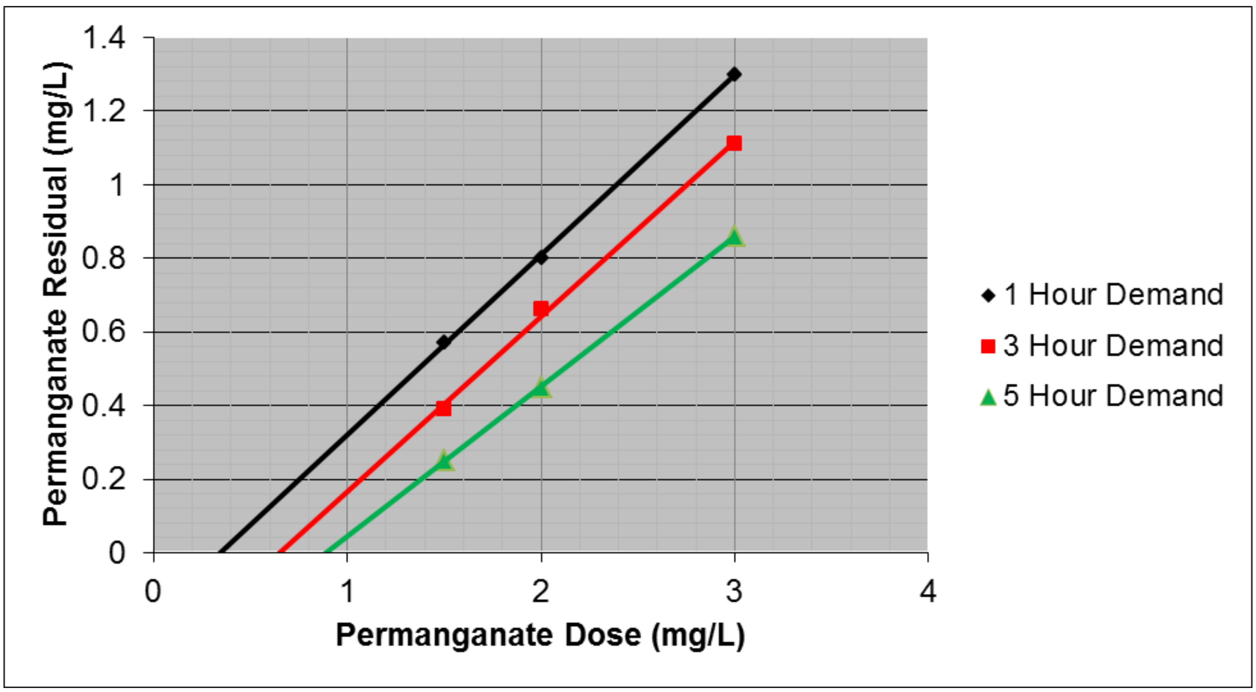
Residual permanganate levels were determined using Carus Analytical Method 106. This method uses standard DPD reagents and is based on the HACH Spectrophotometric Method 8021 for the determination of free chlorine.

Jar test results are shown in Tables 1-2 below. The plot of residual potassium permanganate versus potassium permanganate dose from the jar tests is shown in Graphs 1-2. By extrapolating the line to zero potassium permanganate residual on Graphs 1-2, potassium permanganate demand can then be determined for the tested detention times.

Table 1: Permanganate Demand Jar Test Results for the Lake Lewisville Intake to the Lake Lewisville WTP

Jar #	Permanganate Dose (mg/L)	Permanganate Residual After 1 Hour (mg/L)	Permanganate Residual After 2 Hours (mg/L)	Permanganate Residual After 3 Hours (mg/L)
1	1.50	0.57	0.39	0.25
2	2.00	0.80	0.66	0.45
3	3.00	1.30	1.11	0.86

Graph 1: Residual Permanganate versus Permanganate Dose for the Lake Lewisville Intake to the Lake Lewisville WTP

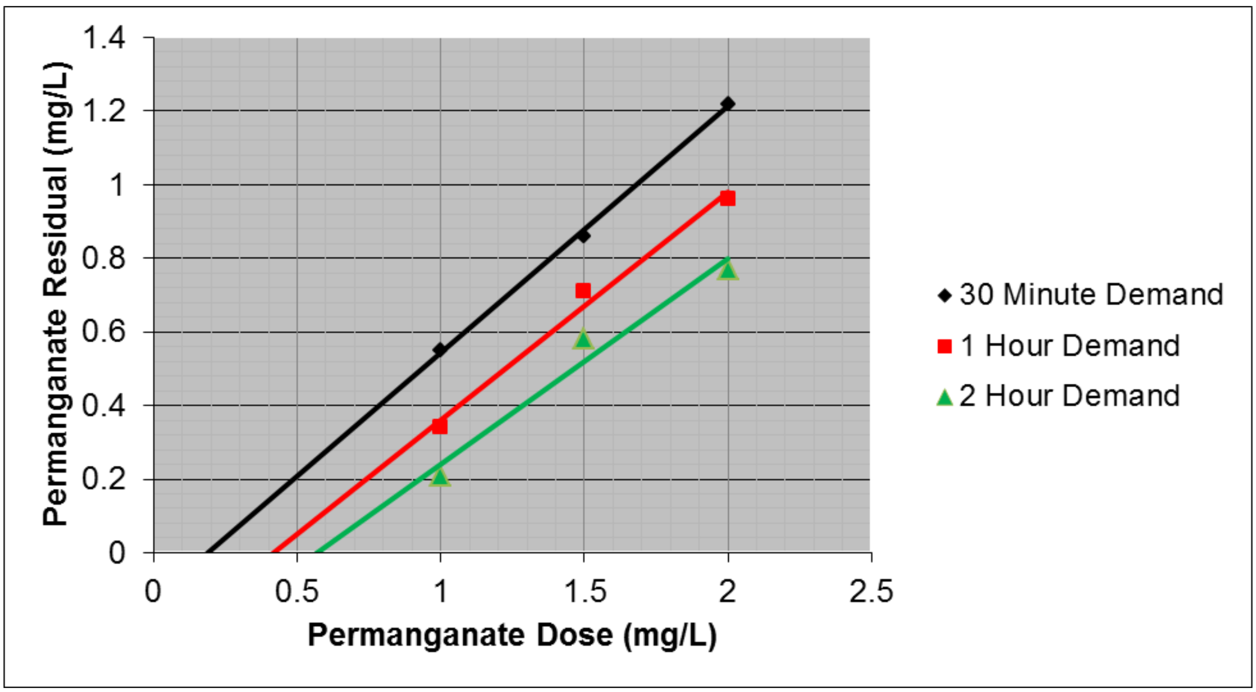


Based on the jar test results, the potassium permanganate demand for the Lake Lewisville Intake to the Lake Lewisville WTP was 0.35 mg/L for the 1 hour demand, 0.65 mg/L for the 3 hour demand, and 0.90 mg/L for the 5 hour demand.

Table 2: Permanganate Demand Jar Test Results for the Lake Ray Roberts Intake to the Lake Ray Roberts WTP

Jar #	Permanganate Dose (mg/L)	Permanganate Residual After 30 Minutes (mg/L)	Permanganate Residual After 1 Hour (mg/L)	Permanganate Residual After 2 Hours (mg/L)
1	1.00	0.55	0.34	0.21
2	1.50	0.86	0.71	0.58
3	2.00	1.22	0.96	0.77

Graph 2: Residual Permanganate versus Permanganate Dose for the Lake Ray Roberts Intake to the Lake Ray Roberts WTP



Based on the jar test results, the potassium permanganate demand for the Lake Ray Roberts Intake to the Lake Ray Roberts WTP was 0.20 mg/L for the 30 minute demand, 0.41 mg/L for the 1 hour demand, and 0.57 mg/L for the 2 hour demand.

The permanganate demand for the Lake Ray Roberts Intake to the Lake Ray Roberts WTP was 0.41 mg/L for the 1 hour demand and 0.57 mg/L for the 2 hour demand.

Calculations:

To calculate the pounds/day of CAIROX® needed for different flow rates, the following formula is used:

(permanganate dosage in mg/L) x (MGD) x (8.34 lbs/gal)= pounds/day of CAIROX®

Example: (0.65 mg/L) x (10 MGD) x (8.34 lbs/gal)= 54 pounds/day of CAIROX®

Conclusions:

CAIROX® is a strong oxidizing agent and an excellent water treatment chemical. It has effectively controlled manganese, iron, tastes, odors, colors, THMs, and HAAs in many water treatment plants. Carus Corporation recommendations are as follows:

Source Water	Destination	Detention Time (Hours)	CAIROX® Demand mg/L	Detention Time (Hours)	CAIROX® Demand mg/L	Detention Time (Hours)	CAIROX® Demand mg/L
Lake Lewisville Intake	Lake Lewisville WTP	1.00	0.35	3.00	0.65	5.00	0.90
Lake Ray Roberts Intake	Lake Ray Roberts WTP	1.00	0.41	2.00	0.51		

Additional Carus Corporation recommendations are as follows:

1. Based on these results, permanganate could be fed at each intake to maintain a residual through the entire intake pipeline by feeding at 1 point.

2. CAIROX® dosage may need to be adjusted according to changes in raw water flow rate and conditions. Jar tests can be performed to determine changes in dosages based on the changing raw water conditions.

Acknowledgements:

Carus Corporation would like to take this opportunity to show gratitude to the personnel at the City of Denton for all the courtesies extended to us during the jar testing.

Darin Skutt
Technical Service Manager
B.S. Chemistry, ACS Certified
Carus Corporation
Peru, IL 61354
800-435-6856 x6833

CHEMICAL DEMAND TESTING RESULTS AND CONCLUSIONS

- Phase I Results
- Phase II Results
- Site-Specific Estimated Chemical Doses
- Conclusions

As a proactive continuous treatment strategy is recommended, a low concentration of chemical must be maintained throughout the system (i.e. through the raw water structures, pipelines and pump stations). In order to appropriately size and estimate costs for chemical storage and feed systems for the short-listed alternatives, chemical demand testing of each short-listed chemical was conducted in both source waters. The site-specific doses selected for conceptual designs and cost estimates were based on the maximum anticipated dose (i.e. the maximum demand plus the recommended chemical residual) required for prevention of zebra mussel settlement. The site-specific doses for annual operations and maintenance costs were based upon an estimated average chemical dose. Chemical demand testing was scheduled in two phases for the LLWTP and RRWTP source waters based upon the detention times listed in Table C-7 with four molluscides including three oxidants (i.e. chlorine dioxide, chloramines, and permanganate) and one polyquarternary ammonium compound (i.e. Bulab 6002).

Table C-7: Source Water Detention Times

Source Water	Begin Location	End Location	Detention Time (Hrs) at Average Flow
Lewisville Lake	LLWTP Intake	LLWTP	4.8
Ray Roberts Lake	RRWTP Intake	RRWTP	0.9

Based on literature sources and team expertise, the target residuals to be considered in selecting a design dose are listed in Table C-8. These target residuals must be maintained throughout the entire system that requires protection from zebra mussel fouling (e.g. through the entire raw water pipeline). Recommended concentrations and application strategies (concentration and durations) for management of zebra mussel macrofouling are summarized in Table C-9. It should be noted that the data presented in literature, and thus presented in Table C-9, are based on applied concentrations in laboratory experiments using water from the Great Lakes region (not the chemical residual in potable water systems) and do not necessarily account for local water quality (e.g. high temperatures and high organic concentrations). Site-specific source water demand must be considered in determining approximate chemical doses required for COD source waters.

Table C-8: Target Residual for Prevention of Zebra Mussel Settlement

Chemical	Target Residual (mg/L)[1]
Chlorine Dioxide	0.25
Chloramines	1.5
Permanganate	0.25
Bulab 6002	0.5

1 – Target residuals must be maintained through the entire system requiring protection from fouling.

Table C-9: Toxicity and Application Methodology of Various Candidate Molluscicides for Prevention or Control of Zebra Mussel Fouling

Molluscicide	Molluscicide Type	Life Stage	Management Approach[1]	Application Method[2]	Concentration	Contact Time[3]	Reference
Chlorine Dioxide	Oxidizing	Adults	Control	Continuous	≥0.2 mg/l	8 days	Mackie & Claudi 2010
		Adults	Control	Continuous	≥0.25 mg/l	4 days	Mackie & Claudi 2010
Chloramines	Oxidizing	Veligers	Prevention	Continuous	≥1.5 mg/l	60 min	Van Benschoten et al., 1992
Potassium Permanganate	Oxidizing	Adults	Control	Continuous	≥2.1 mg/l	6 days	Van Benschoten et al., 1992
		Veligers	Prevention	Continuous	≥1.0 mg/l	Not Available	Mackie & Claudi 2010
		Veligers	Prevention	Continuous	≥0.25 mg/l	Not Available	Mackie & Claudi 2010
Sodium Permanganate	Oxidizing	Similar to that for $KMNO_4$ based on previous project experience and Findlay, OH study.					
Bulab 6002	Cationic Surfactant	Adults	Control	Continuous	≥0.5 mg/l	34 days	McMahon & Chase 1992
		Adults	Control	Continuous	≥1.0 mg/l	28 days	Martin et al. 1993
		Adults	Control	Semi-continuous - 60 min on – 120 min off	≥6 mg/l	24 days	McMahon et al. 1997
		Veligers[4]	Control	Continuous	≥1.0 mg/l	24 hours	Darrigran et al. 2006

1 – Control: apply long enough to eradicate an existing mussel infestation with applications occurring frequently enough to prevent fouling from attaining levels that negatively impact operations. Prevention: apply during periods when zebra mussel veligers are present in the water column to prevent settlement and subsequent fouling.
2 – Application Method: Continuous = applied without ceasing until a mussel infestation is eradicated or to prevent larval settlement, Semi-continuous = applied in a pulsed fashion with a period of chemical feed followed by a period without chemical feed (*e.g.*, 30 min application followed by 90 minutes of non-application).
3 – Long contact times demonstrate that control (i.e. killing veligers) is not feasible for potable water systems and a prevention strategy to prevent settlement should be implemented.
4 – Based on data for Bulab® 6002 against the veligers of the freshwater mussel, *Limnoperna fortunei* (golden mussel), where ≥1.0 mg/l inhibits veliger activity and, thus, settlement. Likely to be a similar for zebra mussel veligers.

PHASE I RESULTS

Table C-10 presents the raw water quality from the samples collected on April 21, 2015 compared to historical water quality for each source water. The water quality for the LLWTP Intake was generally in the middle of the historical range with a few exceptions (i.e. low pH, high manganese and low iron compared to the historical range), suggesting the water quality for the sample date was fairly representative. The water quality for the RRWTP Intake was outside the typical range (i.e. the TOC and DOC was high, alkalinity high, manganese high, iron low and pH low compared to the historical range), likely due to above average precipitation during the month of April.

Table C-10: Raw Water Quality – Phase I

Raw Water Source	LLWTP Intake			RRWTP Intake		
Constituent	Historical Average[1]	Historical Range	4/21/2015	Historical Average[1]	Historical Range	4/21/2015
Temperature (°C)	20.7	7.0 – 31.0	18.8	18.9	9.0 – 27.4	17.8
TOC (mg/L)	6.13	4.04 – 7.85	6.05	4.95	3.92 – 6.40	6.39
DOC (mg/L)	5.50	4.06 – 7.24	5.88	4.61	3.42 – 5.82	6.17
pH (std. units)	8.40	8.10 – 8.80	7.99	7.90	7.20 – 8.20	8.18
Alkalinity (mg/L as $CaCO_3$)	91.62	76.29 – 107.62	103	104.22	97.65 – 112.50	92
Turbidity (NTU)	--	--	11.1	--	--	9.4
Mn_{tot} (µg/L)	34	19 – 50	54	40	3 – 160	21
Mn^{2+} (µg/L)	--	--	12	--	--	6
Fe_{tot} (mg/L)	0.3	0.1 – 0.5	0.08	0.3	0.1 – 1.1	0.02
Fe^{2+} (mg/L)	--	--	0	--	--	0
ORP (mV)	--	--	255	--	--	185
Ammonia (mg/L)	<0.10	<0.10	0.08	<0.10	<0.10	0.26

1 – Historical data was submitted by COD for years 2013-2014.

Based on the demand testing results, the chemical demands required to maintain a measureable residual for the average detention times (Table C-7) are shown in Table C-11. ***These demands do not account for the demand exerted from biofilms, particulates (e.g. clay), or organics on the pipelines.*** Additionally, Table C-11 presents the permanganate results from the testing performed by Carus Corporation on December 17, 2014. Source water quality data was not measured in the samples tested by Carus.

Table C-11: Chemical Demand at Average Flow – Phase I

Source Water	Chlorine Dioxide (mg/L)	Chloramines (mg/L)	Bulab 6002 (mg/L active polyquat)	Sodium Permanganate (mg/L)[1]	Potassium Permanganate (mg/L)	Carus Potassium Permanganate (mg/L)
LLWTP Intake	>1.5	0.1	0.5	1.4	1.5	0.9
RRWTP Intake	0.75	0.05	0.25	0.5	0.5	0.4

1 – Demand testing was only completed with potassium permanganate. An equivalent concentration of sodium permanganate was calculated based upon molar conversions.

PHASE II RESULTS

Phase II repeated demand testing of permanganate and chlorine dioxide on samples collected on June 10, 2015. The water temperature was raised to 30°C based on the high summer temperatures (up to 31°C) experienced in COD source waters. Higher temperatures result in faster chemical decay rates, thereby increasing the dose that must be applied to maintain a residual through the raw water systems. Table C-12 presents the raw water quality from the samples compared to historical water quality for each source water. The water quality for both sources was generally in the middle of the historical range with a few exceptions outlined below, suggesting the water quality for the sample date was fairly representative.

- RRWTP Intake had an alkalinity level that was below the range of historical data.
- Both samples had low iron levels compared to the historical averages and ranges.
- Both had higher ammonia levels than historical levels.
- LLWTP Intake had a manganese concentration on the low end of the historical range.

Table C-12: Raw Water Quality – Phase II

	LLWTP Intake			RRWTP Intake		
Constituent	**Historical Average[1]**	**Historical Range**	**6/10/2015**	**Historical Average[1]**	**Historical Range**	**6/10/2015**
Temperature (°C)	20.7	7.0 – 31.0	30[2]	18.9	9.0 – 27.4	30[2]
TOC (mg/L)	6.13	4.04 – 7.85	6.39	4.95	3.92 – 6.40	4.65
DOC (mg/L)	5.50	4.06 – 7.24	6.17	4.61	3.42 – 5.82	4.51
pH (std. units)	8.40	8.10 – 8.80	8.18	7.90	7.20 – 8.20	7.77
Alkalinity (mg/L as $CaCO_3$)	91.62	76.29 –107.62	92	104.22	97.65 – 112.50	89
Turbidity (NTU)	--	--	9.4	--	--	8.7
Mn_{tot} (µg/L)	34	19 – 50	21	40	3 – 160	33
Mn^{2+} (µg/L)	--	--	6	--	--	6
Fe_{tot} (mg/L)	0.3	0.1 – 0.5	0.02	0.3	0.1 – 1.1	0.09
Fe^{2+} (mg/L)	--	--	0	--	--	0
ORP (mV)	--	--	185	--	--	272
Ammonia (mg/L)	<0.10	<0.10	0.26	<0.10	<0.10	0.12

1 – Historical data was submitted by COD for years 2013-2014.

2 – Simulated water temperature for testing.

The chemical demands required to maintain a measureable residual for the average detention times (Table C-7) is shown in Table C-13. ***These demands do not account for the demand exerted from biofilms, particulates, or organics on the pipelines.***

Table C-13: Chemical Demand at Average Flow – Phase II

Source Water	Chlorine Dioxide (mg/L)	Chloramines (mg/L)	Bulab 6002 (mg/L active polyquat)	Sodium Permanganate (mg/L)[1]	Potassium Permanganate (mg/L)
LLWTP Intake	>1.5	NR	NR	4.5	5.0
RRWTP Intake	>1.5	NR	NR	1.8	2.0

NR – Not recommended or further evaluated based upon discussions with City of Denton staff reviewing the required doses, related regulatory considerations, and potential downstream water quality or treatment consequences.
1 – Demand testing was only completed with potassium permanganate. An equivalent concentration of sodium permanganate was calculated based upon molar conversions.

SITE-SPECIFIC ESTIMATED CHEMICAL DOSES

In order to effectively prevent zebra mussel veliger settlement, a chemical residual must be maintained for the entire detention time of the system to be protected. In systems previously infested with mussels, a decline in the density of mussel settlement has been observed through the length of pipelines. This is likely due to a change in water quality (e.g. low dissolved oxygen) that is unfavorable to settlement. Thus, some systems have been successful with operationally targeting a residual of zero at the end of the pipeline. However, chemical storage and feed systems should be designed to maintain the recommended residual (based on the chemical selected) throughout the system that requires protection from zebra mussel infestations. Table C-14 summarizes the water quality regulations that must be considered in interpreting the feasibility of the estimated doses.

The recommended design doses are presented in Table C-15 and Table C-16. Design doses consider the chemical demand at the average flow for each system, the chemical residual required to prevent settlement based upon literature and project team experience, and a small buffer to account for some unknowns. ***Unknown factors such as demand due to biofilm formation on pipelines, changes in water quality (e.g. seasonal changes in water temperature or organics concentrations), and changes in flow (i.e. a higher dose is required when flow decreases cause an increase in detention time) may significantly change the dose required. The team recommends that chemical feed be optimized following start-up of any chemical systems using biological monitoring (e.g. veliger settlement monitoring and bioboxes). Monitoring may significantly reduce the required dose and duration of chemical feed systems. Conceptual layouts and cost estimates are based upon 15 days of storage at the highest measured demand; monitoring may reduce the frequency of delivery to monthly or bi-monthly using the recommended chemical storage and feed equipment sizes.***

Table C-14: Chemical Regulatory Considerations

Chemical	Regulatory Considerations
Chlorine Dioxide	Chlorite MCL of 1.0 mg/L
Chloramines	Nitrate MCL of 10 mg/L as N Nitrite MCL of 1 mg/L as N Nitrate & Nitrite (Total) MCL of 10 mg/L as N NDMA (anticipated future regulation)
Bulab	NDMA (anticipated future regulation) NSF long-term application limit of 0.5 mg/L
Permanganate	Manganese SMCL of 0.05 mg/L

Table C-15: LLWTP Conceptual Design Doses

Chemical	Phase I Chemical Demand @18°C	Phase II Chemical Demand @30°C	Chemical Residual Required to Prevent Settlement	Estimated Dose[1] at Average Flow and 18°C	Estimated Dose[1] at Average Flow and 30°C	Conceptual Chemical Facility Design Criteria	Estimated Annual Average Chemical Dose
Chlorine Dioxide (mg/L active)	>1.5	>1.5	0.25	>1.5	>1.5	NR	NR
Chloramines (mg/L active)	0.1	NR	1.5	5-7	NR	NR	NR
Bulab (mg/L active polyquat)	0.5	NR	0.5	>1.0	NR	NR	NR
Sodium Permanganate (mg/L active)	1.4	4.5	0.25	1.7	4.8	5.5	3.5
Potassium Permanganate (mg/L active)	1.5	5.0	0.25	1.8	5.3	6.0	3.5

NR – Not recommended or further evaluated based upon discussions with COD staff reviewing the required doses, related regulatory considerations, and potential downstream water quality or treatment consequences.
1 – Doses are based on a TOC concentration of 6.05 and 6.39 m/L for Phases I and II, respectively, and do not account for pipeline demand. Doses are rounded up to two significant figures.

Table C-16: RRWTP Conceptual Design Doses

Chemical	Phase I Chemical Demand @18°C	Phase II Chemical Demand @30°C	Chemical Residual Required to Prevent Settlement	Estimated Dose[1] at Average Flow and 18°C	Estimated Dose[1] at Average Flow and 30°C	Conceptual Chemical Facility Design Criteria	Estimated Annual Average Chemical Dose
Chlorine Dioxide (mg/L active)	0.75	>1.5	0.25	1.0	>1.5	NR	NR
Chloramines (mg/L active)	0.05	NR	1.5	5-7	NR	NR	NR
Bulab (mg/L active polyquat)	0.25	NR	0.5	>1.0	NR	NR	NR
Sodium Permanganate (mg/L active)	0.5	1.8	0.25	0.8	2.1	2.5	1.5
Potassium Permanganate (mg/L active)	0.5	2	0.25	0.8	2.3	3.0	1.5

NR – Not recommended or further evaluated based upon discussions with COD staff reviewing the required doses, related regulatory considerations, and potential downstream water quality or treatment consequences.
1 – Doses are based on a TOC concentration of 4.65 and 5.22 mg/L for Phases I and II, respectively, and do not account for pipeline demand. Doses are rounded up to two significant figures

CONCLUSIONS

The demand testing results highlight that no one chemical is ideal. There are advantages and risks regardless of which chemical is selected. Based upon the results of demand testing and discussions with COD staff, it was determined that **the following three chemicals would not be further evaluated**.

- **Chloramines** – The doses required for chloramines are reasonable. However, the use of chloramines at the intakes could exacerbate nitrification within the water treatment plant, which can result in seeding of ammonia oxidizing bacteria into the distribution system. Chloramines addition also can lead to NDMA formation. The use of chloramines prior to ozonation, which degrades NDMA precursors, would be expected to result in higher NDMA concentrations in the finished water and distribution system than currently observed. While not yet regulated, NDMA has been found to be a potential carcinogen at low nanogram per liter concentrations and it is under consideration by the EPA for a future regulatory determination. Further, chloramines would have to be quenched prior to biofiltration. Quenching would require an additional capital chemical project and additional chemical costs. Chloramines are not recommended as a primary management approach for zebra mussels. However, pre-formed chloramines could be considered for a short-term approach if the potential risks are recognized.
- **Bulab** – The doses required for Bulab are above the NSF long-term application limit. In addition, Bulab was shown to be an NDMA precursor in recent testing conducted by the City of Dallas. Bulab has limited installations for zebra mussel management. The only known use of Bulab for zebra mussel fouling prevention was by the City of Oregon, OH. City of Oregon used 3 mg/L of Bulab at the onset of their zebra mussel issues but has since converted to permanganate for coagulation benefits. Additionally, the Bulab dose is dependent upon the clay particles in the water (i.e. during high turbidity events control of the dose would be difficult). Bulab is not recommended as a primary management approach for zebra mussels. However, Bulab could be tested post-startup if there is interest recognizing the potential risks.
- **Chlorine Dioxide** – Due to the chlorite regulation of 1 mg/L, chlorine dioxide can only be applied at doses less than 1.5 mg/L without requiring a downstream chlorite removal treatment process. Chlorine dioxide may be effective at a dose below 1.5 mg/L, but may only protect a limited portion of the raw water system (i.e. approximately 0.5 miles of the shorter pipelines and 1 mile of the longer pipelines based upon demand testing at 30°C).

Permanganate is a very feasible alternative considering the design and average doses required based on demand testing. The main concern with permanganate is increased manganese concentrations resulting in colored water or turbidity if treatment process controls are not in place to prevent resolubilization of particulate manganese or over-ozonation. Permanganate is available as a dry chemical in the form of potassium permanganate or a liquid chemical in the form of sodium permanganate. Based upon the results of demand testing and discussions with COD staff, it was determined that **sodium permanganate would be further evaluated** by developing conceptual layouts, cost estimates and comparison matrices. In addition, it was determined a non-oxidizing chemical would be further considered.

APPENDIX D: WORKSHOPS

CONTENTS:

- Criteria Ranking
- Management Approach Ranking

CRITERIA RANKING

Criteria Ranking

Rank Evaluation Criteria in Order from 1-9:
1 – Most Important
9 – Least Important

Participants							AVERAGE	OVERALL RANK	% Weight
Life Cycle Cost	4	2	4	4	6	3.5	**3.9**	**4**	**14%**
Effectiveness for Zebra Mussel Management	1	1	1	1	2	1.5	**1.3**	**1**	**22%**
Ease of Operation and Maintenance & Operational Flexibility	3	3	3	2	4	3.5	**3.1**	**2**	**16%**
Impact to Downstream Water Quality & Water Treatment Plant	5	6	5	3	5	7	**5.2**	**5**	**11%**
Impact to Environment / Ecology	6	8	8	8	9	7	**7.7**	**8**	**4%**
Implementability	8	7	2	6	7	7	**6.2**	**7**	**8%**
Health and Safety	9	4	7	7	1	7	**5.8**	**6**	**9%**
Status in the Industry / Record of Performance	2	5	6	5	3	1.5	**3.8**	**3**	**15%**
Public Acceptability	7	9	9	9	8	7	**8.2**	**9**	**2%**
					Total		**45.0**		**100%**

MANAGEMENT APPROACH RANKING

Management Approach Ranking

Rank each Management Approach where:
A (1.0) – Very feasible
B (2.0) – Feasible but some limitations
C (3.0) – Feasible but many limitations
D (4.0) – Not feasible / not interested

Alternatives	City Personnel Rankings						AVERAGE
Metal Alloys	1	2	1	1	2	1.5	1.4
Foul-Release Coatings	1	3	3	3	3	1.5	2.4
Anti-Fouling Coatings	3	3	3	2	3	2.5	2.8
High Flows	4	4	3	4	4	1.5	3.4
Chemical Control - Oxidants	1	1	1	1	2	1.0	1.2
Chemical Control - Non-Oxidizing Molluscicides	3	2	2	2	2	2.5	2.3
Strainers or Screens	3	4	4	4	4	3.5	3.8
Acoustics	4	4	3	4	4	2.5	3.6
Electric Shock / Extremely Low Frequency Magnetism	3	4	3	4	4	2.5	3.4
Biological Treatment	4	3	3	3		2.5	3.1
Bank or Sand Filtration	3	4	4	4	4	4.0	3.8
UV Light	4	4	4	4	4	3.0	3.8
Physical Removal	2	1	1	1	3	1.0	1.5
Dewatering/Desiccation	2	2	1	1	2	1.0	1.5
Oxygen Deprivation		3	4	2	4	1.5	2.9
Thermal Treatment	4	4	4	3	4	3.5	3.8

Oxidant Alternatives	City Personnel Rankings						AVERAGE
Chlorine Dioxide	3	3	2	2	3	1.5	2.4
Sodium Hypochlorite	4	4	3	4	4	3.5	3.8
Chloramines	4	3	2	3	4	2.5	3.1
Chlorine Gas	4	4	4	4	4	4.0	4.0
Sodium Permanganate	2	1	1	1	2	1.5	1.4
Potassium Permanganate	3	2	1	1	2	1.5	1.8
Hydrogen Peroxide	4	4	3	4	3	3.5	3.6
Ozone	4	3	4	4	4	3.5	3.8
Bromine	4	4	4	4	2	4.0	3.7

APPENDIX E: CALCULATIONS AND DETAILED COST ESTIMATES

CONTENTS:

LLWTP PIPELINE VELOCITY CALCULATIONS

The LLWTP intake consists of two pipes of different lengths leading to the raw water pump station. Two pipes, also of differing lengths, also exit the pump station and lead to the treatment plant. Table E-1 displays the velocity and residence time within each section of the four pipe segments.

Table E-1: LLWTP Approximate Velocities and Oxidant Residence Times

Beginning Facility	Ending Facility	Water Treatment Plant	Pipe Diameter (in.)	Pipe Area (ft^2)	Pipe Length (ft)	Flow (MGD) at 6 ft/s	Min. Flow [1] (MGD)	Velocity (ft/s)	Min. Flow - Chemical Residence Time (hrs)	Avg. Flow [2] (MGD)	Velocity (ft/s)	Avg. Flow - Chemical Residence Time (hrs)	Max. Flow [1] (MGD)	Velocity (ft/s)	Max. Flow - Chemical Residence Time (hrs)
Lake Lewisville Intake (Upper)	Raw Water Pump Station	LLWTP	36	7.1	93	27	5	1.09	0.02	8.44	1.85	0.01	30	6.57	0.00
Lake Lewisville Intake (Lower)	Raw Water Pump Station	LLWTP	36	7.1	150	27	5	1.09	0.04	8.44	1.85	0.02	30	6.57	0.01
Raw Water Pump Station 1	Rapid Mix Structure (LLWTP)	LLWTP	27	4.0	45,311	15	5	1.95	6.47	8.44	3.28	3.83	30	11.67	1.08
Raw Water Pump Station 2	Rapid Mix Structure (LLWTP)	LLWTP	30.0	5	45,311	19.00	5.00	2	7.99	8.44	2.66	4.73	30	9.46	1.33

The total minimum and maximum chemical residence times were determined by selecting the shortest and longest residence times for each combination of intake pipe and pump station outlet pipe and combining them for a total residence time for that pipe system combination. The results can be seen in Table E-2.

Table E-2: LLWTP Chemical Residence Times

Beginning Facility	Middle Facility	Ending Facility	Water Treatment Plant	Avg. Flow Total Chemical Residence Time (hrs)	Min. Flow Total Chemical Residence Time (hrs)	Max. Flow Total Chemical Residence Time (hrs)
Lake Lewisville Intake (Upper)	Raw Water Pump Station 1	Rapid Mix Structure (LLWTP)	LLWTP	3.84	6.49	1.08
Lake Lewisville Intake (Lower)	Raw Water Pump Station 1	Rapid Mix Structure (LLWTP)	LLWTP	3.85	6.51	1.09
Lake Lewisville Intake (Upper)	Raw Water Pump Station 2	Rapid Mix Structure (LLWTP)	LLWTP	4.74	8.01	1.33
Lake Lewisville Intake (Lower)	Raw Water Pump Station 2	Rapid Mix Structure (LLWTP)	LLWTP	4.75	8.03	1.34

LLWTP HYDRAULIC CALCULATIONS

LL Raw Water System Headloss without Infestation

Gravity:	32.2	ft/sec2
C (Hz/Wm):	130	for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}:	0.00	ft
Min WSE Z = Static Head, h_{ST}:	0.00	ft

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Frictional Losses:

Hazen Williams Equation (rearranged):

$$\text{Friction loss through Pipe } H_f = \frac{(10.44)(L\ ft)(Q\ gpm)^{\wedge}1{,}85}{(C^{\wedge}1.85)(d\ in)^{\wedge}4.8655}$$

$$\text{Minor losses } H_m = K^* v^2/2g$$

$$\mathbf{H_L = H_f + H_m}$$

Q = 8.44 **MGD** Average Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	36	0	0.50	5,861	13.06	1.85	0.00	0.03	0.03	0.03
PIPE	36	100	0.00	5,861	13.06	1.85	0.03	0.00	0.03	0.06
Exit	36	0	1.00	5,861	13.06	1.85	0.00	0.05	0.05	0.11
	Length:	100								0.11
		Sum Ks:	1.5							

Q = 30 **MGD** Max Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	36	0	0.50	20,833	46.42	6.57	0.00	0.33	0.33	0.33
PIPE	36	100	0.00	20,833	46.42	6.57	0.34	0.00	0.34	0.67
Exit	36	0	1.00	20,833	46.42	6.57	0.00	0.67	0.67	1.34
	Length:	100								1.34
		Sum Ks:	1.5							

LL Raw Water System Headloss with Infestation

Gravity:	32.2	ft/sec2
C (Hz/Wm):	60	for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}:	0.00	ft
Min WSE Z = Static Head, h_{ST}:	0.00	ft

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Frictional Losses:

Hazen Williams Equation (rearranged):

Friction loss through Pipe $H_f = \frac{(10.44)(L\ ft)(Q\ gpm)^{1,85}}{(C^{1.85})(d\ in)^{4.8655}}$

Minor losses $H_m = K^* v^2/2g$

$$H_L = H_f + H_m$$

Q = 8.44 **MGD** Average Flow

Friction and Minor Losses Description	Dia.[1] (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	24	0	0.50	5,861	13.06	4.16	0.00	0.13	0.13	0.13
PIPE	24	100	0.00	5,861	13.06	4.16	0.96	0.00	0.96	1.10
Exit	24	0	1.00	5,861	13.06	4.16	0.00	0.27	0.27	1.37
	Length:	100								1.37
		Sum Ks:	1.5							

Q = 30 **MGD** Max Flow

Friction and Minor Losses Description	Dia.[1] (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	24	0	0.50	20,833	46.42	14.78	0.00	1.70	1.70	1.70
PIPE	24	100	0.00	20,833	46.42	14.78	10.08	0.00	10.08	11.77
Exit	24	0	1.00	20,833	46.42	14.78	0.00	3.39	3.39	15.16
	Length:	100								15.16
		Sum Ks:	1.5							

1 - Diameter reduced assuming 6" depth of mussels around pipeline circumference.

Comparison		
Flow	Average	Maximum
MGD	8.44	30
Feet Headloss without Infestation	0.11	1.34
Feet Headloss with Infestation	1.37	15.16
Increase	**1.26**	**13.82**

LLWTP EXISTING POTASSIUM PERMANGANATE DOSING CAPACITY

The LLWTP Intake has an existing potassium permanganate system would could be utilized to prevent settlement of veligers in the LLWTP raw water system. The table below provides calculations of the maximum dose that could be applied without modifications to the existing system at different flow rates. An electronic version of this calculation spreadsheet was provided to the COD for internal use.

Table E-3: LLWTP Existing Potassium Permanganate Dosing Capacity

Potassium Permanganate Chemical Information	
Chemical Name	Potassium Permanganate
Chemical Formula	KMnO4
Chemical Purity	97%
Percent Active Permanganate	75%
Molecular Weight (g/mol)	158.03
Specific Gravity	1.23
Concentration of KMnO4 at 3% Soln (mg/L)	30000
Concentration of KMnO4 at 3% Soln (lb/gal)	0.25
Dynamic Viscosity (cP)	1.0
DOT Hazard Class	5.1
Crystallization Temperature (°F)	32
Chemical State at Room Temperature	Solid

Pump Information	
Max. Pump Capacity (combined pumps 2 @ 38 gph) (gph):	76

Unit Conversions	
mg/lb	453,600
L/gal	3.785
1%/(mg/L)	10,000

Plant Flow Rate (MGD)	Maximum Potassium Permanganate Dosage Based on Pump Capacity (mg/L)
5.0	**10.6**
8.4	**6.3**
10.0	**5.3**
15.0	**3.5**
32.5	**1.6**

LLWTP DETAILED DETAILED OPINION OF PROBABLE COST

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

OPINION OF PROBABLE NET PRESENT VALUE

Alternative	Capital Cost	Annual O&M Cost[1]	Annual Cleaning and Removal Cost[2]	Net Present Value	Engineering & Construction Administration[3]
A NaMnO4 and Cu Ion System	$ 2,360,000				$ 480,000
8 month NaMnO4 Feed		$ 89,000	$ 58,000	$ 5,470,378	
5 month NaMnO4 Feed (with Monitoring)		$ 74,000	$ 58,000	$ 5,154,263	
Potential Savings on NaMnO4 from Monitoring		$ 15,000	$ -	$ 316,114	
12 month Cu Ion Feed		$ 41,000	$ 58,000	$ 4,901,000	
B Physical Removal and Maintenance Improvements	$ 2,610,000	$ 25,850	$ 200,000	$ 10,329,000	$ 530,000
Optional Additions and Substitutions[3]					
Substitution 1: SS Bar Screen with Jacquelyn Coating (Two Intakes)[4]	$ (86,000)	$ -	$ -	$ (30,000)	$ -
Substitution 2: Chemical Feed Line (Through Pipeline)	$ 30,000	$ -	$ -	$ 30,000	$ 10,000
Addition 1: Lower 36" Intake Improvements	$ 372,000	$ 3,000	$ 3,000	$ 662,000	$ 80,000
Addition 2: PVC Potable Water Line	$ 29,000	$ 24,000	$ -	$ 534,000	$ 10,000
Addition 3: Land Rights for Maintenance Access[5]	$ 244,000	$ -	$ -	$ 244,000	$ 50,000
Addition 4: Site Improvements for Maintenance Access[5]	$ 244,000	$ -	$ -	$ 244,000	$ 50,000

[1] Physical Cleaning and Removal not included.

[2] Physical Cleaning and Removal Cost is represented on annual basis for budgetary purposes, although in reality would occur every 2 years for the first mile of the line. A more extensive cleaning every 5 years is included as a replacement cost for Alternative B.

[3] Subsitutions are represented by the price difference as compared to the respective base option(s).

[4] Engineering fees include $10,000 for regulatory coordination regarding the addition of chemical feed in the intakes and construction of the new mid-intake.

[5] Potential variable costs that may be required for physical removal and disposal access in pipeline segments where property is not owned by COD. Necessity of these variable costs to be determined during detailed design.

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

PRESENT VALUE BASIS CALCULATIONS

Present Value Basis Calculations - Alternative A (NaMnO4, 5 months)

Net Present Value Total:	**$ 5,154,263**
O&M Present/Future Worth:	**$ 2,794,263**
Per Year O&M:	**$ 187,818**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 136,429	$ 158,629	$ -	$ -	$ 286,464
2	0.94260	$ 141,204	$ 158,629	$ -	$ -	$ 282,621
3	0.91514	$ 146,146	$ 158,629	$ -	$ -	$ 278,912
4	0.88849	$ 151,261	$ 158,629	$ -	$ -	$ 275,333
5	0.86261	$ 156,555	$ 158,629	$ -	$ -	$ 271,881
6	0.83748	$ 162,035	$ 158,629	$ -	$ -	$ 268,551
7	0.81309	$ 167,706	$ 158,629	$ -	$ -	$ 265,340
8	0.78941	$ 173,575	$ 158,629	$ -	$ -	$ 262,245
9	0.76642	$ 179,651	$ 158,629	$ -	$ -	$ 259,263
10	0.74409	$ 185,938	$ 158,629	$ 9,000	$ 12,695	$ 265,837
11	0.72242	$ 192,446	$ 158,629	$ -	$ -	$ 253,624
12	0.70138	$ 199,182	$ 158,629	$ -	$ -	$ 250,961
13	0.68095	$ 206,153	$ 158,629	$ -	$ -	$ 248,399
14	0.66112	$ 213,369	$ 158,629	$ -	$ -	$ 245,934
15	0.64186	$ 220,836	$ 158,629	$ -	$ -	$ 243,564
16	0.62317	$ 228,566	$ 158,629	$ -	$ -	$ 241,287
17	0.60502	$ 236,565	$ 158,629	$ -	$ -	$ 239,099
18	0.58739	$ 244,845	$ 158,629	$ -	$ -	$ 236,999
19	0.57029	$ 253,415	$ 158,629	$ -	$ -	$ 234,983
20	0.55368	$ 262,284	$ 158,629	$ 9,000	$ 17,908	$ 242,965
					TOTAL:	**$ 5,154,263**

Present Value Basis Calculations - Alternative A (NaMnO4, 8 months)

Net Present Value Total:	**$ 5,470,378**
O&M Present/Future Worth:	**$ 5,470,378**
Per Year O&M:	**$ 367,695.31**

Interest Rate:	0%
Cost Escalation Factor:	0.0%
A/P (20 years):	#DIV/0!

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 151,971	$ 158,629	$ -	$ -	$ 301,553
2	0.94260	$ 157,290	$ 158,629	$ -	$ -	$ 297,784
3	0.91514	$ 162,795	$ 158,629	$ -	$ -	$ 294,148
4	0.88849	$ 168,492	$ 158,629	$ -	$ -	$ 290,643
5	0.86261	$ 174,390	$ 158,629	$ -	$ -	$ 287,265
6	0.83748	$ 180,493	$ 158,629	$ -	$ -	$ 284,010
7	0.81309	$ 186,811	$ 158,629	$ -	$ -	$ 280,874
8	0.78941	$ 193,349	$ 158,629	$ -	$ -	$ 277,855
9	0.76642	$ 200,116	$ 158,629	$ -	$ -	$ 274,948
10	0.74409	$ 207,120	$ 158,629	$ 9,000	$ 12,695	$ 281,598
11	0.72242	$ 214,369	$ 158,629	$ -	$ -	$ 269,462
12	0.70138	$ 221,872	$ 158,629	$ -	$ -	$ 266,876
13	0.68095	$ 229,638	$ 158,629	$ -	$ -	$ 264,391
14	0.66112	$ 237,675	$ 158,629	$ -	$ -	$ 262,004
15	0.64186	$ 245,994	$ 158,629	$ -	$ -	$ 259,712
16	0.62317	$ 254,604	$ 158,629	$ -	$ -	$ 257,513
17	0.60502	$ 263,515	$ 158,629	$ -	$ -	$ 255,404
18	0.58739	$ 272,738	$ 158,629	$ -	$ -	$ 253,383
19	0.57029	$ 282,284	$ 158,629	$ -	$ -	$ 251,446
20	0.55368	$ 292,164	$ 158,629	$ 9,000	$ 17,908	$ 259,508
					TOTAL:	**$ 5,470,378**

Present Value Basis Calculations - Alternative A (Cu Ion System)

Net Present Value Total:	**$**	**4,901,270**
O&M Present/Future Worth:	**$**	**2,541,270**
Per Year O&M:	**$**	**170,813**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 102,172	$ 158,629	$ 22,000	$ 22,770	$ 275,312
2	0.94260	$ 105,748	$ 158,629	$ 22,000	$ 23,567	$ 271,415
3	0.91514	$ 109,449	$ 158,629	$ 22,000	$ 24,392	$ 267,652
4	0.88849	$ 113,280	$ 158,629	$ 22,000	$ 25,246	$ 264,018
5	0.86261	$ 117,245	$ 158,629	$ 22,000	$ 26,129	$ 260,511
6	0.83748	$ 121,348	$ 158,629	$ 22,000	$ 27,044	$ 257,125
7	0.81309	$ 125,596	$ 158,629	$ 22,000	$ 27,990	$ 253,859
8	0.78941	$ 129,992	$ 158,629	$ 22,000	$ 28,970	$ 250,709
9	0.76642	$ 134,541	$ 158,629	$ 22,000	$ 29,984	$ 247,671
10	0.74409	$ 139,250	$ 158,629	$ 22,000	$ 31,033	$ 244,742
11	0.72242	$ 144,124	$ 158,629	$ 22,000	$ 32,119	$ 241,919
12	0.70138	$ 149,168	$ 158,629	$ 22,000	$ 33,244	$ 239,199
13	0.68095	$ 154,389	$ 158,629	$ 22,000	$ 34,407	$ 236,580
14	0.66112	$ 159,793	$ 158,629	$ 22,000	$ 35,611	$ 234,058
15	0.64186	$ 165,386	$ 158,629	$ 22,000	$ 36,858	$ 231,630
16	0.62317	$ 171,174	$ 158,629	$ 22,000	$ 38,148	$ 229,295
17	0.60502	$ 177,165	$ 158,629	$ 22,000	$ 39,483	$ 227,049
18	0.58739	$ 183,366	$ 158,629	$ 22,000	$ 40,865	$ 224,890
19	0.57029	$ 189,784	$ 158,629	$ 22,000	$ 42,295	$ 222,815
20	0.55368	$ 196,426	$ 158,629	$ 22,000	$ 43,775	$ 220,823
						TOTAL: $ 4,901,270

Present Value Basis Calculations - Alternative B

Net Present Value Total:	**$ 10,328,640**
O&M Present/Future Worth:	**$ 7,718,640**
Per Year O&M:	**$ 518,814**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 233,755	$ 175,433	$ -	$ -	$ 397,270
2	0.94260	$ 241,936	$ 175,433	$ -	$ -	$ 393,410
3	0.91514	$ 250,404	$ 175,433	$ -	$ -	$ 389,701
4	0.88849	$ 259,168	$ 175,433	$ -	$ -	$ 386,137
5	0.86261	$ 268,239	$ 175,433	$ 697,260	$ 828,126	$ 1,097,064
6	0.83748	$ 277,627	$ 175,433	$ -	$ -	$ 379,431
7	0.81309	$ 287,344	$ 175,433	$ -	$ -	$ 376,280
8	0.78941	$ 297,401	$ 175,433	$ -	$ -	$ 373,260
9	0.76642	$ 307,810	$ 175,433	$ -	$ -	$ 370,366
10	0.74409	$ 318,584	$ 175,433	$ 697,260	$ 983,554	$ 1,099,451
11	0.72242	$ 329,734	$ 175,433	$ -	$ -	$ 364,944
12	0.70138	$ 341,275	$ 175,433	$ -	$ -	$ 362,408
13	0.68095	$ 353,219	$ 175,433	$ -	$ -	$ 359,987
14	0.66112	$ 365,582	$ 175,433	$ -	$ -	$ 357,675
15	0.64186	$ 378,378	$ 175,433	$ 697,260	$ 1,168,154	$ 1,105,263
16	0.62317	$ 391,621	$ 175,433	$ -	$ -	$ 353,369
17	0.60502	$ 405,327	$ 175,433	$ -	$ -	$ 351,370
18	0.58739	$ 419,514	$ 175,433	$ -	$ -	$ 349,469
19	0.57029	$ 434,197	$ 175,433	$ -	$ -	$ 347,663
20	0.55368	$ 449,394	$ 175,433	$ 697,260	$ 1,387,400	$ 1,114,121
						TOTAL: $ 10,328,640

Present Value Basis Calculations - Substitution 1

Net Present Value Total:	**$ (30,287)**
O&M Present/Future Worth:	**$ 55,838**
Per Year O&M:	**$ 3,753.16**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment	Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -
1	0.97087	$ -	$ (5,789)	$ -	$ (5,620)
2	0.94260	$ -	$ (5,789)	$ -	$ (5,457)
3	0.91514	$ -	$ (5,789)	$ -	$ (5,298)
4	0.88849	$ -	$ (5,789)	$ -	$ (5,143)
5	0.86261	$ -	$ (5,789)	$ -	$ (4,994)
6	0.83748	$ -	$ (5,789)	$ -	$ (4,848)
7	0.81309	$ -	$ (5,789)	$ -	$ (4,707)
8	0.78941	$ -	$ (5,789)	$ -	$ (4,570)
9	0.76642	$ -	$ (5,789)	$ -	$ (4,437)
10	0.74409	$ -	$ (5,789)	$ 60,531	$ 40,733
11	0.72242	$ -	$ (5,789)	$ -	$ (4,182)
12	0.70138	$ -	$ (5,789)	$ -	$ (4,060)
13	0.68095	$ -	$ (5,789)	$ -	$ (3,942)
14	0.66112	$ -	$ (5,789)	$ -	$ (3,827)
15	0.64186	$ -	$ (5,789)	$ -	$ (3,716)
16	0.62317	$ -	$ (5,789)	$ -	$ (3,607)
17	0.60502	$ -	$ (5,789)	$ -	$ (3,502)
18	0.58739	$ -	$ (5,789)	$ -	$ (3,400)
19	0.57029	$ -	$ (5,789)	$ -	$ (3,301)
20	0.55368	$ -	$ (5,789)	$ 19,500	$ 7,591
				TOTAL:	**$ (30,287)**

Present Value Basis Calculations - Addition 1

Net Present Value Total:	**$**	**662,195**
O&M Present/Future Worth:	**$**	**290,477**
Per Year O&M:	**$**	**19,525**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment	Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -
1	0.97087	$ 6,210	$ 24,985	$ -	$ 30,286.74
2	0.94260	$ 6,427	$ 24,985	$ -	$ 29,609
3	0.91514	$ 6,652	$ 24,985	$ -	$ 28,953
4	0.88849	$ 6,885	$ 24,985	$ -	$ 28,317
5	0.86261	$ 7,126	$ 24,985	$ -	$ 27,700
6	0.83748	$ 7,376	$ 24,985	$ -	$ 27,102
7	0.81309	$ 7,634	$ 24,985	$ -	$ 26,522
8	0.78941	$ 7,901	$ 24,985	$ -	$ 25,961
9	0.76642	$ 8,177	$ 24,985	$ -	$ 25,416
10	0.74409	$ 8,464	$ 24,985	$ 126,500	$ 119,017
11	0.72242	$ 8,760	$ 24,985	$ -	$ 24,378
12	0.70138	$ 9,066	$ 24,985	$ -	$ 23,883
13	0.68095	$ 9,384	$ 24,985	$ -	$ 23,404
14	0.66112	$ 9,712	$ 24,985	$ -	$ 22,939
15	0.64186	$ 10,052	$ 24,985	$ -	$ 22,489
16	0.62317	$ 10,404	$ 24,985	$ -	$ 22,053
17	0.60502	$ 10,768	$ 24,985	$ -	$ 21,631
18	0.58739	$ 11,145	$ 24,985	$ -	$ 21,223
19	0.57029	$ 11,535	$ 24,985	$ -	$ 20,827
20	0.55368	$ 11,939	$ 24,985	$ 126,500	$ 90,484
				TOTAL:	**$ 662,195**

Present Value Basis Calculations - Addition 2

Net Present Value Total:	**$ 533,754**
O&M Present/Future Worth:	**$ 505,235**
Per Year O&M:	**$ 33,960**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment	Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -
1	0.97087	$ 24,840	$ 1,917	$ -	$ 25,977.58
2	0.94260	$ 25,709	$ 1,917	$ -	$ 26,040
3	0.91514	$ 26,609	$ 1,917	$ -	$ 26,105
4	0.88849	$ 27,541	$ 1,917	$ -	$ 26,173
5	0.86261	$ 28,504	$ 1,917	$ -	$ 26,242
6	0.83748	$ 29,502	$ 1,917	$ -	$ 26,313
7	0.81309	$ 30,535	$ 1,917	$ -	$ 26,386
8	0.78941	$ 31,603	$ 1,917	$ -	$ 26,461
9	0.76642	$ 32,710	$ 1,917	$ -	$ 26,538
10	0.74409	$ 33,854	$ 1,917	$ -	$ 26,617
11	0.72242	$ 35,039	$ 1,917	$ -	$ 26,698
12	0.70138	$ 36,266	$ 1,917	$ -	$ 26,780
13	0.68095	$ 37,535	$ 1,917	$ -	$ 26,865
14	0.66112	$ 38,849	$ 1,917	$ -	$ 26,951
15	0.64186	$ 40,208	$ 1,917	$ -	$ 27,039
16	0.62317	$ 41,616	$ 1,917	$ -	$ 27,128
17	0.60502	$ 43,072	$ 1,917	$ -	$ 27,219
18	0.58739	$ 44,580	$ 1,917	$ -	$ 27,312
19	0.57029	$ 46,140	$ 1,917	$ -	$ 27,406
20	0.55368	$ 47,755	$ 1,917	$ -	$ 27,502
					TOTAL: $ 533,754

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

DESIGN CRITERIA AND ASSUMPTIONS

Category	Unit Cost or Assumption			Basis
FLOW	Minimum Flow	5	MGD	Plant RW Flow Data from 2012-2015
	Average Flow	8.4	MGD	
	Maximum Flow	30	MGD	
CHEMICAL DOSE	Sodium Permanganate Design Dose	5.5	ppm	Chemical Demand Testing
	Sodium Permanganate Annual Average Dose	3.5	ppm	
	Potassium Permanganate Design Dose	6	ppm	
	Potassium Permanganate Annual Average Dose	4	ppm	
	Copper Dose (During Settlement)	5.0	ppb	Mfr Recommendations
	Copper Dose (No Settlement)	2	ppb	
	Aluminum Dose (During Settlement)	0.5	ppb	
	Aluminum Dose (No Settlement)	0.2	ppb	
CHEMICAL COST	Cost of Cu/Al Anode Cell	5,500	$/year	Mfr Cost Estimate
	Cost of Potassium Permanganate	2.0	$/lb	Carus Cost Estimate
	Cost of Sodium Permanganate	1.65	$/lb	
	Delivery Cost	500	$/delivery	Estimate
CHEMICAL PROPERTIES	Sodium Permanganate Solution Strength	40%		Mfr Specifications
	Dry Potassium Permanganate Active	97%		
CHEMICAL DOSING FREQUENCY	$NaMnO_4$ Dosing Frequency	12	hr/d	Estimate from Previous Project Experience
	$KMnO_4$ Dosing Frequency	24	hr/d	
	Copper Ion Dosing Frequency	24	hr/d	Mfr Recommendations
	Months of Chemical Feed	8	mo/yr	Estimate from Previous Project Experience
	Months of Chemical Feed (Monitoring)	5	mo/yr	
ZEBRA MUSSEL CLEANING & DISPOSAL	Mussel Coverage Without Management	30%		Estimate from Previous Project Experience
	Mussel Coverage With Management	10%		
	Average Thickness of Mussel Coverage Without Management across the Pipeline	1	inch	
	Average Thickness of Mussel Coverage With Management across the Pipeline	0.5	inch	
	Mussel Density	76	lb/cy	
	Linear feet of pipe cleaned	300	lf/day	
	Frequency of cleaning (first mile of each line)	2	every...years	
	Frequency of cleaning (entire line)	5	every...years	
	Cost of Physical Cleaning	10,000	$/day	
	Dumpster fee	150	EA (30 CY)	
	Minimum Cost for Short Distance Hauling	350	$	
	Mussel Transport to landfill	9	$/mile	
	Mussel Disposal Fee	26	$/ton	
LIFECYCLE COST	Escalation Factor	3.50%		Estimate
	Interest Rate	3%		
	Lifecycle	20	years	

Category	Unit Cost or Assumption			Basis
O&M COST	Energy Cost	0.09	$/kWh	Current Industry Rates
	Water Cost	0.0027	$/gal	
	Ion Generator Power (Maximum)	0.64	kW	
	Ion Generator Power (Minimum)	0.08	kW	
	Operator Chemical Rate	50	$/hr	
	Instrument Technician Rate	60	$/hr	
	Mechanical Technician Rate	55	$/hr	
CAPITAL COST	Mobilization and Demobilization	3%		Estimate
	General Requirements	5%		
	Bonds and Insurance	2%		
	Contractor's Profit	15%		
	Contingency	30%		
	Labor and Installation	30%		

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

OPINION OF PROBABLE CONSTRUCTION COST

		Unit Cost		Alternative A: (NaMnO$_4$ and Cu Ion System)				Alternative B: (Physical Removal & Maintenance Improvements)			
	Item Description	Unit Cost	Units	Qty	Subtotal	Installation and Labor Cost	Total Cost	Qty	Subtotal	Installation and Labor Cost	Total Cost
1	**Improving the Upper Intake Bar Screen**					**Subtotal**	**$ 51,750**			**Subtotal**	**$ 51,750**
	New Copper Alloy Bar Screen (Upper Intake)	$ 21,750	EA	1	$ 21,750	$ 30,000	$ 51,750	1	$ 21,750	$ 30,000	$ 51,750
2	**New 36" Mid-Level Intake**					**Subtotal**	**$ 451,750**			**Subtotal**	**$ 376,750**
	Construction of New Mid-Level 36" Intake	$ 250,000	EA	1	$ 250,000	$ 150,000	$ 400,000	1	$ 250,000	$ 75,000	$ 325,000
	New Copper Alloy Bar Screen (Mid Intake)	$ 21,750	EA	1	$ 21,750	$ 30,000	$ 51,750	1	$ 21,750	$ 30,000	$ 51,750
3	**Chemical System Improvements - NaMnO4 and Cu Ion System**					**Subtotal**	**$ 783,250**			**Subtotal**	**$ -**
	Double-Contained Chemical Feed Line to Upper Intake (Aboveground)	$ 40	LF	300	$ 12,000	$ 15,000	$ 27,000	0	$ -	$ -	$ -
	Double-Contained Chemical Feed Line to Mid Intake (Aboveground)	$ 40	LF	150	$ 6,000	$ 15,000	$ 21,000	0	$ -	$ -	$ -
	Miscellaneous Excavation and Backfill	$ 30	CY	40	$ 1,200	$ 360	$ 1,560	0	$ -	$ -	$ -
	275 gallon IBC Totes	$ 3,000	EA	3	$ 9,000	$ 2,700	$ 11,700	0	$ -	$ -	$ -
	500 gallon Tank	$ 2,000	EA	1	$ 2,000	$ 600	$ 2,600	0	$ -	$ -	$ -
	Lift Truck	$ 5,000	EA	1	$ 5,000	$ 1,500	$ 6,500	0	$ -	$ -	$ -
	(16'x20') 12" Concrete Enclosure Pad for Bulk Storage	$ 800	CY	20	$ 16,000	$ 4,800	$ 20,800	0	$ -	$ -	$ -
	12" Concrete Containment Walls	$ 1,000	CY	2	$ 2,000	$ 600	$ 2,600	0	$ -	$ -	$ -
	20'x20' New Chemical Building	$ 325	SF	400	$ 130,000	$ 39,000	$ 169,000	0	$ -	$ -	$ -
	Emergency Eyewash Shower	$ 5,000	EA	2	$ 10,000	$ 3,000	$ 13,000	0	$ -	$ -	$ -
	PVC Potable Water Line	$ 27	LF	500	$ 13,500	$ 4,050	$ 17,550	0	$ -	$ -	$ -
	Site Improvements (Road, Clearing & Grubbing, Fence)	$ 25,000	LS	1	$ 25,000	$ 7,500	$ 32,500	0	$ -	$ -	$ -
	Pump (Transfer, Metering)	$ 4,500	EA	2	$ 9,000	$ 2,700	$ 11,700	0	$ -	$ -	$ -
	Chemical Piping and Valves	$ 35,000	LS	1	$ 35,000	$ 10,500	$ 45,500	0	$ -	$ -	$ -
	Water Quality Analyzers	$ 15,000	LS	1	$ 15,000	$ 4,500	$ 19,500	0	$ -	$ -	$ -
	Copper Ion Skid with PLC and 3 Cells	$ 115,000	LS	1	$ 115,000	$ 34,500	$ 149,500	0	$ -	$ -	$ -
	Spare 10 MGD Cell	$ 5,500	EA	1	$ 5,500	$ -	$ 5,500	0	$ -	$ -	$ -
	Self Backwashing Strainer	$ 2,000	EA	2	$ 4,000	$ -	$ 4,000	0	$ -	$ -	$ -
	Instrumentation and Controls	$ 80,000	LS	1	$ 80,000	$ -	$ 80,000	0	$ -	$ -	$ -
	Electrical	**20%**	LS	1	$ 141,740	$ -	$ 141,740	0	$ -	$ -	$ -
4	**Physical Removal of Zebra Mussels**					**Subtotal**	**$ 167,600**			**Subtotal**	**$ 1,179,700**
	Installation of 4' Manway (27" and 30")	$ 20,000	EA	2	$ 40,000	$ 12,000	$ 52,000	30	$ 600,000	$ 180,000	$ 780,000
	Cleaning: Physical Removal and Disposal[1]		LS	1	$ 115,600	$ -	$ 115,600	1	$ 399,700	$ -	$ 399,700

SUBTOTAL		$ 1,454,400	$ 1,608,200
GENERAL REQUIREMENTS	**5%**	$ 72,720	$ 80,410
MOBILIZATION/DEMOBILIZATION	**3%**	$ 43,632	$ 48,246
BONDS AND INSURANCE	**2%**	$ 29,088	$ 32,164
CONTRACTOR'S PROFIT	**15%**	$ 218,160	$ 241,230
SUBTOTAL		$ 1,818,000	$ 2,010,300
CONTINGENCY	**30%**	$ 545,400	$ 603,090
TOTAL OPINION OF PROBABLE CONSTRUCTION COST		**$ 2,360,000**	**$ 2,610,000**
ENGINEERING AND CONSTRUCTION ADMINISTRATION		**$ 480,000**	**$ 530,000**

Substitutions and Additional Items

Item Description	Unit Cost	Units	Qty.	Subtotal	Installation and Labor Cost	Contractor Costs (25%)	Contingency (30%)	Total Cost	Cost Difference	Eng. & Const. Admin
Substitution 1: SS Bar Screen with Jacquelyn Coating (Two Intakes	$ 10,250	EA	2	$ 20,500	$ 30,000	$ 12,625	$ 18,938	**$ 82,063**	**$ (86,125)**	
Substitution 2: Chemical Feed Line (Through Pipeline)	$ 5,000	LS	1	$ 5,000	$ 30,000	$ 8,750	$ 13,125	**$ 56,875**	**$ 29,875**	**$ 10,000**
Addition 1: Lower 36" Intake Improvements				$ 147,750	$ 81,000	$ 57,188	$ 85,781	**$ 371,719**	**$ 371,719**	**$ 80,000**
Dredging of Lower 36" Intake	$120,000	LS	1	$ 120,000	$ 36,000					
New Copper Alloy Bar Screen (Lower Intake)	$ 21,750	EA	1	$ 21,750	$ 30,000					
Chemical Feed Line to Intake (Aboveground)	$ 40	LF	150	$ 6,000	$ 15,000					
Addition 2: PVC Potable Water Line	$ 27	LF	500	$ 13,500	$ 4,050	$ 4,388	$ 6,581	**$ 28,519**	**$ 28,519**	**$ 10,000**
Addition 3: Land Rights for Maintenance Access[2]	$ 5,000	EA	30	$ 150,000	$ -	$ 37,500	$ 56,250	**$ 243,750**	**$ 243,750**	**$ 50,000**
Addition 4: Site Improvements for Maintenance Access[2]	$ 5,000	EA	30	$ 150,000	$ -	$ 37,500	$ 56,250	**$ 243,750**	**$ 243,750**	**$ 50,000**

[1] Physical removal and disposal costs presented under the capital costs are the costs of a one-time cleaning; although removal and disposal are assumed to be required every 2 years

[2] Potential variable costs that may be required for physical removal and disposal access in pipeline segments where property is not owned by COD. Necessity of these variable costs to be determined during detaile

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

O&M COST SUMMARY

	Unit Cost		Alternative A: (NaMnO4 System, 5 months)		Alternative A: (NaMnO4 System, 8 months)		Alternative A: (Cu Ion System)		Alternative B: (Physical Removal & Maintenance Improvements)	
Item Description	**Unit Cost**	**Unit**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**
Annual O&M Costs										
Monitoring and CCTV	$ 25,000	LS	1	$ 25,000	0.5	$ 12,500	0.75	$ 18,750	1	$ 25,000
Chemical Cost		LS[1]	1	$ 30,849	1	$ 49,358	1	$ -	0	$ -
Freight Charge	$ 500	EA	6	$ 3,000	8	$ 4,107	1	$ 500	0	$ -
Personnel Cost		LS[1]	1	$ 12,200	1	$ 19,520	1	$ 19,163	0	$ -
Operating Cost (Energy, Water)		LS[1]	1	$ 966	1	$ 1,546	1	$ 505	0	$ -
Equipment Maintenance	$ 1,000	LS	1	$ 1,000	1	$ 1,000	1	$ 1,000	0	$ -
Annual Physical Removal Costs										
Light Power Washing of Bar Screens	$ 1,000	LS	1	$ 1,000	1	$ 1,000	1	$ 1,000	1	$ 1,000
Cleaning: Physical Removal and Disposal[2]		LS[1]	1	$ 57,800	1	$ 57,800	1	$ 57,800	1	$ 199,850
			SUBTOTAL:	**$ 131,815**	**SUBTOTAL:**	**$ 146,831**	**SUBTOTAL:**	**$ 98,717**	**SUBTOTAL:**	**$ 225,850**
Replacement Costs										
Cu Ion Cell Replacement (Annual)	$ 5,500	EA	0	$ -	0	$ -	4	$ 22,000	0	$ -
Chemical Pump Replacement (10 years)	$ 4,500	LS	2	$ 9,000	2	$ 9,000	0	$ -	0	$ -
Full Pipeline Chemical Cleaning (5 years)	$697,260	LS	0	$ -	0	$ -	0	$ -	1	$ 697,260

[1] Unit costs vary per alternative and are presented on the detailed O&M cost page.

[2] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations it was converted to an annual maintenance cost.

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

O&M COST SUMMARY (Substitutions and Additions)

	Unit Cost		Substitution 1: SS Bar Screen with Jacquelyn Coating (Two Intakes)[3]			Addition 1: Lower 36" Intake Improvements			Addition 2: PVC Potable Water Line		
Item Description	**Unit Cost**	**Unit**	**Qty**		**Cost Estimate**	**Qty**		**Cost Estimate**	**Qty**		**Cost Estimate**
Annual O&M Costs											
Monitoring and CCTV	$ 25,000	LS	0	$	-	0.1	$	2,500	0	$	-
Chemical Cost		LS[1]	0	$	-	0	$	-	0	$	-
Freight Charge	$ 500	EA	0	$	-	0	$	-	0	$	-
Personnel Cost		LS[1]	0	$	-	0	$	-	0	$	-
Operating Cost (Energy, Water)		LS[1]	0	$	-	0	$	-	0	$	24,000
Equipment Maintenance	$ 1,000	LS	0	$	-	0	$	-	0	$	-
Annual Physical Removal Costs											
Light Power Washing of Bar Screens	$ 1,000	LS	0	$	-	0.5	$	500	0	$	-
Cleaning: Physical Removal and Disposal[2]		LS[1]	0	$	-	1	$	3,000	0	$	-
			SUBTOTAL:	**$**	**-**	**SUBTOTAL:**	**$**	**6,000**	**SUBTOTAL:**	**$**	**24,000**
Replacement Costs											
Bar Screen Coating (10 years)	$ 6,500	EA	3	$	19,500	1	$	6,500	0	$	-
Extra Bar Screen To Cycle Replacement	$ 41,031	LS	1	$	41,031	0	$	-	0	$	-
Periodic Dredging of Lower Intake (10 years)	$ 120,000	LS	0	$	-	1	$	120,000	0	$	-

[1] Unit costs vary per alternative and are presented on the detailed O&M cost page.

[2] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations it was converted to an annual maintenance cost.

[3] Subsitutions are represented by the price difference as compared to the respective base option(s).

Zebra Mussel Control Alternatives Evaluation - Lake Lewisville

DETAILED O&M COSTS

	Alternative A: NaMnO4, 5 months	Alternative A: NaMnO4, 8 months	Alternative B: Copper Ion System	Alternative C: Physical Removal and Maintenance Improvements	Addition 1: Lower Intake Improvements	Addition 2: PVC Potable Water Line
PERSONNEL COST						
Operator (hr/day)	0.5	0.5	0.5	0	0	0
Operator Rate ($/hr)	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
Operator Cost ($/day)	$ 25	$ 25	$ 25	$ -	$ -	$ -
Instrument Tech (hr/day)	0	0	0	0	0	0
Instrument Tech Rate ($/hr)	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
Instrument Tech Cost ($/day)	$ -	$ -	$ -	$ -	$ -	$ -
Mechanical Tech (hr/day)	1	1	0.5	0	0	0
Mechanical Tech Rate ($/hr)	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55
Mechanical Tech Cost ($/day)	$ 55	$ 55	$ 28	$ -	$ -	$ -
Personnel Cost ($/day)	$ 80	$ 80	$ 53	$ -	$ -	$ -
Days of Operation (days/yr)	153	244	365	0	0	244
Personnel Cost ($/yr)	**$ 12,200**	**$ 19,520**	**$ 19,163**	**$ -**	**$ -**	**$ -**
POWER COST						
MIXER MOTOR						
No. of Mixers	0	0	0	0	0	0
Mixer Power Use (kWh/day)	0	0	0	0	0	0
Mixer Motor Usage (hr/day)	0	0	0	0	0	0
FEED PUMP						
No. of Motors	1	1	0	0	0	0
Motor Power Use (kWh/day)	120	120	0	0	0	0
Motor Usage (hr/day)	12	12	0	0	0	0
TRANSFER PUMP						
No. of Motors	1	1	0	0	0	0
Motor Power Use (kWh/day)	500	500	0	0	0	0
Motor Usage (hr/day)	0.5	0.5	0	0	0	0
ION GENERATOR						
Ion Generator Usage (hr/day)	0	0	24	0	0	0
Ion Generator Power Use (kW)	0	0	0.64	0	0	0
POWER						
Energy Rate ($/kWh)	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
Power Cost ($/day)	$ 6.34	6.34	$ 1.38	$ -	$ -	$ -
Power Cost ($/yr)	**$ 966**	**$ 1,546**	**$ 505**	**$ -**	**$ -**	**$ -**
WATER COST						
Target Flowrate (gpm)	0	0	0	0	0	50
Water Usage (gal/day)	0	0	0	0	0	36,000
Water Rate ($/gal)	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027
Water Cost ($/day)	$ -	$ -	$ -	$ -	$ -	$ 97
Water Cost ($/yr)	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 23,717**

	Alternative A: NaMnO4, 5 months	Alternative A: NaMnO4, 8 months	Alternative B: Copper Ion System	Alternative C: Physical Removal and Maintenance Improvements	Addition 1: Lower Intake Improvements	Addition 2: PVC Potable Water Line
CHEMICAL COST						
Chemical Unit Cost ($/lb)	$ 1.65	$ 1.65	$ -	$1.99	$/lb	$0.00
Chemical Usage (lb/day)	123	123	0	0	0	0
Daily Cost ($/day)	$ 202	202	$ -	$ -	$ -	$ -
Annual Cost ($/year)	**$ 30,849**	**$ 49,358**	**$ -**	**$ -**	**$ -**	**$ -**
PHYSICAL REMOVAL COST						
Frequency of Cleaning (Every….years)	2	2	2	2	2	0
Days of Physical Cleaning (days)	10	10	10	34.7	0.5	0.0
Hausting Distance to Landfill (mi)	8	8	8	8	8	8
Mussel Coverage (%)	10%	10%	10%	30%	10%	10%
Thickness of Mussel Coverage (in)	0.5	0.5	0.5	1	1	1
Average Pipeline Diameter (ft)	2.6	2.6	2.6	2.6	2.6	2.6
Mussel Coverage Distance (ft)	10,400	10,400	10,400	10,400	10,400	10,400
Mussel Coverage Surface Area (ft^2)	8,440	8,440	8,440	25,321	8,440	8,440
Zebra Mussel Removal Volume (cy)	13	13	13	78	13	13
Mussel Density (lb/cy)	76	76	76	76	76	76
Cost of Physical Cleaning ($)	$ 100,000	$ 100,000	$ 100,000	$ 346,667	$ 5,000	$ -
Cost of Transport to Landfill ($)	$ 350	$ 350	$ 350	$ 350	$ 350	$ 350
Zebra Mussel Disposal Cost ($)	$ 13	$ 13	$ 13	$ 77	$ 13	$ 13
Dumpster Fee ($)	$ 150	$ 150	$ 150	$ 450	$ 150	$ 150
Mobilization, Demobilization, Bonds, etc. ($)	$ 15,077	$ 15,077	$ 15,077	$ 52,132	$ 827	$ 77
Physical Removal Cost ($/cleaning)	**$ 115,600**	**$ 115,600**	**$ 115,600**	**$ 399,700**	**$ 6,400**	**$ 600**
Physical Removal Cost[1] ($/year)	**$ 57,800**	**$ 57,800**	**$ 57,800**	**$ 199,850**	**$ 3,200**	**0**
TOTAL O&M COST ($/YEAR):	**$ 101,900**	**$ 128,300**	**$ 77,500**	**$ 199,900**	**$ 3,200**	**$ 23,800**

[1] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations it was converted to an annual maintenance cost.

RRWTP PIPELINE VELOCITY CALCULATIONS

The RRWTP intake consists ofa 60-inch pipeline leading to the raw water pump station. A 42-inch pipelines exits the pump station and leads to the treatment plant. Table 1 displays the velocity and residence time within each pipe segment.

Table E-4: RRWTP Approximate Velocities and Oxidant Residence Times

Beginning Facility	Ending Facility	Water Treatment Plant	Pipe Diameter (in.)	Pipe Area (ft^2)	Pipe Length (ft)	Flow (MGD) at 6 ft/s	Min. Flow [1] (MGD)	Velocity (ft/s)	Min. Flow - Chemical Residence Time (hrs)	Avg. Flow [2] (MGD)	Velocity (ft/s)	Avg. Flow - Chemical Residence Time (hrs)	Max. Flow [1] (MGD)	Velocity (ft/s)	Max. Flow - Chemical Residence Time (hrs)
Lake Ray Roberts Intake	Vault	RRWTP	60	19.6	777	76	5	0.39	0.55	9.9	0.78	0.28	20	1.58	0.14
Vault	Raw Water Pump Station	RRWTP	60	19.6	294	76	5	0.39	0.21	9.9	0.78	0.10	20	1.58	0.05
Raw Water Pump Station	RRWTP	RRWTP	42	9.6	3,090	37	5	0.80	1.07	9.9	1.59	0.54	20	3.22	0.27

The total minimum and maximum chemical residence times were determined by selecting the shortest and longest residence times for each combination of intake pipe and pump station outlet pipe and combining them for a total residence time for that pipe system combination. The results can be seen in Table E-4.

Table E-5: Lake Ray Roberts Chemical Residence Time

Beginning Facility	Middle Facility	Ending Facility	Water Treatment Plant	Avg. Flow Total Chemical Residence Time (hrs)	Min. Flow Total Chemical Residence Time (hrs)	Max. Flow Total Chemical Residence Time (hrs)
Lake Ray Roberts Intake	Vault	RRWTP	RRWTP	0.92	1.82	0.46

RRWTP HYDRAULIC CALCULATIONS

RR Raw Water System Headloss without Infestation (60" Pipeline)

Gravity: 32.2 ft/sec2

C (Hz/Wm): 130 for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}: 0.00 ft

Min WSE Z = Static Head, h_{ST}: 0.00 ft

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Wye	0.5
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Frictional Losses:

Hazen Williams Equation (rearranged):

Friction loss through Pipe $H_f = \dfrac{(10.44)(L\ ft)(Q\ gpm)^{\wedge}1{,}85}{(C^{\wedge}1.85)(d\ in)^{\wedge}4.8655}$

Minor losses $H_m = K^* v^2/2g$

$$H_L = H_f + H_m$$

Q = **9.90** **MGD** Average Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	60	0	0.50	6,875	15.32	0.78	0.00	0.00	0.00	0.00
45 Deg	60	0	0.15	6,875	15.32	0.78	0.00	0.00	0.00	0.01
PIPE	60	56	0.00	6,875	15.32	0.78	0.00	0.00	0.00	0.01
45 Deg	60	0	0.15	6,875	15.32	0.78	0.00	0.00	0.00	0.01
PIPE	60	900	0.00	6,875	15.32	0.78	0.03	0.00	0.03	0.04
45 Deg	60	0	0.15	6,875	15.32	0.78	0.00	0.00	0.00	0.04
PIPE	60	60	0.00	6,875	15.32	0.78	0.00	0.00	0.00	0.05
Wye	60	0	0.50	6,875	15.32	0.78	0.00	0.00	0.00	0.05
PIPE	60	50	0.00	6,875	15.32	0.78	0.00	0.00	0.00	0.05
Wye	60	0	0.50	6,875	15.32	0.78	0.00	0.00	0.00	0.06
PIPE	60	90	0.00	6,875	15.32	0.78	0.00	0.00	0.00	0.06
45 Deg	60	0	0.15	6,875	15.32	0.78	0.00	0.00	0.00	0.06
PIPE	60	280	0.00	6,875	15.32	0.78	0.01	0.00	0.01	0.07
45 Deg	60	0	0.15	6,875	15.32	0.78	0.00	0.00	0.00	0.07
PIPE	60	30	0.00	6,875	15.32	0.78	0.00	0.00	0.00	0.07
	Length:	1,466								0.07
		Sum Ks:	2.3							

Q = 20 **MGD** Max Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	60	0	0.50	13,889	30.95	1.58	0.00	0.02	0.02	0.02
45 Deg	60	0	0.15	13,889	30.95	1.58	0.00	0.01	0.01	0.03
PIPE	60	56	0.00	13,889	30.95	1.58	0.01	0.00	0.01	0.03
45 Deg	60	0	0.15	13,889	30.95	1.58	0.00	0.01	0.01	0.04
PIPE	60	900	0.00	13,889	30.95	1.58	0.12	0.00	0.12	0.16
45 Deg	60	0	0.15	13,889	30.95	1.58	0.00	0.01	0.01	0.16
PIPE	60	60	0.00	13,889	30.95	1.58	0.01	0.00	0.01	0.17
Wye	60	0	0.50	13,889	30.95	1.58	0.00	0.02	0.02	0.19
PIPE	60	50	0.00	13,889	30.95	1.58	0.01	0.00	0.01	0.20
Wye	60	0	0.50	13,889	30.95	1.58	0.00	0.02	0.02	0.22
PIPE	60	90	0.00	13,889	30.95	1.58	0.01	0.00	0.01	0.23
45 Deg	60	0	0.15	13,889	30.95	1.58	0.00	0.01	0.01	0.23
PIPE	60	280	0.00	13,889	30.95	1.58	0.04	0.00	0.04	0.27
45 Deg	60	0	0.15	13,889	30.95	1.58	0.00	0.01	0.01	0.28
PIPE	60	30	0.00	13,889	30.95	1.58	0.00	0.00	0.00	0.28
	Length:	1,466								0.28
		Sum Ks:	2.3							

RR Raw Water System Headloss with Infestation (60" Pipeline)

Gravity: 32.2 ft/sec2
C (Hz/Wm): 60 for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}: 0.00 ft
Min WSE Z = Static Head, h_{ST}: 0.00 ft

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Wye	1
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Frictional Losses:

Hazen Williams Equation (rearranged):

$$\text{Friction loss through Pipe } H_f = \frac{(10.44)(L\ ft)(Q\ gpm)^{1,85}}{(C^{1.85})(d\ in)^{4.8655}}$$

$$\text{Minor losses } H_m = K^* v^2/2g$$

$$H_L = H_f + H_m$$

Q = 9.90 **MGD** Average Flow

Friction and Minor Losses Description	Dia.[1] (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	48	0	0.50	6,875	15.32	1.22	0.00	0.01	0.01	0.01
45 Deg	48	0	0.15	6,875	15.32	1.22	0.00	0.00	0.00	0.02
PIPE	48	56	0.00	6,875	15.32	1.22	0.02	0.00	0.02	0.04
45 Deg	48	0	0.15	6,875	15.32	1.22	0.00	0.00	0.00	0.04
PIPE	48	900	0.00	6,875	15.32	1.22	0.40	0.00	0.40	0.44
45 Deg	48	0	0.15	6,875	15.32	1.22	0.00	0.00	0.00	0.45
PIPE	48	60	0.00	6,875	15.32	1.22	0.03	0.00	0.03	0.47
Wye	48	0	1.00	6,875	15.32	1.22	0.00	0.02	0.02	0.50
PIPE	48	50	0.00	6,875	15.32	1.22	0.02	0.00	0.02	0.52
Wye	48	0	1.00	6,875	15.32	1.22	0.00	0.02	0.02	0.54
PIPE	48	90	0.00	6,875	15.32	1.22	0.04	0.00	0.04	0.58
45 Deg	48	0	0.15	6,875	15.32	1.22	0.00	0.00	0.00	0.59
PIPE	48	280	0.00	6,875	15.32	1.22	0.12	0.00	0.12	0.71
45 Deg	48	0	0.15	6,875	15.32	1.22	0.00	0.00	0.00	0.71
PIPE	48	30	0.00	6,875	15.32	1.22	0.01	0.00	0.01	0.73
	Length:	1,466								0.73
		Sum Ks:	3.3							

Q = **20** **MGD** Max Flow

Friction and Minor Losses Description	Dia.[1] (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Entrance	48	0	0.50	13,889	30.95	2.46	0.00	0.05	0.05	0.05
45 Deg	48	0	0.15	13,889	30.95	2.46	0.00	0.01	0.01	0.06
PIPE	48	56	0.00	13,889	30.95	2.46	0.09	0.00	0.09	0.15
45 Deg	48	0	0.15	13,889	30.95	2.46	0.00	0.01	0.01	0.17
PIPE	48	900	0.00	13,889	30.95	2.46	1.47	0.00	1.47	1.64
45 Deg	48	0	0.15	13,889	30.95	2.46	0.00	0.01	0.01	1.65
PIPE	48	60	0.00	13,889	30.95	2.46	0.10	0.00	0.10	1.75
Wye	48	0	1.00	13,889	30.95	2.46	0.00	0.09	0.09	1.84
PIPE	48	50	0.00	13,889	30.95	2.46	0.08	0.00	0.08	1.92
Wye	48	0	1.00	13,889	30.95	2.46	0.00	0.09	0.09	2.02
PIPE	48	90	0.00	13,889	30.95	2.46	0.15	0.00	0.15	2.17
45 Deg	48	0	0.15	13,889	30.95	2.46	0.00	0.01	0.01	2.18
PIPE	48	280	0.00	13,889	30.95	2.46	0.46	0.00	0.46	2.64
45 Deg	48	0	0.15	13,889	30.95	2.46	0.00	0.01	0.01	2.65
PIPE	48	30	0.00	13,889	30.95	2.46	0.05	0.00	0.05	2.70
	Length:	1,466								2.70
		Sum Ks:	3.3							

1 - Diameter reduced assuming 6" depth of mussels around pipeline circumference.

RR Raw Water System Headloss without Infestation (42" Pipeline)

Gravity:	32.2	ft/sec2
C (Hz/Wm):	130	for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}:	0.00	ft
Min WSE Z = Static Head, h_{ST}:	0.00	ft

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Wye	0.5
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Frictional Losses:

Hazen Williams Equation (rearranged):

Friction loss through Pipe $H_f = \frac{(10.44)(L\ ft)(Q\ gpm)^{1.85}}{(C^{1.85})(d\ in)^{4.8655}}$

Minor losses $H_m = K^* v^2/2g$

$$H_L = H_f + H_m$$

Q = 9.90 **MGD** Average Flow

<u>**Friction and Minor Losses**</u> Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Reducer	42	0	0.30	6,875	15.32	1.59	0.00	0.01	0.01	0.01
PIPE	42	60	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.02
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.03
PIPE	42	5	0.00	6,875	15.32	1.59	0.00	0.00	0.00	0.03
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.04
Reducer	36	0	0.30	6,875	15.32	2.17	0.00	0.02	0.02	0.06
PIPE	36	35	0.00	6,875	15.32	2.17	0.02	0.00	0.02	0.07
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	0.08
Reducer	42	0	0.30	6,875	15.32	1.59	0.00	0.01	0.01	0.10
PIPE	42	55	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.11
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.11
PIPE	42	100	0.00	6,875	15.32	1.59	0.02	0.00	0.02	0.13
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.14
PIPE	42	500	0.00	6,875	15.32	1.59	0.10	0.00	0.10	0.24
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.25
PIPE	42	325	0.00	6,875	15.32	1.59	0.07	0.00	0.07	0.31
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.32
PIPE	42	700	0.00	6,875	15.32	1.59	0.14	0.00	0.14	0.46

45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.47
PIPE	42	125	0.00	6,875	15.32	1.59	0.03	0.00	0.03	0.49
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.50
PIPE	42	275	0.00	6,875	15.32	1.59	0.06	0.00	0.06	0.56
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.56
PIPE	42	360	0.00	6,875	15.32	1.59	0.07	0.00	0.07	0.63
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.64
PIPE	42	30	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.65
90 Deg	42	0	0.20	6,875	15.32	1.59	0.00	0.01	0.01	0.65
PIPE	42	20	0.00	6,875	15.32	1.59	0.00	0.00	0.00	0.66
90 Deg	42	0	0.20	6,875	15.32	1.59	0.00	0.01	0.01	0.67
PIPE	42	100	0.00	6,875	15.32	1.59	0.02	0.00	0.02	0.69
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.69
PIPE	42	160	0.00	6,875	15.32	1.59	0.03	0.00	0.03	0.73
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.73
PIPE	42	50	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.74
90 Deg	42	0	0.20	6,875	15.32	1.59	0.00	0.01	0.01	0.75
PIPE	42	240	0.00	6,875	15.32	1.59	0.05	0.00	0.05	0.80
Reducer	54	0	0.30	6,875	15.32	0.96	0.00	0.00	0.00	0.80
PIPE	54	10	0.00	6,875	15.32	0.96	0.00	0.00	0.00	0.80
90 Deg	54	0	0.20	6,875	15.32	0.96	0.00	0.00	0.00	0.81
PIPE	42	50	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.82
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.82
PIPE	42	30	0.00	6,875	15.32	1.59	0.01	0.00	0.01	0.83
45 Deg	42	0	0.15	6,875	15.32	1.59	0.00	0.01	0.01	0.83
PIPE	42	20	0.00	6,875	15.32	1.59	0.00	0.00	0.00	0.84
Exit	36	0	1.00	6,875	15.32	2.17	0.00	0.07	0.07	0.91
	Length:	3,250								0.91
		Sum Ks:	5.3							

Q = 20 **MGD** Max Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Reducer	42	0	0.30	13,889	30.95	3.22	0.00	0.05	0.05	0.05
PIPE	42	60	0.00	13,889	30.95	3.22	0.04	0.00	0.04	0.09
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	0.12
PIPE	42	5	0.00	13,889	30.95	3.22	0.00	0.00	0.00	0.12
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	0.15
Reducer	36	0	0.30	13,889	30.95	4.38	0.00	0.09	0.09	0.23
PIPE	36	35	0.00	13,889	30.95	4.38	0.06	0.00	0.06	0.29
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	0.33
Reducer	42	0	0.30	13,889	30.95	3.22	0.00	0.05	0.05	0.38
PIPE	42	55	0.00	13,889	30.95	3.22	0.04	0.00	0.04	0.42
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	0.45
PIPE	42	100	0.00	13,889	30.95	3.22	0.07	0.00	0.07	0.52
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	0.55
PIPE	42	500	0.00	13,889	30.95	3.22	0.37	0.00	0.37	0.92
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	0.94
PIPE	42	325	0.00	13,889	30.95	3.22	0.24	0.00	0.24	1.19
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	1.21
PIPE	42	700	0.00	13,889	30.95	3.22	0.52	0.00	0.52	1.74
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	1.76
PIPE	42	125	0.00	13,889	30.95	3.22	0.09	0.00	0.09	1.85
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	1.88
PIPE	42	275	0.00	13,889	30.95	3.22	0.21	0.00	0.21	2.08
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	2.11
PIPE	42	360	0.00	13,889	30.95	3.22	0.27	0.00	0.27	2.38
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	2.40
PIPE	42	30	0.00	13,889	30.95	3.22	0.02	0.00	0.02	2.42
90 Deg	42	0	0.20	13,889	30.95	3.22	0.00	0.03	0.03	2.46
PIPE	42	20	0.00	13,889	30.95	3.22	0.01	0.00	0.01	2.47
90 Deg	42	0	0.20	13,889	30.95	3.22	0.00	0.03	0.03	2.50

PIPE	42	100	0.00	13,889	30.95	3.22	0.07	0.00	0.07	2.58
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	2.60
PIPE	42	160	0.00	13,889	30.95	3.22	0.12	0.00	0.12	2.72
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	2.74
PIPE	42	50	0.00	13,889	30.95	3.22	0.04	0.00	0.04	2.78
90 Deg	42	0	0.20	13,889	30.95	3.22	0.00	0.03	0.03	2.81
PIPE	42	240	0.00	13,889	30.95	3.22	0.18	0.00	0.18	2.99
Reducer	54	0	0.30	13,889	30.95	1.95	0.00	0.02	0.02	3.01
PIPE	54	10	0.00	13,889	30.95	1.95	0.00	0.00	0.00	3.01
90 Deg	54	0	0.20	13,889	30.95	1.95	0.00	0.01	0.01	3.03
PIPE	42	50	0.00	13,889	30.95	3.22	0.04	0.00	0.04	3.06
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	3.09
PIPE	42	30	0.00	13,889	30.95	3.22	0.02	0.00	0.02	3.11
45 Deg	42	0	0.15	13,889	30.95	3.22	0.00	0.02	0.02	3.13
PIPE	42	20	0.00	13,889	30.95	3.22	0.01	0.00	0.01	3.15
Exit	36	0	1.00	13,889	30.95	4.38	0.00	0.30	0.30	3.45
	Length:	3,250								3.45
		Sum Ks:	5.3							

RR Raw Water System Headloss with Infestation (42" Pipeline)

Gravity:	32.2	ft/sec2
C (Hz/Wm):	60	for Concrete Pipe

Static Head:

Max WSE Z = Static Head, h_{ST}:	0.00	ft
Min WSE Z = Static Head, h_{ST}:	0.00	ft

Frictional Losses:

Hazen Williams Equation (rearranged):

Friction loss through Pipe $H_f = \frac{(10.44)(L\ ft)(Q\ gpm)^{1.85}}{(C^{1.85})(d\ in)^{4.8655}}$

Minor losses $H_m = K^* v^2/2g$

$$H_L = H_f + H_m$$

Q = 9.90 **MGD** Average Flow

K values	Fitting
Entrance	0.5
Reducer	0.3
90 Deg	0.2
45 Deg	0.15
Flow Meter	0
Tee Straight	0.5
Tee Branch	1
Wye	1
Gate Valve	0.2
Butterfly Valve	0.4
Exit	1

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Reducer	36	0	0.30	6,875	15.32	2.17	0.00	0.02	0.02	0.02
PIPE	36	60	0.00	6,875	15.32	2.17	0.11	0.00	0.11	0.13
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	0.14
PIPE	36	5	0.00	6,875	15.32	2.17	0.01	0.00	0.01	0.15
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	0.16
Reducer	30	0	0.30	6,875	15.32	3.12	0.00	0.05	0.05	0.21
PIPE	30	35	0.00	6,875	15.32	3.12	0.15	0.00	0.15	0.36
45 Deg	30	0	0.15	6,875	15.32	3.12	0.00	0.02	0.02	0.38
Reducer	36	0	0.30	6,875	15.32	2.17	0.00	0.02	0.02	0.40
PIPE	36	55	0.00	6,875	15.32	2.17	0.10	0.00	0.10	0.50
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	0.51
PIPE	36	100	0.00	6,875	15.32	2.17	0.18	0.00	0.18	0.69
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	0.71
PIPE	36	500	0.00	6,875	15.32	2.17	0.90	0.00	0.90	1.61
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	1.62
PIPE	36	325	0.00	6,875	15.32	2.17	0.59	0.00	0.59	2.20
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	2.21
PIPE	36	700	0.00	6,875	15.32	2.17	1.26	0.00	1.26	3.48

45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	3.49
PIPE	36	125	0.00	6,875	15.32	2.17	0.23	0.00	0.23	3.71
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	3.72
PIPE	36	275	0.00	6,875	15.32	2.17	0.50	0.00	0.50	4.22
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	4.23
PIPE	36	360	0.00	6,875	15.32	2.17	0.65	0.00	0.65	4.88
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	4.89
PIPE	36	30	0.00	6,875	15.32	2.17	0.05	0.00	0.05	4.94
90 Deg	36	0	0.20	6,875	15.32	2.17	0.00	0.01	0.01	4.96
PIPE	36	20	0.00	6,875	15.32	2.17	0.04	0.00	0.04	4.99
90 Deg	36	0	0.20	6,875	15.32	2.17	0.00	0.01	0.01	5.01
PIPE	36	100	0.00	6,875	15.32	2.17	0.18	0.00	0.18	5.19
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	5.20
PIPE	36	160	0.00	6,875	15.32	2.17	0.29	0.00	0.29	5.49
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	5.50
PIPE	36	50	0.00	6,875	15.32	2.17	0.09	0.00	0.09	5.59
90 Deg	36	0	0.20	6,875	15.32	2.17	0.00	0.01	0.01	5.60
PIPE	36	240	0.00	6,875	15.32	2.17	0.43	0.00	0.43	6.04
Reducer	48	0	0.30	6,875	15.32	1.22	0.00	0.01	0.01	6.04
PIPE	48	10	0.00	6,875	15.32	1.22	0.00	0.00	0.00	6.05
90 Deg	48	0	0.20	6,875	15.32	1.22	0.00	0.00	0.00	6.05
PIPE	36	50	0.00	6,875	15.32	2.17	0.09	0.00	0.09	6.14
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	6.15
PIPE	36	30	0.00	6,875	15.32	2.17	0.05	0.00	0.05	6.21
45 Deg	36	0	0.15	6,875	15.32	2.17	0.00	0.01	0.01	6.22
PIPE	36	20	0.00	6,875	15.32	2.17	0.04	0.00	0.04	6.26
Exit	30	0	1.00	6,875	15.32	3.12	0.00	0.15	0.15	6.41
	Length:	3,250								6.41
		Sum Ks:	5.3							

Q = **20** **MGD** Max Flow

Friction and Minor Losses Description	Dia. (in.)	Length (ft)	K	Capacity (Q) (gpm)	Capacity (Q) (cfs)	Velocity (fps)	Hf (ft)	Hm (ft)	H_L (ft)	Total H_L (ft)
Reducer	36	0	0.30	13,889	30.95	4.38	0.00	0.09	0.09	0.09
PIPE	36	60	0.00	13,889	30.95	4.38	0.40	0.00	0.40	0.49
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	0.53
PIPE	36	5	0.00	13,889	30.95	4.38	0.03	0.00	0.03	0.56
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	0.61
Reducer	30	0	0.30	13,889	30.95	6.30	0.00	0.19	0.19	0.79
PIPE	30	35	0.00	13,889	30.95	6.30	0.56	0.00	0.56	1.36
45 Deg	30	0	0.15	13,889	30.95	6.30	0.00	0.09	0.09	1.45
Reducer	36	0	0.30	13,889	30.95	4.38	0.00	0.09	0.09	1.54
PIPE	36	55	0.00	13,889	30.95	4.38	0.36	0.00	0.36	1.90
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	1.95
PIPE	36	100	0.00	13,889	30.95	4.38	0.66	0.00	0.66	2.61
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	2.65
PIPE	36	500	0.00	13,889	30.95	4.38	3.31	0.00	3.31	5.96
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	6.01
PIPE	36	325	0.00	13,889	30.95	4.38	2.15	0.00	2.15	8.16
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	8.20
PIPE	36	700	0.00	13,889	30.95	4.38	4.63	0.00	4.63	12.84
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	12.88
PIPE	36	125	0.00	13,889	30.95	4.38	0.83	0.00	0.83	13.71
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	13.76
PIPE	36	275	0.00	13,889	30.95	4.38	1.82	0.00	1.82	15.58
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	15.62
PIPE	36	360	0.00	13,889	30.95	4.38	2.38	0.00	2.38	18.00
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	18.05
PIPE	36	30	0.00	13,889	30.95	4.38	0.20	0.00	0.20	18.25
90 Deg	36	0	0.20	13,889	30.95	4.38	0.00	0.06	0.06	18.31
PIPE	36	20	0.00	13,889	30.95	4.38	0.13	0.00	0.13	18.44
90 Deg	36	0	0.20	13,889	30.95	4.38	0.00	0.06	0.06	18.50
PIPE	36	100	0.00	13,889	30.95	4.38	0.66	0.00	0.66	19.16

45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	19.21
PIPE	36	160	0.00	13,889	30.95	4.38	1.06	0.00	1.06	20.26
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	20.31
PIPE	36	50	0.00	13,889	30.95	4.38	0.33	0.00	0.33	20.64
90 Deg	36	0	0.20	13,889	30.95	4.38	0.00	0.06	0.06	20.70
PIPE	36	240	0.00	13,889	30.95	4.38	1.59	0.00	1.59	22.29
Reducer	48	0	0.30	13,889	30.95	2.46	0.00	0.03	0.03	22.32
PIPE	48	10	0.00	13,889	30.95	2.46	0.02	0.00	0.02	22.33
90 Deg	48	0	0.20	13,889	30.95	2.46	0.00	0.02	0.02	22.35
PIPE	36	50	0.00	13,889	30.95	4.38	0.33	0.00	0.33	22.68
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	22.73
PIPE	36	30	0.00	13,889	30.95	4.38	0.20	0.00	0.20	22.93
45 Deg	36	0	0.15	13,889	30.95	4.38	0.00	0.04	0.04	22.97
PIPE	36	20	0.00	13,889	30.95	4.38	0.13	0.00	0.13	23.10
Exit	30	0	1.00	13,889	30.95	6.30	0.00	0.62	0.62	23.72
	Length:	3,250								23.72
		Sum Ks:	5.3							

1 - Diameter reduced assuming 6" depth of mussels around pipeline circumference.

Comparison		
Flow	Average	Maximum
MGD	9.90	20
Feet Headloss without Infestation (60")	0.07	0.28
Feet Headloss with Infestation (60")	0.73	2.70
Increase	**0.65**	**2.42**
Feet Headloss without Infestation (42")	0.91	3.45
Feet Headloss with Infestation (42")	6.41	23.72
Increase	**5.49**	**20.27**

RRWTP DETAILED DETAILED OPINION OF PROBABLE COST

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

OPINION OF PROBABLE NET PRESENT VALUE

	Alternative	Capital Cost	Annual O&M Cost[1]	Annual Cleaning and Removal Cost[2]	Net Present Value	Engineering and Construction Administration
A	**NaMnO4 and Cu Ion System**	$ 2,180,000				$ 440,000
	8 Month NaMnO4 Feed		$ 61,000	$ 58,000	$ 4,707,000	
	5 Month NaMnO4 Feed (with Monitoring)		$ 56,000	$ 58,000	$ 4,597,000	
	Potential Savings from Monitoring		$ 5,000	$ -	$ 110,000	
	12 Month Cu Ion Feed		$ 40,000	$ 58,000	$ 4,594,000	
B	**Physical Removal and Maintenance Improvements**	$ 930,000	$ 26,000	$ 121,000	$ 4,032,000	$ 190,000
Optional Additions and Substitutions						
Addition 1: Bypass Line		$ 109,000	$ 12,000	$ 12,000	$ 1,219,000	$ 70,000
Addition 2: Duplicate Raw Water Line		$ 3,053,000	$ 25,000	$ 90,000	$ 5,465,000	$ 300,000
Addition 3: Potable Water for Chemical Feed		$ -	$ 24,000	$ -	$ 847,000	$ -

[1] Physical Cleaning and Removal not included.

[2] Physical Cleaning and Removal Cost is represented on annual basis for budgetary purposes, although in reality would occur every 2 years.

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

PRESENT VALUE BASIS CALCULATIONS

Present Value Basis Calculations - Alternative A: NaMnO4, 5 Months

Net Present Value Total:	**$ 4,596,527**
O&M Present/Future Worth:	**$ 2,416,527**
Per Year O&M:	**$ 162,429**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 117,857	$ 146,530	$ -	$ -	$ 256,687
2	0.94260	$ 121,982	$ 146,530	$ -	$ -	$ 253,099
3	0.91514	$ 126,252	$ 146,530	$ -	$ -	$ 249,634
4	0.88849	$ 130,670	$ 146,530	$ -	$ -	$ 246,289
5	0.86261	$ 135,244	$ 146,530	$ -	$ -	$ 243,061
6	0.83748	$ 139,977	$ 146,530	$ -	$ -	$ 239,946
7	0.81309	$ 144,877	$ 146,530	$ -	$ -	$ 236,940
8	0.78941	$ 149,947	$ 146,530	$ -	$ -	$ 234,042
9	0.76642	$ 155,195	$ 146,530	$ -	$ -	$ 231,248
10	0.74409	$ 160,627	$ 146,530	$ 9,000	$ 12,695	$ 238,001
11	0.72242	$ 166,249	$ 146,530	$ -	$ -	$ 225,959
12	0.70138	$ 172,068	$ 146,530	$ -	$ -	$ 223,458
13	0.68095	$ 178,090	$ 146,530	$ -	$ -	$ 221,051
14	0.66112	$ 184,324	$ 146,530	$ -	$ -	$ 218,733
15	0.64186	$ 190,775	$ 146,530	$ -	$ -	$ 216,503
16	0.62317	$ 197,452	$ 146,530	$ -	$ -	$ 214,358
17	0.60502	$ 204,363	$ 146,530	$ -	$ -	$ 212,296
18	0.58739	$ 211,515	$ 146,530	$ -	$ -	$ 210,314
19	0.57029	$ 218,919	$ 146,530	$ -	$ -	$ 208,410
20	0.55368	$ 226,581	$ 146,530	$ 9,000	$ 17,908	$ 216,498
					TOTAL:	**$ 4,596,527**

Present Value Basis Calculations - Alternative A: NaMnO4, 8 Months

Net Present Value Total:	**$ 4,706,901**
O&M Present/Future Worth:	**$ 2,526,901**
Per Year O&M:	**$ 169,847**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	#DIV/0!

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 123,284	$ 146,530	$ -	$ -	$ 261,955
2	0.94260	$ 127,599	$ 146,530	$ -	$ -	$ 258,393
3	0.91514	$ 132,065	$ 146,530	$ -	$ -	$ 254,954
4	0.88849	$ 136,687	$ 146,530	$ -	$ -	$ 251,635
5	0.86261	$ 141,471	$ 146,530	$ -	$ -	$ 248,432
6	0.83748	$ 146,422	$ 146,530	$ -	$ -	$ 245,343
7	0.81309	$ 151,547	$ 146,530	$ -	$ -	$ 242,364
8	0.78941	$ 156,851	$ 146,530	$ -	$ -	$ 239,492
9	0.76642	$ 162,341	$ 146,530	$ -	$ -	$ 236,724
10	0.74409	$ 168,023	$ 146,530	$ 9,000	$ 12,695	$ 243,504
11	0.72242	$ 173,904	$ 146,530	$ -	$ -	$ 231,488
12	0.70138	$ 179,991	$ 146,530	$ -	$ -	$ 229,015
13	0.68095	$ 186,290	$ 146,530	$ -	$ -	$ 226,635
14	0.66112	$ 192,810	$ 146,530	$ -	$ -	$ 224,344
15	0.64186	$ 199,559	$ 146,530	$ -	$ -	$ 222,141
16	0.62317	$ 206,543	$ 146,530	$ -	$ -	$ 220,024
17	0.60502	$ 213,772	$ 146,530	$ -	$ -	$ 217,989
18	0.58739	$ 221,254	$ 146,530	$ -	$ -	$ 216,035
19	0.57029	$ 228,998	$ 146,530	$ -	$ -	$ 214,159
20	0.55368	$ 237,013	$ 146,530	$ 9,000	$ 17,908	$ 222,274
					TOTAL:	**$ 4,706,901**

Present Value Basis Calculations - Alternative A: Cu Ion System

Net Present Value Total:	**$ 4,594,117**
O&M Present/Future Worth:	**$ 2,414,117**
Per Year O&M:	**$ 162,267**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 101,137	$ 146,530	$ -	$ 17,078	$ 257,034
2	0.94260	$ 104,677	$ 146,530	$ -	$ 17,675	$ 253,447
3	0.91514	$ 108,341	$ 146,530	$ -	$ 18,294	$ 249,984
4	0.88849	$ 112,133	$ 146,530	$ -	$ 18,934	$ 246,641
5	0.86261	$ 116,057	$ 146,530	$ -	$ 19,597	$ 243,415
6	0.83748	$ 120,119	$ 146,530	$ -	$ 20,283	$ 240,301
7	0.81309	$ 124,323	$ 146,530	$ -	$ 20,993	$ 237,298
8	0.78941	$ 128,675	$ 146,530	$ -	$ 21,727	$ 234,401
9	0.76642	$ 133,178	$ 146,530	$ -	$ 22,488	$ 231,608
10	0.74409	$ 137,840	$ 146,530	$ 4,500	$ 29,623	$ 233,640
11	0.72242	$ 142,664	$ 146,530	$ -	$ 24,090	$ 226,323
12	0.70138	$ 147,657	$ 146,530	$ -	$ 24,933	$ 223,824
13	0.68095	$ 152,825	$ 146,530	$ -	$ 25,805	$ 221,419
14	0.66112	$ 158,174	$ 146,530	$ -	$ 26,708	$ 219,103
15	0.64186	$ 163,710	$ 146,530	$ -	$ 27,643	$ 216,875
16	0.62317	$ 169,440	$ 146,530	$ -	$ 28,611	$ 214,732
17	0.60502	$ 175,370	$ 146,530	$ -	$ 29,612	$ 212,671
18	0.58739	$ 181,508	$ 146,530	$ -	$ 30,649	$ 210,691
19	0.57029	$ 187,861	$ 146,530	$ -	$ 31,721	$ 208,789
20	0.55368	$ 194,436	$ 146,530	$ 4,500	$ 41,786	$ 211,921
						TOTAL: $ 4,594,117

Present Value Basis Calculations - Alternative B

Net Present Value Total:	**$ 4,031,932**
O&M Present/Future Worth:	**$ 3,101,932**
Per Year O&M:	**$ 208,499**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 152,507	$ 62,511	$ -	$ -	$ 208,755
2	0.94260	$ 157,845	$ 62,511	$ -	$ -	$ 207,706
3	0.91514	$ 163,370	$ 62,511	$ -	$ -	$ 206,712
4	0.88849	$ 169,088	$ 62,511	$ -	$ -	$ 205,772
5	0.86261	$ 175,006	$ 62,511	$ -	$ -	$ 204,884
6	0.83748	$ 181,131	$ 62,511	$ -	$ -	$ 204,046
7	0.81309	$ 187,470	$ 62,511	$ -	$ -	$ 203,257
8	0.78941	$ 194,032	$ 62,511	$ -	$ -	$ 202,517
9	0.76642	$ 200,823	$ 62,511	$ -	$ -	$ 201,823
10	0.74409	$ 207,852	$ 62,511	$ -	$ -	$ 201,175
11	0.72242	$ 215,127	$ 62,511	$ -	$ -	$ 200,571
12	0.70138	$ 222,656	$ 62,511	$ -	$ -	$ 200,010
13	0.68095	$ 230,449	$ 62,511	$ -	$ -	$ 199,491
14	0.66112	$ 238,515	$ 62,511	$ -	$ -	$ 199,013
15	0.64186	$ 246,863	$ 62,511	$ -	$ -	$ 198,575
16	0.62317	$ 255,503	$ 62,511	$ -	$ -	$ 198,175
17	0.60502	$ 264,445	$ 62,511	$ -	$ -	$ 197,814
18	0.58739	$ 273,701	$ 62,511	$ -	$ -	$ 197,489
19	0.57029	$ 283,281	$ 62,511	$ -	$ -	$ 197,200
20	0.55368	$ 293,195	$ 62,511	$ -	$ -	$ 196,946
					TOTAL:	**$ 4,031,932**

Present Value Basis Calculations - Addition 1

Net Present Value Total:	**$ 1,218,603**
O&M Present/Future Worth:	**$ 512,603**
Per Year O&M:	**$ 34,455**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 25,202	$ 47,454	$ -	$ -	$ 70,540
2	0.94260	$ 26,084	$ 47,454	$ -	$ -	$ 69,317
3	0.91514	$ 26,997	$ 47,454	$ -	$ -	$ 68,134
4	0.88849	$ 27,942	$ 47,454	$ -	$ -	$ 66,989
5	0.86261	$ 28,920	$ 47,454	$ -	$ -	$ 65,881
6	0.83748	$ 29,932	$ 47,454	$ -	$ -	$ 64,810
7	0.81309	$ 30,980	$ 47,454	$ -	$ -	$ 63,774
8	0.78941	$ 32,064	$ 47,454	$ -	$ -	$ 62,773
9	0.76642	$ 33,187	$ 47,454	$ -	$ -	$ 61,804
10	0.74409	$ 34,348	$ 47,454	$ -	$ -	$ 60,869
11	0.72242	$ 35,550	$ 47,454	$ -	$ -	$ 59,964
12	0.70138	$ 36,795	$ 47,454	$ -	$ -	$ 59,090
13	0.68095	$ 38,082	$ 47,454	$ -	$ -	$ 58,246
14	0.66112	$ 39,415	$ 47,454	$ -	$ -	$ 57,431
15	0.64186	$ 40,795	$ 47,454	$ -	$ -	$ 56,644
16	0.62317	$ 42,223	$ 47,454	$ -	$ -	$ 55,884
17	0.60502	$ 43,700	$ 47,454	$ -	$ -	$ 55,150
18	0.58739	$ 45,230	$ 47,454	$ -	$ -	$ 54,442
19	0.57029	$ 46,813	$ 47,454	$ -	$ -	$ 53,759
20	0.55368	$ 48,451	$ 47,454	$ -	$ -	$ 53,101
					TOTAL:	**$ 1,218,603**

Present Value Basis Calculations - Addition 2

Net Present Value Total:	**$**	**5,465,444**
O&M Present/Future Worth:	**$**	**2,411,444**
Per Year O&M:	**$**	**162,087**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital Investment		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 118,559	$ 205,277	$ -	$ -	$ 314,404
2	0.94260	$ 122,709	$ 205,277	$ -	$ -	$ 309,158
3	0.91514	$ 127,004	$ 205,277	$ -	$ -	$ 304,084
4	0.88849	$ 131,449	$ 205,277	$ -	$ -	$ 299,176
5	0.86261	$ 136,049	$ 205,277	$ -	$ -	$ 294,431
6	0.83748	$ 140,811	$ 205,277	$ -	$ -	$ 289,843
7	0.81309	$ 145,740	$ 205,277	$ -	$ -	$ 285,408
8	0.78941	$ 150,840	$ 205,277	$ -	$ -	$ 281,122
9	0.76642	$ 156,120	$ 205,277	$ -	$ -	$ 276,980
10	0.74409	$ 161,584	$ 205,277	$ -	$ -	$ 272,979
11	0.72242	$ 167,240	$ 205,277	$ -	$ -	$ 269,114
12	0.70138	$ 173,093	$ 205,277	$ -	$ -	$ 265,381
13	0.68095	$ 179,151	$ 205,277	$ -	$ -	$ 261,777
14	0.66112	$ 185,421	$ 205,277	$ -	$ -	$ 258,298
15	0.64186	$ 191,911	$ 205,277	$ -	$ -	$ 254,940
16	0.62317	$ 198,628	$ 205,277	$ -	$ -	$ 251,700
17	0.60502	$ 205,580	$ 205,277	$ -	$ -	$ 248,575
18	0.58739	$ 212,775	$ 205,277	$ -	$ -	$ 245,562
19	0.57029	$ 220,223	$ 205,277	$ -	$ -	$ 242,656
20	0.55368	$ 227,930	$ 205,277	$ -	$ -	$ 239,856
					TOTAL:	**$ 5,465,444**

Present Value Basis Calculations - Addition 3

Net Present Value Total:	**$**	**846,622**
O&M Present/Future Worth:	**$**	**846,622**
Per Year O&M:	**$**	**56,906**

Interest Rate:	3%
Cost Escalation Factor:	3.5%
A/P (20 years):	0.0672157

Year, n	Present/Future Worth (p/f)	Annual O&M Costs	Debt Service Payment on Capital		Repair/Replacement Costs	Annual O&M Payment (p/f x Annual O&M Costs) + Annual Repair Costs
0	1.00000	$ -	$ -	$ -	$ -	$ -
1	0.97087	$ 24,547	$ -	$ -	$ 17,078	$ 40,412
2	0.94260	$ 25,406	$ -	$ -	$ 17,675	$ 40,608
3	0.91514	$ 26,295	$ -	$ -	$ 18,294	$ 40,805
4	0.88849	$ 27,216	$ -	$ -	$ 18,934	$ 41,003
5	0.86261	$ 28,168	$ -	$ -	$ 19,597	$ 41,202
6	0.83748	$ 29,154	$ -	$ -	$ 20,283	$ 41,402
7	0.81309	$ 30,174	$ -	$ -	$ 20,993	$ 41,603
8	0.78941	$ 31,230	$ -	$ -	$ 21,727	$ 41,805
9	0.76642	$ 32,324	$ -	$ -	$ 22,488	$ 42,008
10	0.74409	$ 33,455	$ -	$ -	$ 23,275	$ 42,212
11	0.72242	$ 34,626	$ -	$ -	$ 24,090	$ 42,417
12	0.70138	$ 35,838	$ -	$ -	$ 24,933	$ 42,623
13	0.68095	$ 37,092	$ -	$ -	$ 25,805	$ 42,830
14	0.66112	$ 38,390	$ -	$ -	$ 26,708	$ 43,038
15	0.64186	$ 39,734	$ -	$ -	$ 27,643	$ 43,247
16	0.62317	$ 41,125	$ -	$ -	$ 28,611	$ 43,457
17	0.60502	$ 42,564	$ -	$ -	$ 29,612	$ 43,668
18	0.58739	$ 44,054	$ -	$ -	$ 30,649	$ 43,880
19	0.57029	$ 45,596	$ -	$ -	$ 31,721	$ 44,093
20	0.55368	$ 47,191	$ -	$ -	$ 32,832	$ 44,307
					TOTAL:	**$ 846,622**

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

DESIGN CRITERIA AND ASSUMPTIONS

Category	Unit Cost or Assumption			Basis
FLOW	Minimum Flow	5	MGD	Plant RW Flow Data from 2012-2015
	Average Flow	9.9	MGD	
	Maximum Flow	20	MGD	
CHEMICAL DOSE	Sodium Permanganate Design Dose	2.5	ppm	Chemical Demand Testing
	Sodium Permanganate Annual Average Dose	1.5	ppm	
	Copper Dose (During Settlement)	5.0	ppb	Mfr Recommendations
	Copper Dose (No Settlement)	2	ppb	
	Aluminum Dose (During Settlement)	0.5	ppb	
	Aluminum Dose (No Settlement)	0.2	ppb	
CHEMICAL COST	Cost of Cu/Al Anode Cell	5,500	$/year	Mfr Cost Estimate
	Cost of Sodium Permanganate	1.65	$/lb	Carus Cost Estimate
	Delivery Cost	500	$/delivery	Estimate
CHEMICAL PROPERTIES	Sodium Permanganate %	40%		Mfr Specifications
CHEMICAL DOSING FREQUENCY	$NaMnO_4$ Dosing Frequency	12	hours/day	Estimate from Previous Project Experience
	Copper Ion Dosing Frequency	24	hours/day	Mfr Recommendations
	Months of Chemical Feed	8	months/year	Estimate from Previous Project Experience
	Months of Chemical Feed (Monitoring)	5	months/year	
ZM CLEANING	Mussel Coverage Without Management	50%		Estimate from Previous Project Experience
	Mussel Coverage With Management	10%		
	Average Thickness of Mussel Coverage Without Management across Pipeline	1	inch	
	Average Thickness of Mussel Coverage With Mangament across Pipeline	0.5	inch	
	Mussel Density	76	lb/cy	
	Linear feet of pipe cleaned	200	lf/day	
	Frequency of cleaning	2	every …years	
	Cost of Physical Cleaning	10000	$/day	
	Dumpster fee	150	EA (30 CY)	
	Minimum Cost for Short Distance Hauling	350	$	
	Mussel Transport to landfill	9	$/mile	
	Mussel Disposal Fee	26	$/ton	
LIFECYCLE COST	Escalation Factor	3.50%		Estimate
	Interest Rate	3%		
	Lifecycle	20	years	
O&M COST	Energy Cost	0.09	$/kWh	Current Industry Rates
	Water Cost	0.0027	$/day	
	Ion Generator Power (Maximum)	0.64	kW	
	Ion Generator Power (Minimum)	0.08	kW	
	Operator Chemical Rate	50	$/hr	
	Instrument Technician Rate	60	$/hr	
	Mechanical Technician Rate	55	$/hr	
CAPITAL COST	Mobilization and Demobilization	3%		Estimate
	General Requirements	5%		
	Bonds and Insurance	2%		
	Contractor's Profit	15%		
	Contingency	30%		
	Labor and Installation	30%		

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

OPINION OF PROBABLE CONSTRUCTION COST

	Unit Cost		Alternative A: ($NaMnO_4$ and Cu Ion System)				Alternative B: (Physical Removal & Maintenance Improvements)			
Item Description	**Unit Cost**	**Units**	**Qty**	**Subtotal**	**Installation and Labor Cost**	**Total Cost**	**Qty**	**Subtotal**	**Installation and Labor Cost**	**Total Cost**
1 Raw Water Pipeline Improvements for Physical Removal					**Subtotal**	**$ 462,000**			**Subtotal**	**$ 572,850**
60" Butterfly Valve (Valve Vault 1)	$ 65,000	EA	1	$ 65,000	$ 19,500	$ 84,500	1	$ 65,000	$ 19,500	$ 84,500
60" Manway (Valve Vault 1)	$ 18,000	EA	1	$ 18,000	$ 5,400	$ 23,400	1	$ 18,000	$ 5,400	$ 23,400
60" Manway (Valve Vault 2)	$ 18,000	EA	1	$ 18,000	$ 5,400	$ 23,400	1	$ 18,000	$ 5,400	$ 23,400
42" Manhole and Manway (Raw Water Pump Station)	$ 18,000	EA	1	$ 18,000	$ 5,400	$ 23,400	1	$ 18,000	$ 5,400	$ 23,400
Site Work and Vault/Piping Preparations (Incl. crane rental)	$ 50,000	LS	1	$ 50,000	$ -	$ 50,000	1	$ 50,000	$ -	$ 50,000
Extension Stem at 12" Drain Line	$ 2,000	EA	1	$ 2,000	$ 600	$ 2,600	1	$ 2,000	$ 600	$ 2,600
Monitoring and CCTV	$ 25,000	LS	1	$ 25,000	$ 7,500	$ 32,500	0.5	$ 12,500	$ 3,750	$ 16,250
Cleaning: Physical Removal and Disposal[1]		LS	1	$ 115,600	$ -	$ 115,600	1	$ 242,700	$ -	$ 242,700
Potable Water Line from WTP to Raw Water Pump Station	$ 73,000	LS	1	$ 73,000	$ 21,900	$ 94,900	1	$ 73,000	$ 21,900	$ 94,900
Potable Water Access (Hose Bibs, Hydrants, Hose Stations)	$ 9,000	LS	1	$ 9,000	$ 2,700	$ 11,700	1	$ 9,000	$ 2,700	$ 11,700
2 Chemical System - $NaMnO_4$ and Cu Ion System					**Subtotal**	**$ 881,220**				**$ -**
Raw Water Sampling Point (Valve Vault 1)	$ 12,000	LS	1	$ 12,000	$ 3,600	$ 15,600	0	$ -	$ -	$ -
Primary Chemical Feed Point (Valve Vault 1)	$ 23,000	LS	1	$ 23,000	$ 6,900	$ 29,900	0	$ -	$ -	$ -
Secondary Chemical Feed Point (Valve Vault 2)	$ 19,000	LS	1	$ 19,000	$ 5,700	$ 24,700	0	$ -	$ -	$ -
Miscellaneous Excavation and Backfill	$ 30	CY	200	$ 6,000	$ 1,800	$ 7,800	0	$ -	$ -	$ -
6,500 gallon Bulk Tank	$ 40,000	LS	1	$ 40,000	$ 12,000	$ 52,000	0	$ -	$ -	$ -
500 gal Day Tank	$ 2,000	EA	1	$ 2,000	$ 600	$ 2,600	0	$ -	$ -	$ -
(16'x20') 12" Concrete Enclosure Pad for Bulk Storage Tank	$ 800	CY	20	$ 16,000	$ 4,800	$ 20,800	0	$ -	$ -	$ -
12" Concrete Containment Walls	$ 1,000	CY	6	$ 6,000	$ 1,800	$ 7,800	0	$ -	$ -	$ -
Emergency Eyewash Shower	$ 5,000	EA	2	$ 10,000	$ 3,000	$ 13,000	0	$ -	$ -	$ -
19'x20' Chemical Building	$ 325	SF	400	$ 130,000	$ 39,000	$ 169,000	0	$ -	$ -	$ -
Site Improvements (Road, Clearing & Grubbing, Fence)	$ 50,000	LS	1	$ 50,000	$ 15,000	$ 65,000	0	$ -	$ -	$ -
Pump (Transfer, Metering)	$ 4,500	EA	2	$ 9,000	$ 2,700	$ 11,700	0	$ -	$ -	$ -
Chemical Piping and Valves	$ 30,000	LS	1	$ 30,000	$ 9,000	$ 39,000	0	$ -	$ -	$ -
Copper Ion Skid with PLC and 2 Cells	$ 95,000	LS	1	$ 95,000	$ 28,500	$ 123,500	0	$ -	$ -	$ -
Spare Cu Cell	$ 5,500	EA	1	$ 5,500	$ 1,650	$ 7,150	0	$ -	$ -	$ -
Self Backwashing Strainer	$ 2,000	EA	1	$ 2,000	$ 600	$ 2,600	0	$ -	$ -	$ -
Pump (Recirculation)	$ 4,500	EA	1	$ 4,500	$ 1,350	$ 5,850	0	$ -	$ -	$ -
Water Quality Analyzers	$ 15,000	LS	1	$ 15,000	$ 4,500	$ 19,500	0	$ -	$ -	$ -
Instrumentation and Controls	$ 75,000	LS	1	$ 75,000	$ -	$ 75,000	0	$ -	$ -	$ -
Electrical	**20%**	LS	1	$ 188,720	$ -	$ 188,720	0	$ -	$ -	$ -

SUBTOTAL		$ 1,343,200	$ 572,900
GENERAL REQUIREMENTS	**5%**	$ 67,160	$ 28,645
MOBILIZATION/DEMOBILIZATION	**3%**	$ 40,296	$ 17,187
BONDS AND INSURANCE	**2%**	$ 26,864	$ 11,458
CONTRACTOR'S PROFIT	**15%**	$ 201,480	$ 85,935
SUBTOTAL		$ 1,679,000	$ 716,100
CONTINGENCY	**30%**	$ 503,700	$ 214,830
TOTAL OPINION OF PROBABLE CONSTRUCTION COST		**$ 2,180,000**	**$ 930,000**
ENGINEERING AND CONSTRUCTION ADMINISTRATION		**$ 440,000**	**$ 190,000**

Additional Items[3]

Item Description	Unit Cost	Units	Qty.	Subtotal	Installation and Labor Cost	Contractor Costs (25%)	Contingency (30%)	Total Cost	Cost Difference	Eng. & Const. Admin.
Addition 1: Bypass Line Including BFV and Manhole Switch	$ 354,000	LS	1	$ 354,000	$ 80,000	$ 108,500	$ 162,750	$ 706,000	$ 706,000	$ 70,000
Addition 2: Duplicate Raw Water Line				$ 1,445,357	$ 433,607	$ 469,741	$ 704,611	$ 3,054,000	$ 3,054,000	$ 300,000
Clearing and Grubbing	$ 5,000	LS	1	$ 5,000	$ 1,500					
Excavation	$ 12	CY	12,056	$ 144,667	$ 43,400					
Backfill	$ 20	CY	11,453	$ 229,056	$ 68,717					
42" Concrete Pipeline	$ 269	LF	3,100	$ 832,734	$ 249,820					
42" Manhole	$ 18,000	EA	8	$ 144,000	$ 43,200					
42" BFV	$ 39,900	EA	1	$ 39,900	$ 11,970					
Miscellaneous (Grading, Fittings,…)	$ 50,000	LS	1	$ 50,000	$ 15,000					
Addition 3: Potable Water for Chemical Feed[2]	$ -	LS	1	$ -	$ -	$ -	$ -	$ -	$ -	$ -

[1] Physical removal and disposal costs presented under the capital costs are the costs of a one-time cleaning; although removal and disposal are assumed to be required every 2 years

[2] Capital costs for a potable water line are included in Alternatives A and B to provide a water line for physical removal. This addition accounts for additional O&M costs should the City use this line to supply potable wat

[3] Additions are represented by the price difference as compared to the respective base option(s).

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

O&M COST SUMMARY

	Unit Cost		Alternative A: (NaMnO4 System, 5 Months)		Alternative A: (NaMnO4 System, 8 Months)		Alternative A: (Cu Ion System)		Alternative B: (Physical Removal & Maintenance Improvements)	
Item Description	**Unit Cost**	**Unit**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**
Annual O&M Costs										
Monitoring and CCTV	$ 25,000	LS	1	$ 25,000	0.5	$ 12,500	0.75	$ 18,750	1	$ 25,000
Chemical Cost		LS[1]	1	$ 15,582	1	$ 24,931	1	$ -	0	$ -
Freight Charge	$ 500	EA	1	$ 500	1	$ 500	1	$ 500	0	$ -
Personnel Cost		LS[1]	1	$ 12,200	1	$ 19,520	1	$ 19,163	1	$ -
Operating Cost (Energy, Water)		LS[1]	1	$ 1,790	1	$ 2,864	1	$ 505	0	$ -
Equipment Maintenance	$ 1,000	LS	1	$ 1,000	1	$ 1,000	1	$ 1,000	1	$ 1,000
Annual Physical Removal Costs										
Cleaning: Physical Removal and Disposal[2]		LS[1]	1	$ 57,800	1	$ 57,800	1	$ 57,800	1	$ 121,350
			SUBTOTAL:	**$ 113,872**	**SUBTOTAL:**	**$ 119,115**	**SUBTOTAL:**	**$ 97,717**	**SUBTOTAL:**	**$ 147,350**
Repair/Replacement Costs										
Cu Ion Cell Replacement (Annual)	$ 5,500	EA	0	$ -	0	$ -	3	$ 16,500	0	$ -
Chemical Pump Replacement (10 years)	$ 4,500	LS	2	$ 9,000	2	$ 9,000	1	$ 4,500	0	$ -

[1] Unit costs vary per alternative and are presented on the detailed O&M cost page.

[2] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations it was converted to an annual maintenance cost.

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

O&M COST SUMMARY (Additions)

	Unit Cost		Addition[2] 1: Bypass Line Including BFV and Manhole Switch		Addition 2: Duplicate Raw Water Line		Addition 3: Potable Water for Chemical Feed[3]	
Item Description	**Unit Cost**	**Unit**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**	**Qty**	**Cost Estimate**
Annual O&M Costs								
Monitoring and CCTV	$ 25,000	LS	0.5	$ 12,500	1	$ 25,000	0	$ -
Chemical Cost		LS[1]	0	$ -	0	$ -	0	$ -
Freight Charge	$ 500	EA	0	$ -	0	$ -	0	$ -
Personnel Cost		LS[1]	0	$ -	0	$ -	0	$ -
Operating Cost (Energy, Water)		LS[1]	0	$ -	0	$ -	1	$ 23,717
Equipment Maintenance	$ 1,000	LS	0	$ -	0	$ -	0	$ -
Annual Physical Removal Costs								
Cleaning: Physical Removal and Disposal[2]		LS[1]	1	$ 11,850	1	$ 89,550	0	$ -
			SUBTOTAL:	**$ 24,350**	**SUBTOTAL:**	**$ 114,550**	**SUBTOTAL:**	**$ 23,717**
Repair/Replacement Costs								
Cu Ion Cell Replacement (Annual)	$ 5,500	EA	0	$ -	0	$ -	0	$ -
Chemical Pump Replacement (10 years)	$ 4,500	LS	0	$ -	0	$ -	0	$ -

[1] Unit costs vary per alternative and are presented on the detailed O&M cost page.

[2] Additions are represented by the price difference as compared to the respective base option(s).

[3] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations it was converted to an annual maintenance cost.

Zebra Mussel Control Alternatives Evaluation - Lake Ray Roberts

DETAILED O&M COST

	Alternative A: NaMnO4, 5 Months	Alternative A: NaMnO4, 8 Months	Alternative B: Copper Ion System	Alternative C: Physical Removal and Maintenance Improvements	Addition 1: Bypass Line Including BFV and Manhole Switch[2]	Addition 2: Duplicate Raw Water Line	Addition 3: Potable Water for Chemical Feed[3]
LABOR COST							
Operator (hr/day)	0.5	0.5	0.5	0.5	0	0	0
Operator Rate ($/hr)	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50	$ 50
Operator Cost ($/day)	$ 25	$ 25	$ 25	$ 25	$ -	$ -	$ -
Instrument Tech (hr/day)	0	0	0	0	0	0	0
Instrument Tech Rate ($/hr)	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60	$ 60
Instrument Tech Cost ($/day)	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Mechanical Tech (hr/day)	1	1	0.5	1	0	0	0
Mechanical Tech Rate ($/hr)	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55	$ 55
Mechanical Tech Cost ($/day)	$ 55	$ 55	$ 28	$ 55	$ -	$ -	$ -
Personnel Cost ($/day)	$ 80	$ 80	$ 53	$ 80	$ -	$ -	$ -
Days of Operation (day/yr)	153	244	$ 365				244
Personnel Cost ($/yr)	**$ 12,200**	**$ 19,520**	**$ 19,163**	**$ -**	**$ -**	**$ -**	**$ -**
POWER COST							
FEED PUMP							
No. of Motors	1	1	0	0	0	0	0
Motor Power Use (kWh/day)	240	240	0	0	0	0	0
Motor Usage (hr/day)	12	12	0	0	0	0	0
TRANSFER PUMP							
No. of Motors	1	1	1	0	0	0	0
Motor Power Use (kWh/day)	500	500	500	0	0	0	0
Motor Usage (hr/day)	0.5	0.5	0	0	0	0	0
ION GENERATOR							
Ion Generator Usage (hr/day)	0	0	24	0	0	0	0
Ion Generator Power Use (kW)	0	0	0.64	0	0	0	0
POWER							
Energy Rate ($/kWh)	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09	$ 0.09
Power Cost ($/day)	$ 12	$ 12	$ 1.38	$ -	$ -	$ -	$ -
Power Cost ($/yr)	**$ 1,790**	**$ 2,864**	**$ 505**	**$ -**	**$ -**	**$ -**	**$ -**
WATER COST							
Target Flowrate (gpm)	0	0	0	0	0	0	50
Water Usage (gal/day)	0	0	0	0	0	0	36,000
Water Rate ($/gal)	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027	$ 0.0027
Water Cost ($/day)	$ -	$ -	$ -	$ -	$ -	$ -	$ 97
Water Cost ($/yr)	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**	**$ 23,717**

	Alternative A: NaMnO4, 5 Months	Alternative A: NaMnO4, 8 Months	Alternative B: Copper Ion System	Alternative C: Physical Removal and Maintenance Improvements	Addition 1: Bypass Line Including BFV and Manhole Switch[2]	Addition 2: Duplicate Raw Water Line	Addition 3: Potable Water for Chemical Feed[3]
CHEMICAL COST							
Chemical Unit Cost ($/lb)	$ 1.65	$ 1.65	$ -	$ -	$ -	$ -	$ -
Chemical Usage (lb/day)	62	62	0	0	0	0	0
Daily Cost ($/day)	$ 102	$ 102	$ -	$ -	$ -	$ -	$ -
Annual Cost ($/year)	**$ 15,582**	**$ 24,931**	**$ -**	**$ -**	**$ -**	**$ -**	**$ -**
PHYSICAL REMOVAL COST							
Frequency of Cleaning (Every....years)	2	2	2	2	2	2	0
Days of Physical Cleaning (days)	10	10	10	21	2	15.5	0
Hausting Distance to Landfille (mi)	13.5	13.5	13.5	13.5	13.5	13.5	13.5
Mussel Coverage (%)	10%	10%	10%	50%	30%	30%	30%
Thickness of Mussel Coverage (in)	0.5	0.5	0.5	1	1	1	1
Average Pipeline Diameter (ft)	5	5	5	5	5	5	5
Mussel Coverage Distance (ft)	4,200	4,200	4,200	4,200	4,200	3,100	4,200
Mussel Coverage Surface Area (ft^2)	5,938	5,938	5,938	29,688	17,813	13,148	17,813
Zebra Mussel Removal Volume (cy)	9	9	9	92	27	41	55
Mussel Density (lb/cy)	76	76	76	76	76	76	76
Cost of Physical Cleaning ($)	$ 100,000	$ 100,000	$ 100,000	$ 210,000	$ 20,000	$ 155,000	$ -
Cost of Transport to Landfill ($)	$ 350	$ 350	$ 350	$ 350	$ 350	$ 350	$ 350
Zebra Mussel Disposal Cost ($)	$ 9	$ 9	$ 9	$ 91	$ 27	$ 40	$ 54
Dumpster Fee ($)	$ 150	$ 150	$ 150	$ 600	$ 150	$ 300	$ 300
Mobilization, Demobilization, Bonds, etc. ($)	$ 15,076.36	$ 15,076.36	$ 15,076	$ 31,656	$ 3,079	$ 23,354	$ 106
Physical Removal Cost ($/cleaning)	**$ 115,600**	**$ 115,600**	**$ 115,600**	**$ 242,700**	**$ 23,700**	**$ 179,100**	**$ -**
Physical Removal Cost$_1$ ($/year)	**$ 57,800**	**$ 57,800**	**$ 57,800**	**$ 121,350**	**$ 11,850**	**$ 89,550**	**$ -**
TOTAL O&M COST:	**$ 87,372**	**$ 105,115**	**$ 77,467**	**$ 121,350**	**$ 11,850**	**$ 89,550**	**$ 23,717**

[1] Physical Removal and Disposal assumed to be required every 2 years; for budgetary calculations
[2] Additions are represented by the price difference as compared to the respective base option(s).
[3] Capital costs for a potable water line are included in Alternatives A and B to provide a water line for physical removal. This addition accounts for additional O&M costs should the City use this

APPENDIX F: SUPPLEMENTAL INFORMATION ON COPPER ION SYSTEMS

CONTENTS:

- Manufacturer Brochures
- Manufacturer Cutsheets of Equipment
- Discussions with Operators of Existing Installations
- Material Safety Data Sheets

MANUFACTURER BROCHURES

Fortress Mc Systems

SAFE, COST EFFECTIVE LONG-TERM MUSSEL CONTROL

FREDRICK ONGECHE, O-N-G CONSULTING LLC, 735 N. GOLDEN HILLS WICHITA, KS 67212
T: 316 215 6515, F: 316 215 6522 EM: fredrick@ongcon.com

musselcontrol.com

Discussion Outline

- Introduction
- Mussel Essentials
- Copper: Micro-Macrofouling
- Intake Protection Process
- How Fortress Mc System
- Fortress MC Advantages
- Cost Comparison
- CIG Installed Sites

ONG History-Team

History

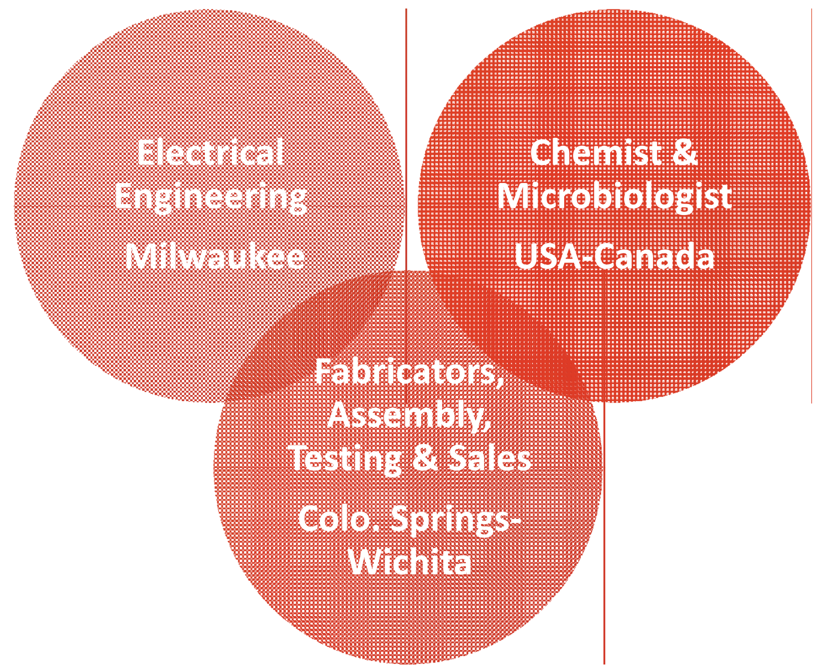
- Founded in 2005
- Focus: Fouling Control in H_2O Dist. Systems
- Process Heating/Cooling, Legionella, mussels
- 2 Patents filed, 2 in Pre-application process

Team

- Staff- 2 Electrical Engineers, Chemist, Microbiologist, fabricators- sales = 17

Manufacturing

- Electrical/Electronic Design- Milwaukee
- Equipment Fabrication – Colorado Springs
- Final Assembly/Testing/Sales - Wichita



What Mussels Need to Thrive

Zebra/Quagga Mussels Essentials

Suitable Environment

- Ca > 16mg/L
- Alkalinity > 45mg/L
- Tot. Hardness > 45mg/L
- DO > 7mg/l

Suitable Anchor

- Hard Surface, Biofilm Enhances Attachment

Need to Feed

- Mussels feed when conditions are favorable

Copper Macro-Microbial Control

AquaCulture

- ❖Algae, parasite & Pathogen Control, Antifouling Wire Cages

Agriculture

- ❖Mold & Rot Control, Fungicide, micronutrients

Healthcare

- ❖Legionella Control, Antimicrobial Touch Surfaces, Wound dressings

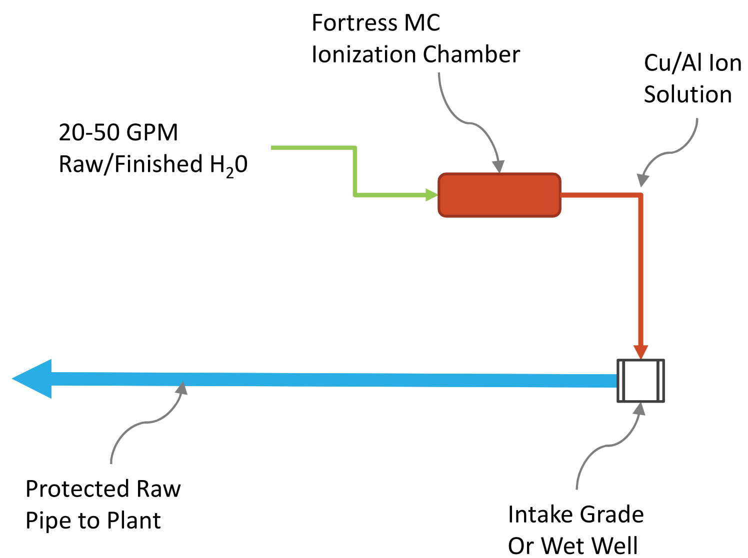
Other

- ❖Antifouling Paints- Boats
- ❖Ballast Water Fouling Control
- ❖Garments- Odor and dust mite control

Fortress MC Intake Protection

Simple and Straight Forward

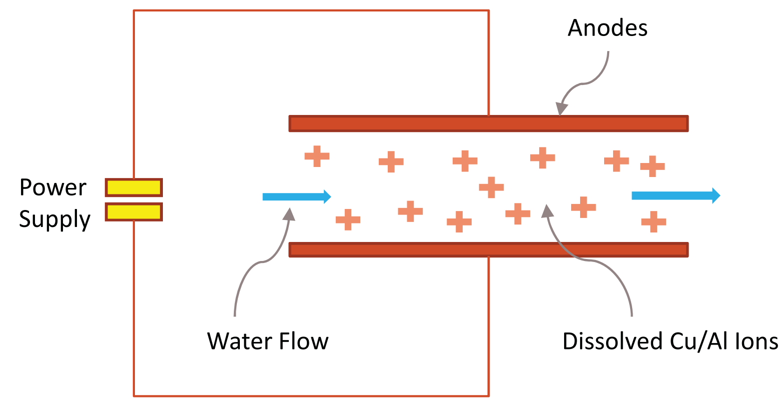
- FMC Treatment Process Creates a Solution of Copper/Aluminum ions
- The Ionic Solution is Injected at the Intake to Maintain 5-10ppb Cu^{+2} in Raw Water
- Cu/Al Ions in raw water prevent mussel fouling downstream of injection point



Fortress MC Technology Basic

Fortress Mc Basics

- Use Industrial-grade Electrolytic dissolution of Copper/Aluminum Anodes
- Anodic dissolution create Cu^{+2} & Al^{+3} ions- the active ingredients
- Cu/Al Ions in raw water prevent mussel fouling downstream of injection point



Anodic Dissolution of Cu/Al

$Cu \rightarrow Cu^{+2} + 2e^{-}$ Biocide

$Al \rightarrow Al^{+3} + 3e^{-}$ Alum Floc

Fortress Mc Antifouling Process

Prevention at Crucial Stages

- Ions interfere with Growth & Mussel Development at All Stages
- Poison & Immobilize Veligers
- Prevent Feeding = Death via Starvation
- $[Al(OH)_4]Cu$ gel floc Coats Pipe Surfaces Denying Mussel Surface to Anchor
- $[Al(OH)_4]Cu$ gel floc Inhibit Biofilm and Microbial Induced Corrosion

Fortress Antifouling Process

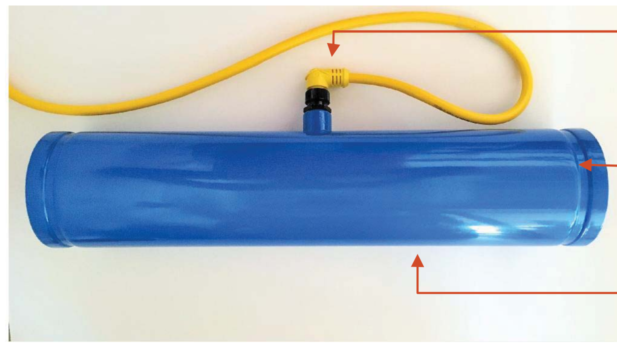
- Poison & Immobilize
- Create Starvation
- Deny Settlement

Fortress MC Major Components

HMI Display

Status LED

ON/OFF Switch



Industrial-grade-Water-tight Ion Chamber Connection

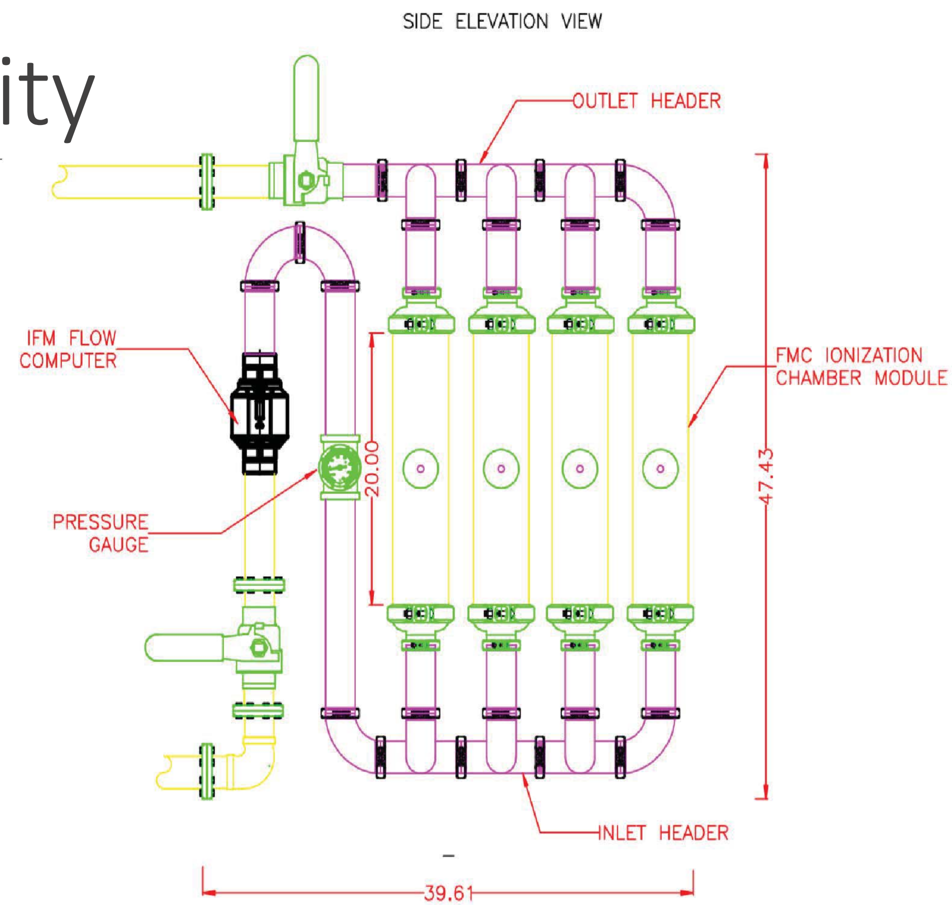
Grooved –End Coupling

S.S Housing, passivated and powder coated

Ion Chamber Modularity

Flexibility and Versatility

- Multiple Ion Chambers can be assembled to treat higher flows
- Flexible Installation Options; Skid, Wall or Floor mounting
- Modularity Provides Redundancy
- Easy Future Expansion
- Each Chamber Can be Isolated & Serviced without taking entire unit off-line



Fortress MC Control Panels

Automatic Control

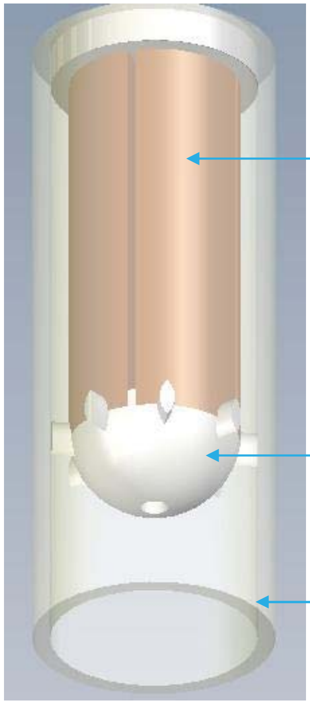
Cu-Dose™ Technology

- PLC Controlled + Simple Operator Interface
- View Status, Read Alarms, logged Faults
- Local & Remote Monitoring
- Precise Treatment in Varying Water Conditions
- Auto-Adapts to Changing Water Quality
- Flow-Paced to Deliver Consistent Treatment
- Eliminates Under/Over Treatment
- Automatic Ion Output Adjustment
- Each Ion Chamber Powered & Controlled Individually- Redundancy

Fortress MC Ionization Chamber

Ion Chamber Module

- Stainless Steel Housing = Will Not Rust
- Each Module can Treat Up to 20MGD
- Optimized Flow = Consistent Ionization
- Self-Cleaning = No Scaling or Plugging
- Prolonged Anode Life = Lower O&M Cost
- Grooved-End Coupling = Faster Servicing
- No Hoists or Power tools = Safer Servicing
- Compact Module = Small footprint



Fortress MC is Right For You

Operational, Economical and Environmental Benefits

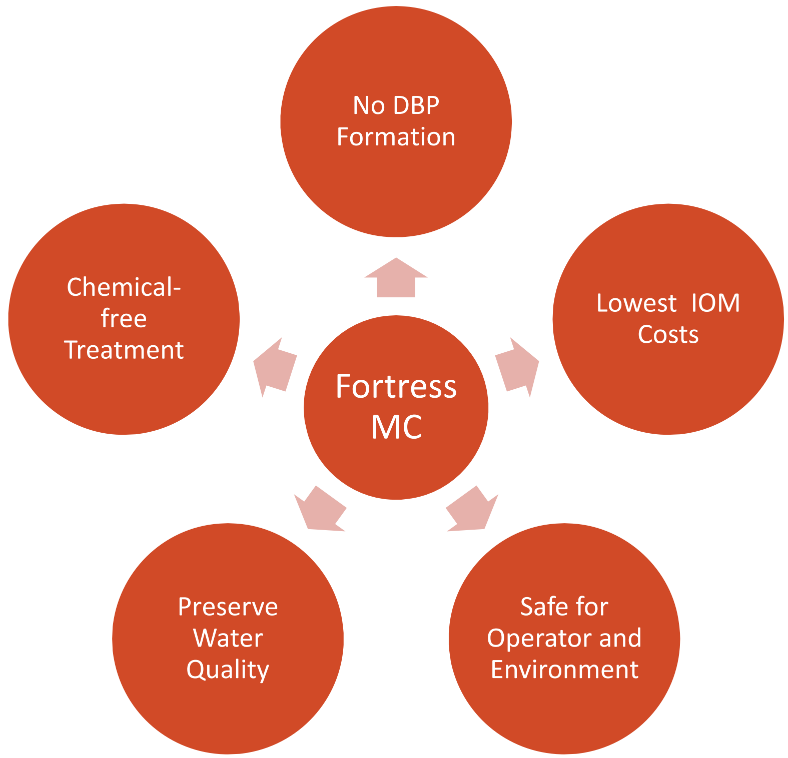
- **Drinking Water Safe**: Only 5-10ppb Cu^{+2} in raw H_2O
- **No DBP Formation**: Preserves Water Quality
- **Cost Effective**: Lowest Infrastructure & IOM Costs
- **Simplicity**: Only Water and Electricity Needed
- **Proven**: Over 18 yrs, Power, Industrial & Municipal
- **Safest:** No chemicals Involved
- **Compatible:** No Need to Modify Treatment Train
- **No Detox**: Eliminate Regulatory Burdens

musselcontrol.com

Mussel Control Options: Cost Comparison

Control Options (10MGD System)	Infrastructure Costs (0.5-1.5ppm)	Operations Costs $/MGD/Day
Sodium Hypochlorite	$120,000 - $140,000	$5.20 -$15.60
Potassium Permanganate	$290,000 - $320,000	$14.60 - $43.80
Chlorine Dioxide	$160,000 - $220,000	$23.70 - $71.00
Fortress MC	Negligible	$1.53 - $3.06
Cost Comparison for Mussel Control Options for 10 MGD Raw Water; Zebra Mussel Resource Document, Trinity River Basin, US Army Corps of Engineers		

Fortress MC Summary



MacroTech

Copper Ion Generator

Insures the safe and efficient operation of raw water systems by preventing the attachment and growth of marine organisms.

Features of the system include:

- Environmentally friendly. Treatment level is ≤ 5 PPB of electrolytically produced ionic copper, which is effective against both micro- and macro-biological fouling.
- Proven control technology.
- Safer and more convenient than chemical injection systems - no handling or storage of hazardous or toxic chemicals.
- Both initial capital and operating costs are lower than chlorination systems.
- Prevents Biofilm Formation
  Algae • Bacteria • Viruses
- Prevents Settlement
  Zebra & Quagga Mussels • Bryozoa
  Asiatic Clams • Blue Mussels • Barnacles

Sample User's List:

AES (2)	Alliant Energy (2)	Cargill
General Motors	Thilmany Paper (2)	US Salt
Nuclear Management (2)	Exelon Nuclear (3)	WE Energies
FPL Energy	Georgia-Pacific	NL Hydro (Canada)
NY Power Authority (2)	SCA Tissue	Westar Energy
Adams County, CO	B.R.I.C.	Unilever

MacroTech, Inc.
246 Mamaroneck Road
Scarsdale, NY 10583-7242
Tel: (914) 723-6185 • Fax: (914) 723-6085
wjblume@verizon.net
www.macrotechinc.com

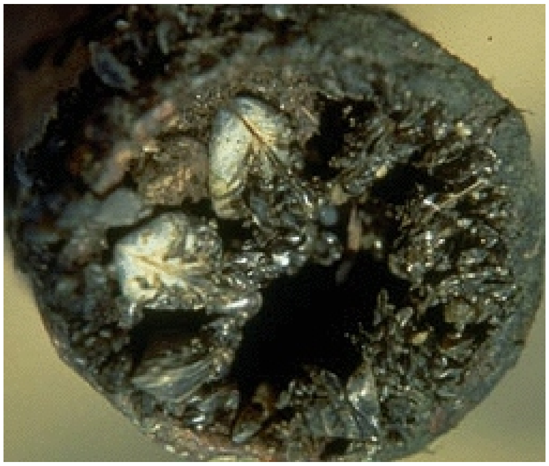
• Proudly Made in the U.S.A. •

• Since 1991 •

Stops Fouling Before It Starts

Please see other side . . .

This . . .



Or . . . A MacroTech Copper Ion Generator.

60,000GPM ◂ Sea Water Treatment Units ▸ 15,000 GPM

35,000 GPM
Fresh Water Treatment Unit

Description
The anodes are installed in a treatment tank (sea water systems) or cells (fresh water units). A side-stream of water is passed thru the unit and a copper-rich concentrate is formed. The treated solution is then distributed to one or more intakes to treat all the users.

MacroTech Copper Ion Generator

Made in U.S.A. Since 1991

MacroTech, Inc.

246 Mamaroneck Road

Scarsdale, NY 10583-7242

(914) 723-6185

Fax ▪ 723-6085

wjblume@blumesales.com

How Does Ionic Copper Work?

- Prevents Biofilm Formation
  - Algae
  - Bacteria

How Does Ionic Copper Work?

- Prevents Biofilm Formation

  Algae

  Bacteria

- Prevents Veliger Settlement

  Fresh Water (Zebra Mussels, Quagga Mussels, Bryozoa, Asiatic Clams)

  Sea Water (Barnacles, Mussels)

Features

- Environmentally Friendly

Features

- Environmentally Friendly
- Prevents Biofilm

Features

- Environmentally Friendly
- Prevents Biofilm
- Prevents Settlement

Features

- Environmentally Friendly
- Prevents Biofilm
- Prevents Settlement
- Proven Control Technology

Features

- Environmentally Friendly
- Prevents Biofilm
- Prevents Settlement
- Proven Control Technology
- Safer and More Operator-Friendly

Features

- Environmentally Friendly
- Prevents Biofilm
- Prevents Settlement
- Proven Control Technology
- Safer and More Operator-Friendly
- Lower Capital Cost

Features

- Environmentally Friendly
- Prevents Biofilm
- Prevents Settlement
- Proven Control Technology
- Safer and More Operator-Friendly
- Lower Capital Cost
- Lower Operating Cost

MacroTech
Copper Ion Generator

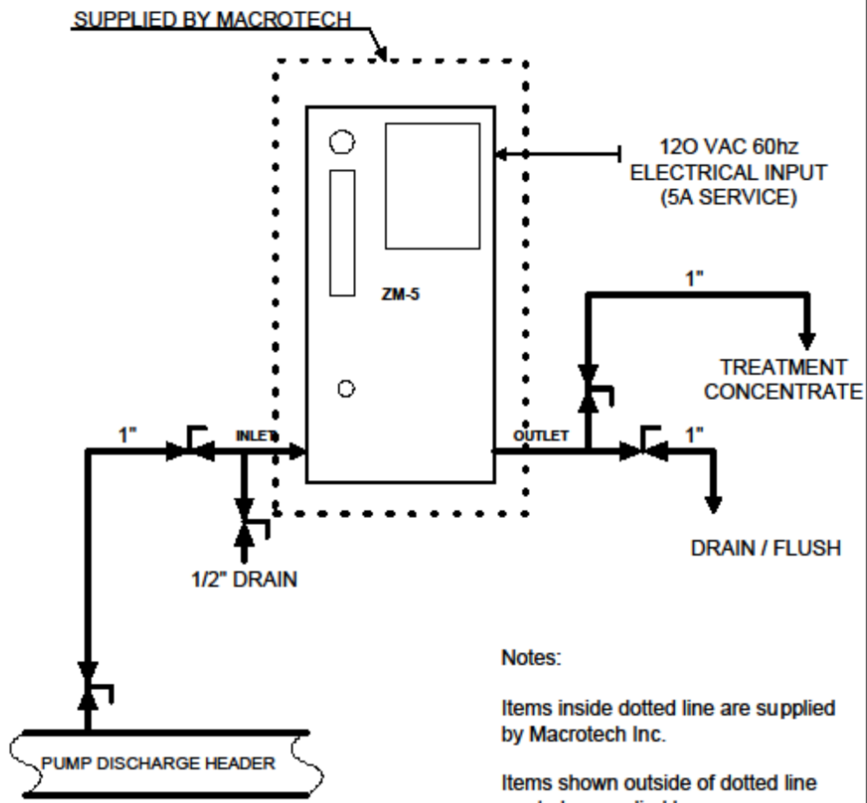
Stops Fouling Before It Starts

Made in the U.S.A.

Since 1991

Users Include…

- AES
- Adams County CO
- Alliant Energy
- Exelon Nuclear
- FPL Energy
- Nuclear Management
- NL Hydro
- NY Power Authority
- WE Energies
- Cargill
- General Motors
- Georgia Pacific
- International Paper
- SCA Tissue
- US Salt
- Unilever
- City of Wichita
- Westar Energy
- Grand River Dam



Notes:

Items inside dotted line are supplied by Macrotech Inc.

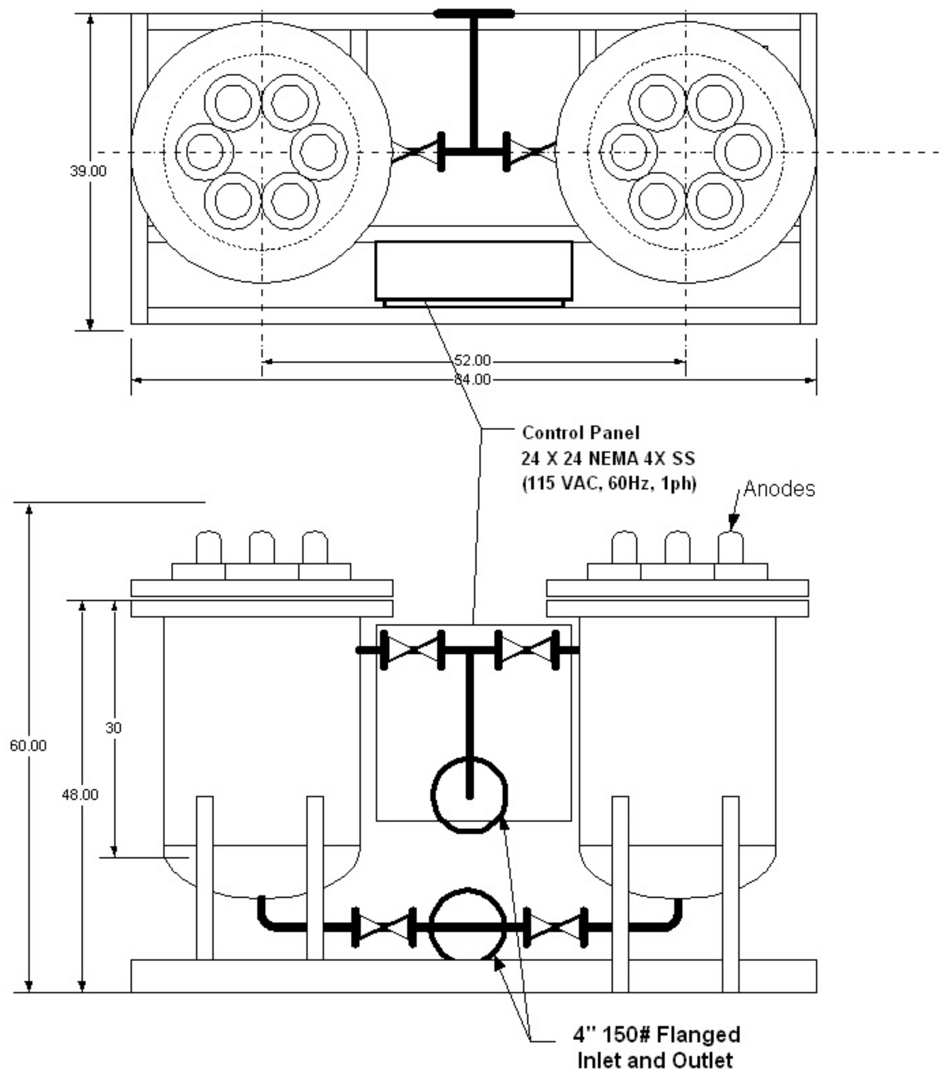
Items shown outside of dotted line are to be supplied by user.

All valves shown are 1/4 turn Ball valves

ZM-5 Piping / Installation	**MACROTECH INC.** 246 MAMARONECK RD. SCARSDALE, NY 10583 (914) 723-6185	
DATE 4-16-97 / FILENAME ZM05-P&ID.VSD	DWG ZM05-64-201	REV 0


MacroTech, Inc.
246 MAMARONECK RD. SCARSDALE NY 10583
FRESH WATER ANTIFOULING SYSTEM
SERIAL NO. ZM005-00106


1
2
3
4
5
MacroTech Inc



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MacroTech, Inc.

246 Mamaroneck Rd. Scarsdale, NY 10583 USA

Pacific Gas & Electric / Diablo Canyon / Main Cooling Water

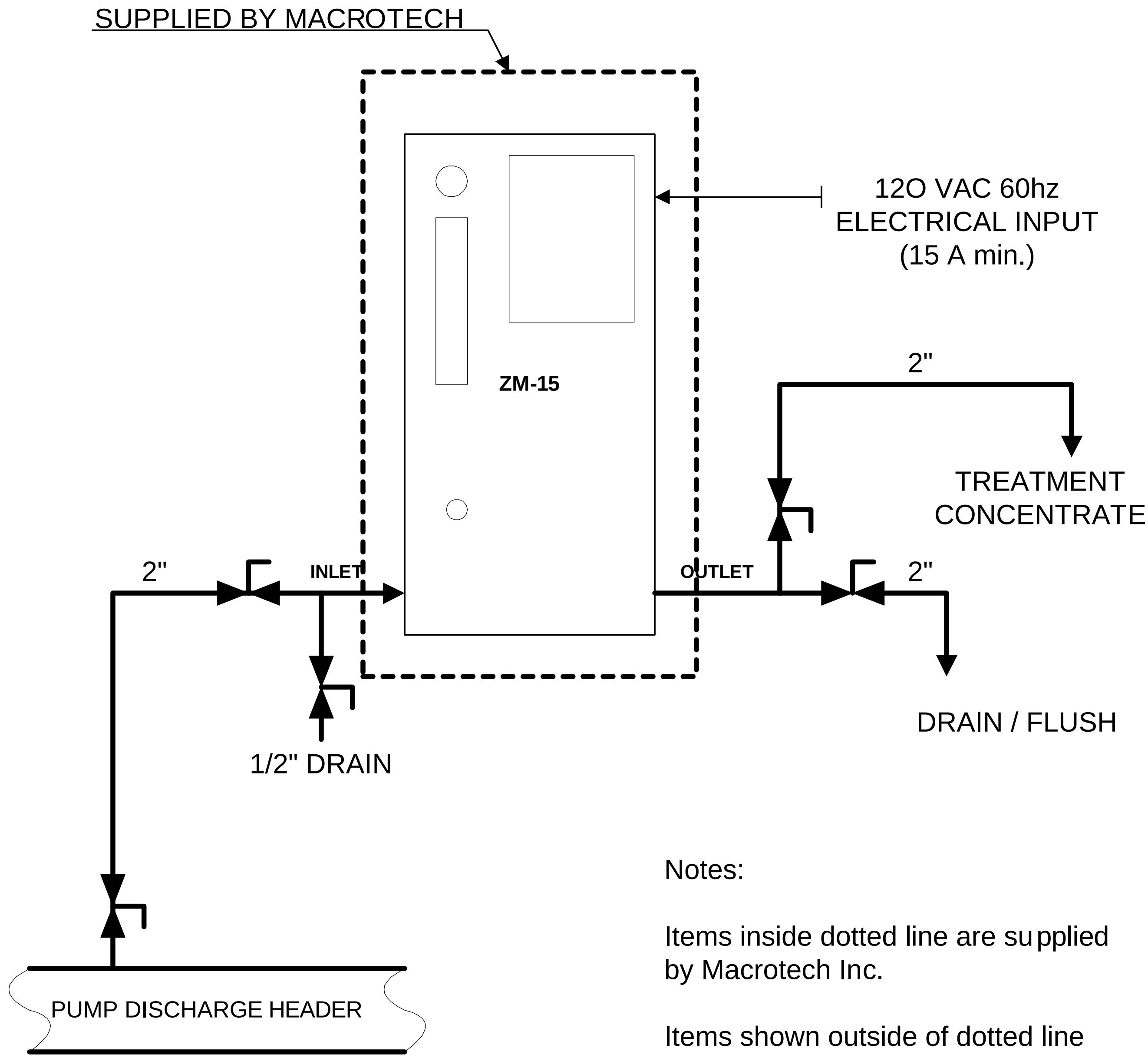
PROPOSED *MacroTech* Skid

General Arrangement

SIZE	FSCM NO	DWG NO	REV
		MCW - GA-62-211	0
SCALE	NONE	SHEET	1 OF 1

REV.	DESCRIPTION	DATE	BY

MANUFACTURER CUTSHEETS OF EQUIPMENT



Notes:

Items inside dotted line are supplied by Macrotech Inc.

Items shown outside of dotted line are to be supplied by user.

All valves shown are 1/4 turn Ball valves

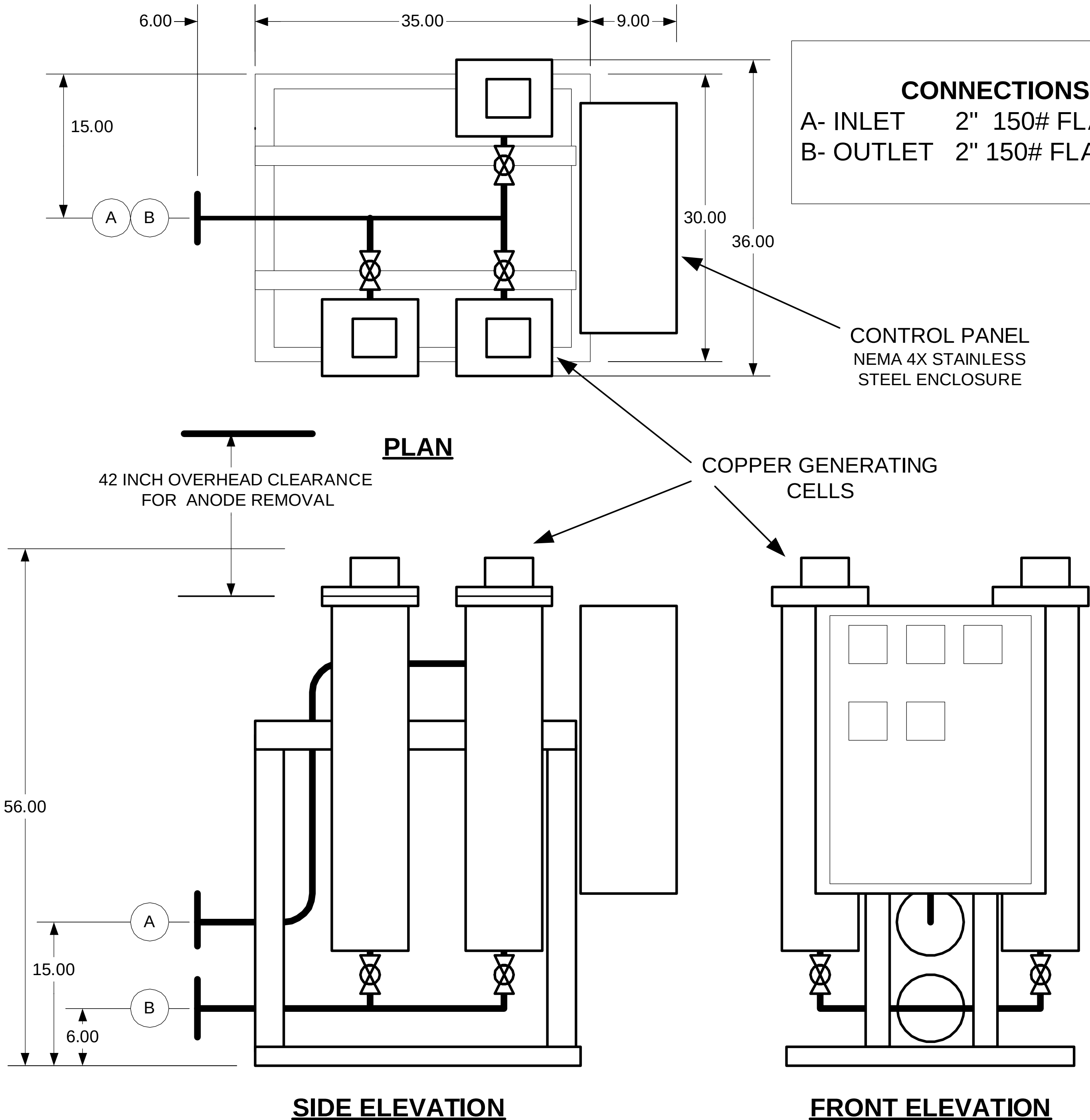
FILENAME
ZM15P&ID.VSD

ZM-15 Piping / Installation	***MACROTECH INC.*** **246 MAMARONECK RD. SCARSDALE, NY 10583** **(914) 723-6185**
DATE 4-16-97	**DWG** **ZM15-64-201** **REV** **0**

POWER INPUT- 120 VAC, 1ph, 60hz, 15 A
DRY WEIGHT- 1700 Lbs. (approx.)
OPERATING WEIGHT- 1925 lbs. (approx.)
NOMINAL WATER FLOW- 60-75 GPM

CONNECTIONS

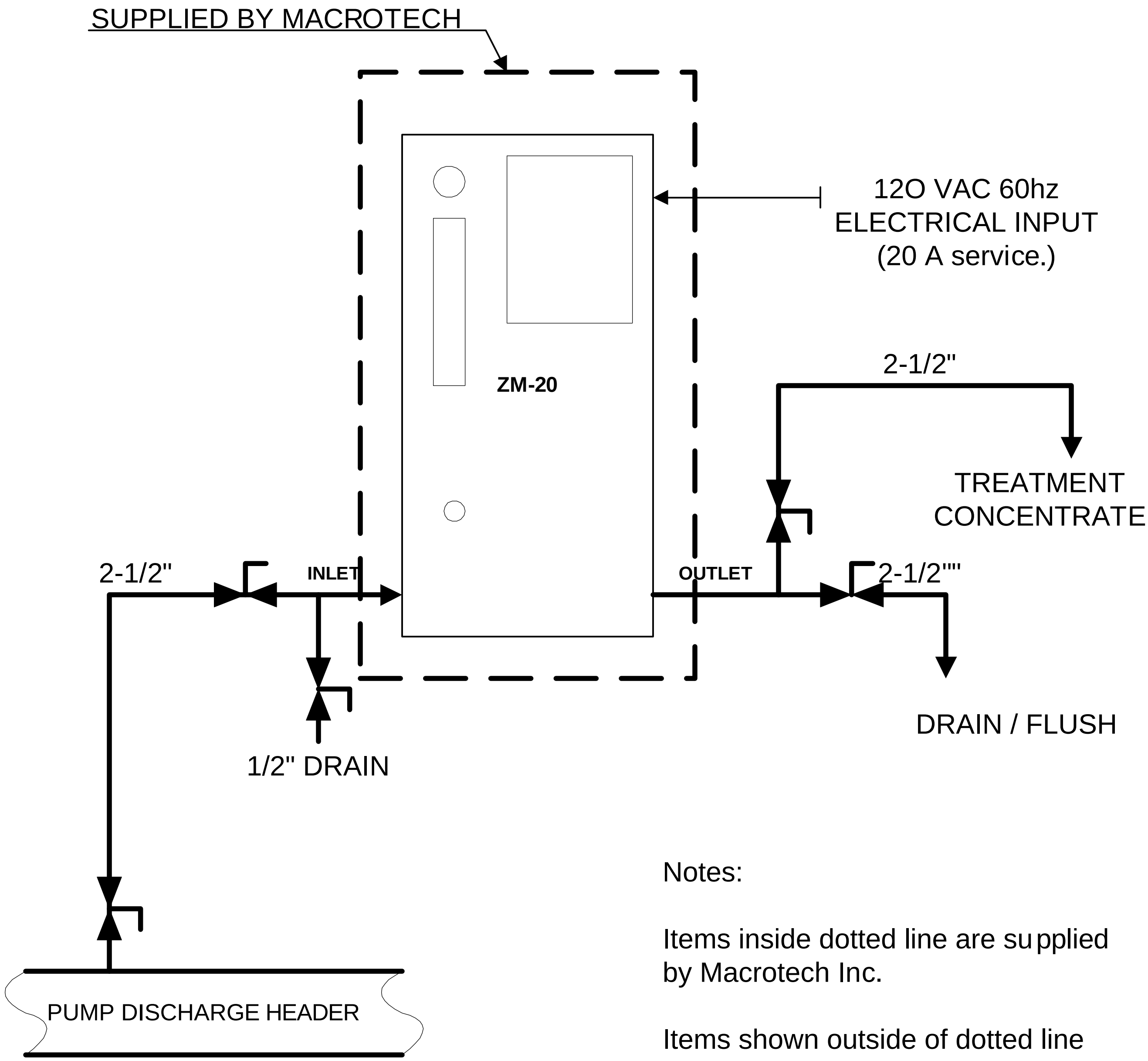
A- INLET 2" 150# FLANGE
B- OUTLET 2" 150# FLANGE



MacroTech, Inc
246 Mamaroneck Rd. Scarsdale, NY 10583
www.macrotechinc.com

General Arrangement
ZM-15 High Output

FILENAME	SIZE	FSCM NO	DWG NO	REV
ZM-15 HO GEN ARR.VSD	F-44		**ZM-15 GA-001P**	**0**
	SCALE 1/16 : 1		SHEET 1 OF 1	



Notes:

Items inside dotted line are supplied by Macrotech Inc.

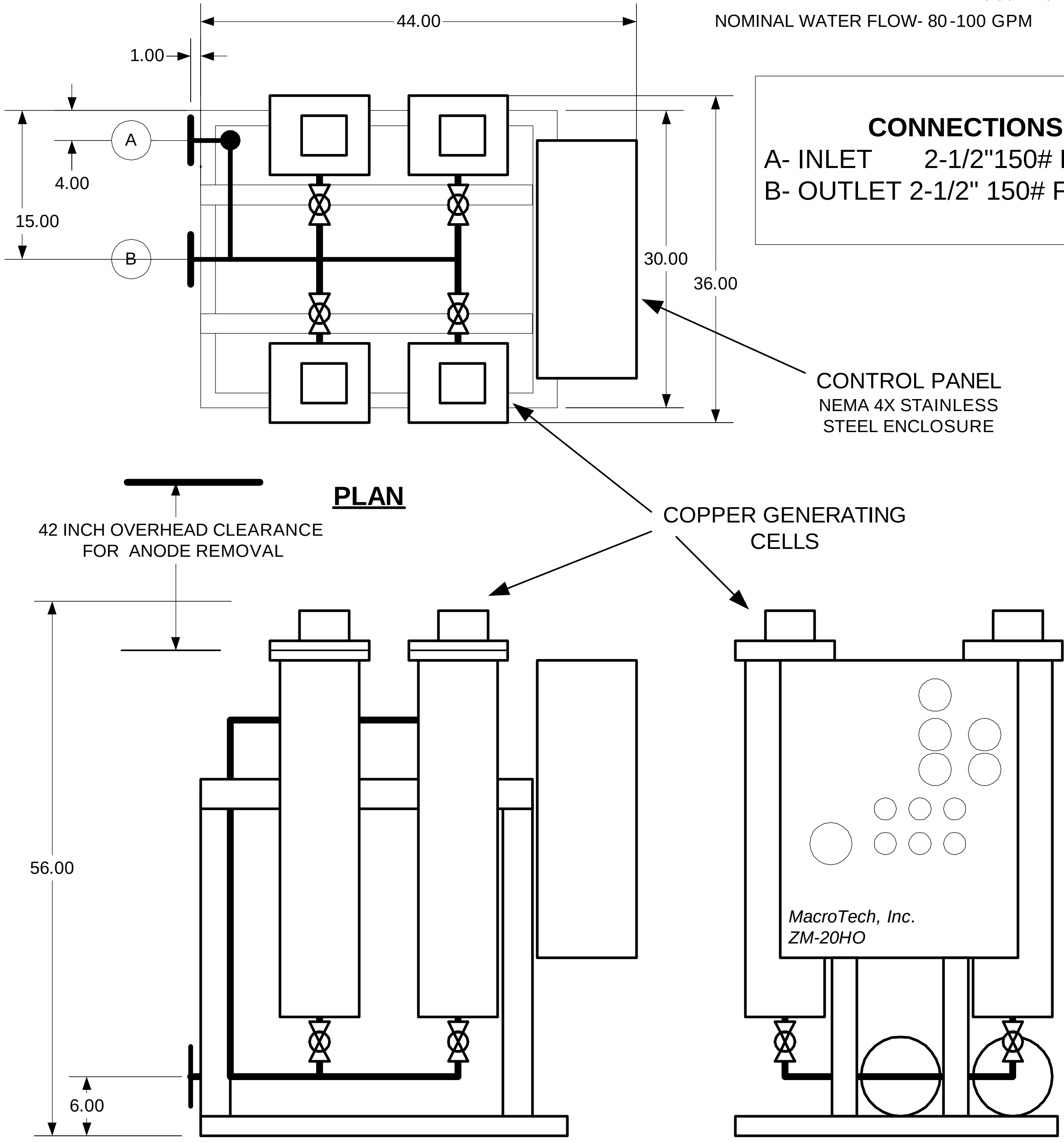
Items shown outside of dotted line are to be supplied by user.

All valves shown are 1/4 turn Ball valves

ZM-20 Piping / Installation	***MACROTECH INC.*** **246 MAMARONECK RD. SCARSDALE, NY 10583** **(914) 723-6185**
DATE 4-16-97 FILENAME ZM20_P&ID.VSD F-45	**DWG** **ZM20-64-201** **REV** **0**

POWER INPUT- 120/240 VAC, 1ph, 60hz, 18/9A
DRY WEIGHT- 1950 Lbs. (approx.)
OPERATING WEIGHT- 2600 lbs. (approx.)
NOMINAL WATER FLOW- 80-100 GPM

CONNECTIONS
A- INLET 2-1/2"150# FLANGE
B- OUTLET 2-1/2" 150# FLANGE



PLAN

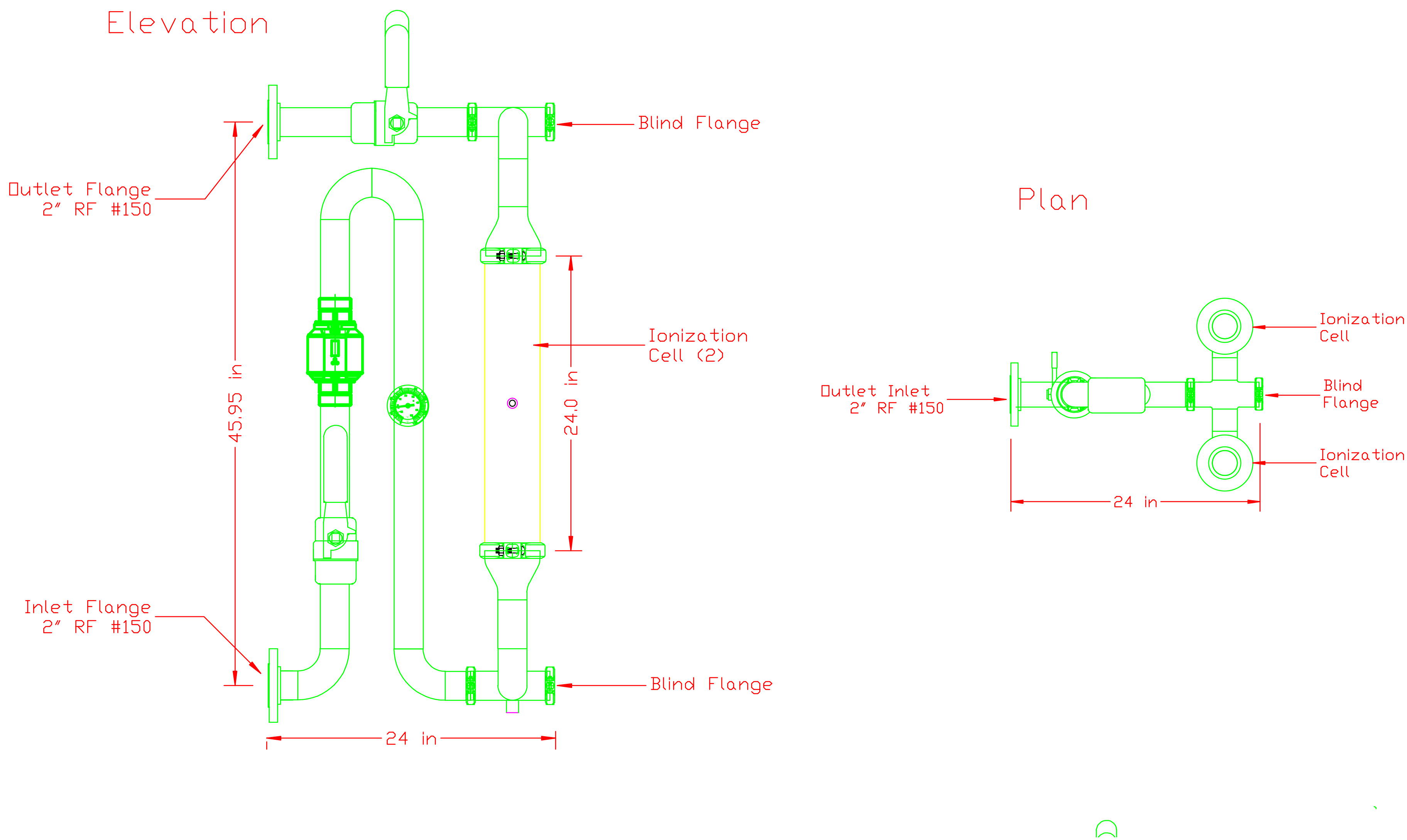
SIDE ELEVATION

FRONT ELEVATION

MacroTech, Inc
246 Mamaroneck Rd. Scarsdale, NY 10583
www.macrotechinc.com

General Arrangement
ZM-20 High Output

FILENAME	SIZE	FSCM NO	DWG NO	REV
ZM-20 HO GEN ARR.VSD	F-46		**ZM-20 GA-001P**	**0**
	SCALE 1/16 : 1		SHEET 1 OF 1	



REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

F-47

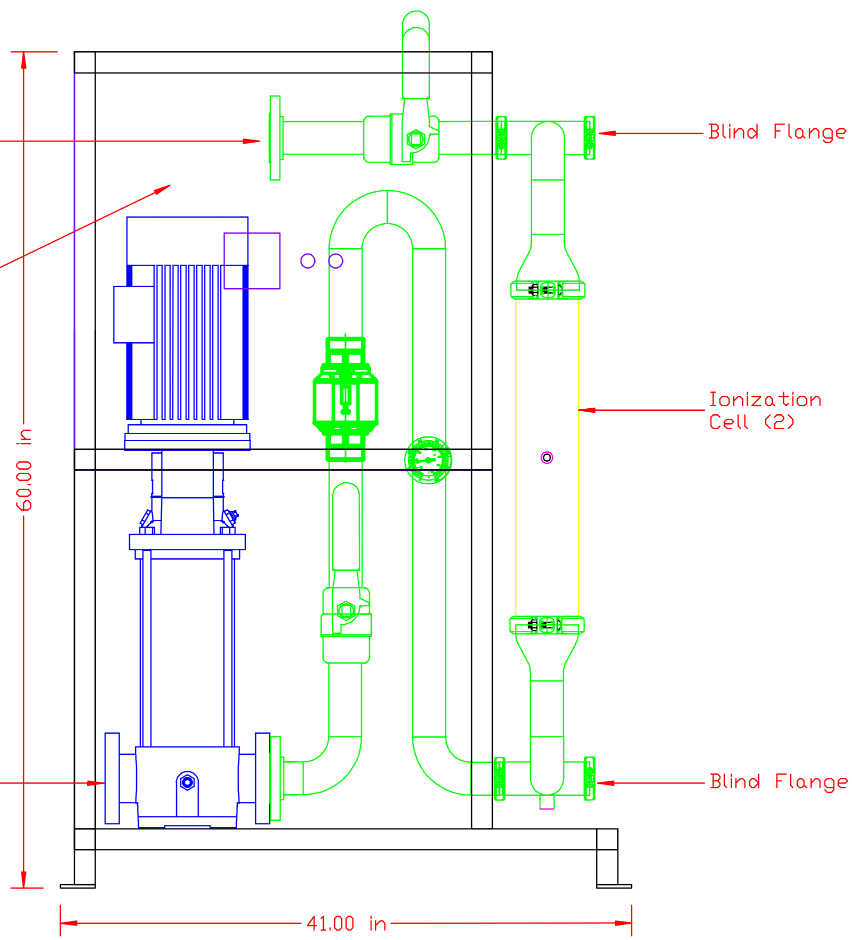
ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

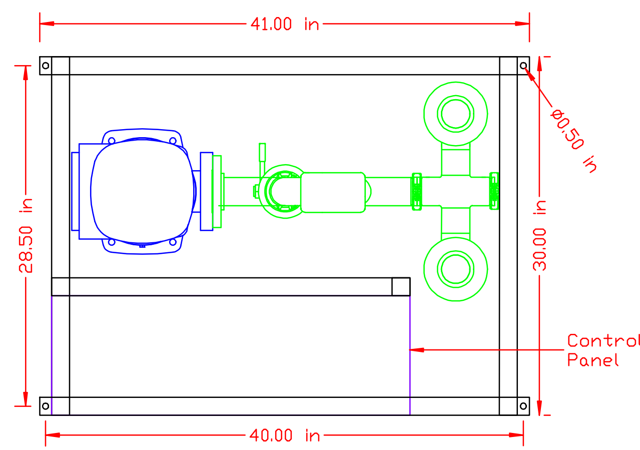
Fortress MC 20

DRAWN BY	FBO	SIZE	A	DRAWING NO. Denton RRWTP	REV 2
DATE	07-29-2015				
FILE	Quad Enclosure.tcw	SCALE		SHEET	2 of 3

Elevation



Plan



REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

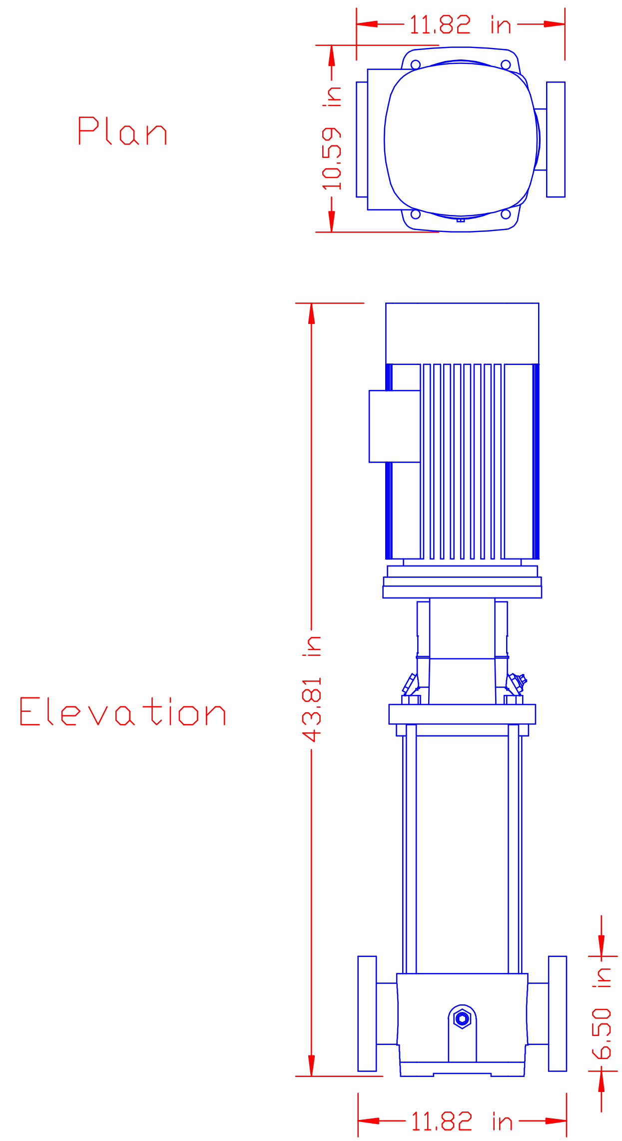
F-48

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress MC 20

DRAWN BY: FBO	SIZE: A	DRAWING NO.: Denton RRWTP		REV: 2
DATE: 07-29-2015				
FILE: Quad Enclosure.tcw	SCALE:	SHEET: 1 of 3		



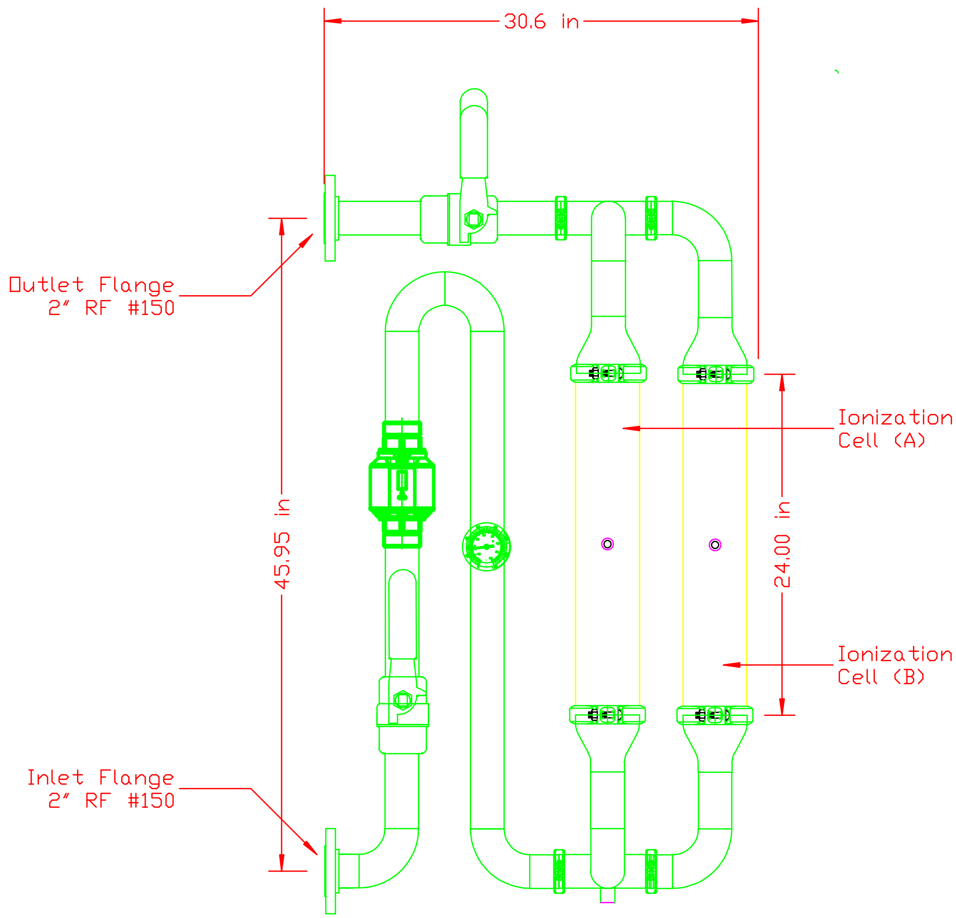
REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

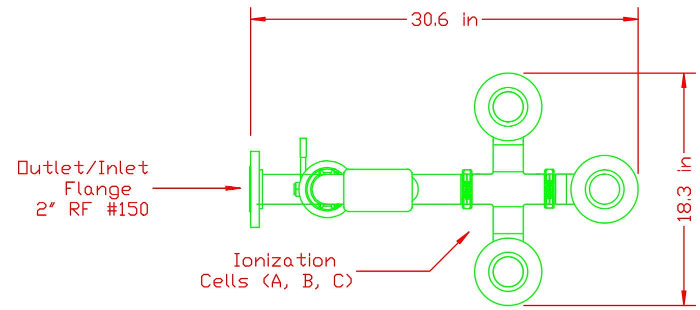
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress MC 20

DRAWN BY	FBO	SIZE	A
DATE	07-29-2015	DRAWING NO.	Denton RRWTP
FILE	Quad Enclosure.tcw	REV	2
SCALE		SHEET	3 of 3



Elevation



Plan

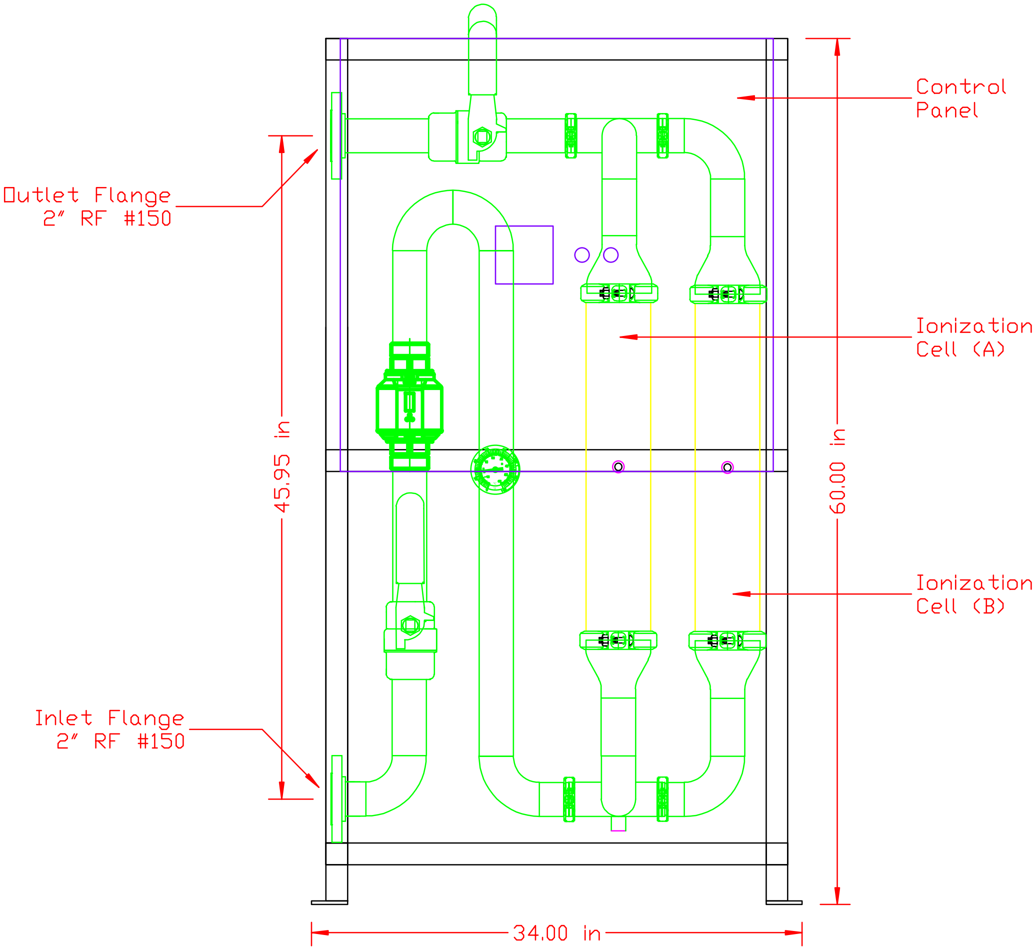
REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary
		F-50	

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

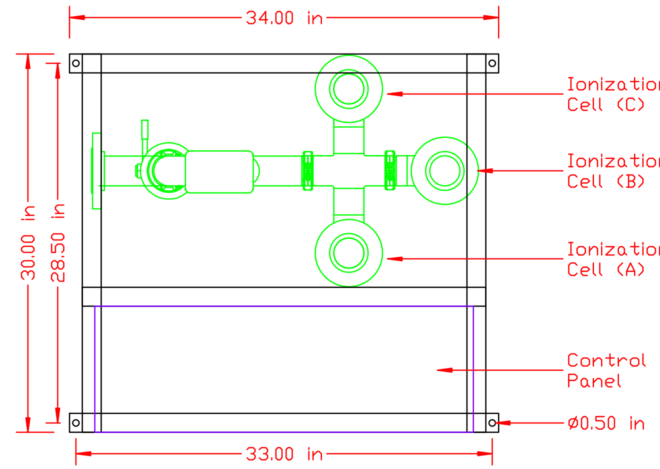
UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress MC 30

DRAWN BY	FBO	SIZE	DRAWING NO.	REV
DATE	07-29-2015	A	Denton LLWTP	2
FILE	Quad Enclosure.tcw	SCALE	SHEET	2 of 2



Elevation



Plan

REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

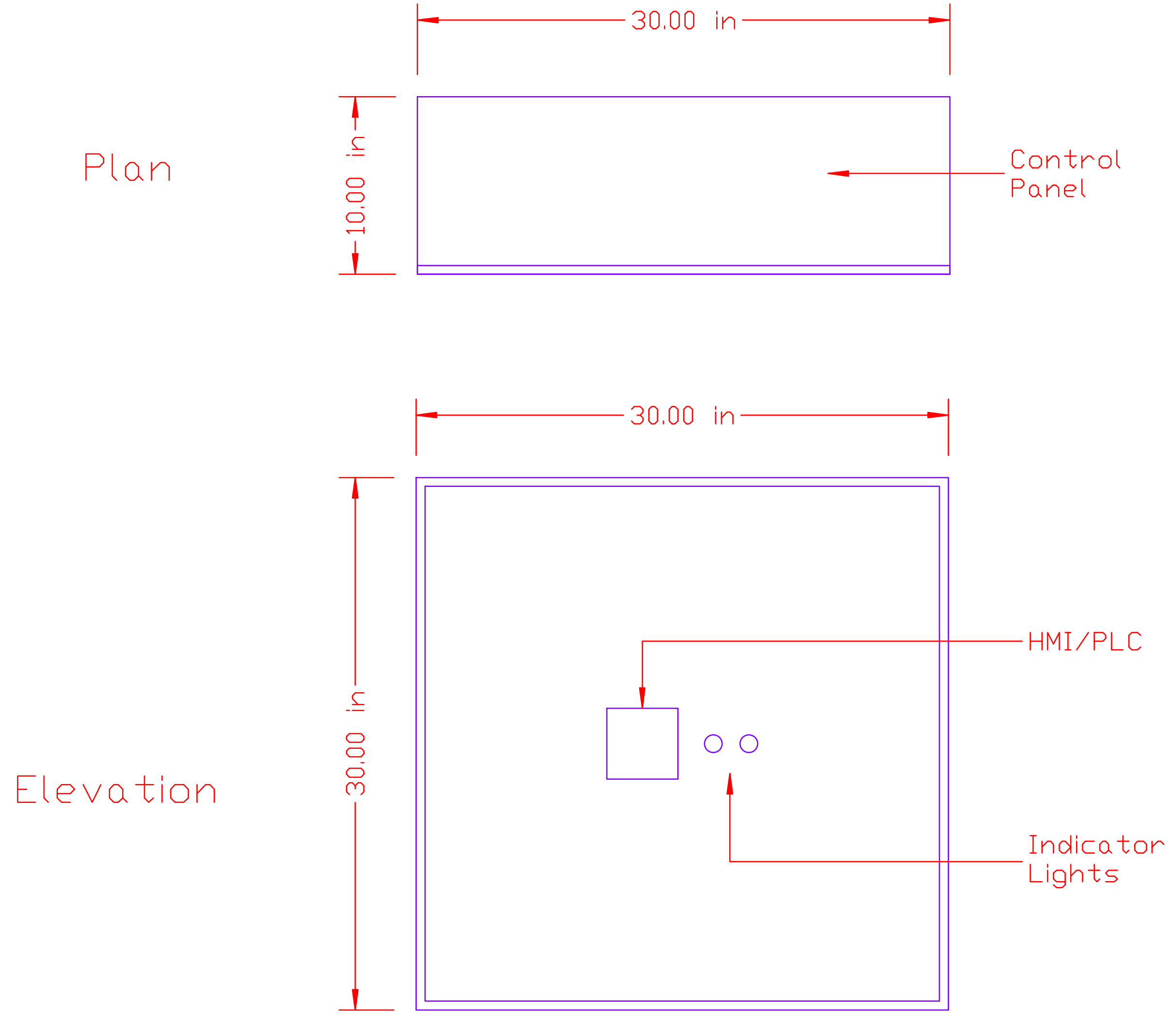
F-51

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress MC 30

DRAWN BY	FBO	SIZE A	DRAWING NO. Denton LLWTP
DATE	07-29-2015	REV	2
FILE	Quad Enclosure.tcw	SCALE	SHEET 1 of 2



REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

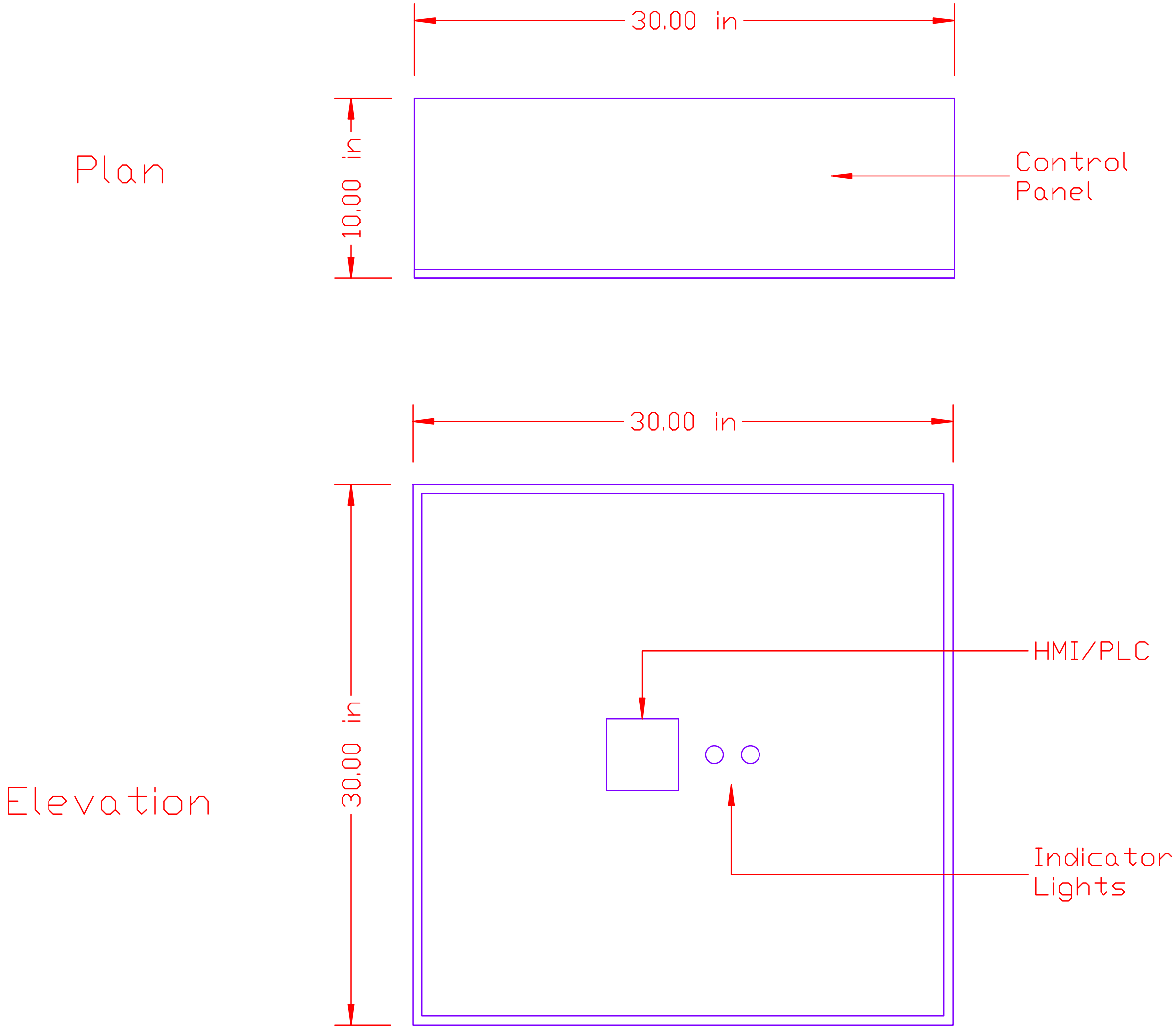
F-52

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress Control Panel

DRAWN BY	FBO	SIZE	A	DRAWING NO.	City of Denton	REV	2
DATE	07-29-2015						
FILE	Quad Enclosure.tcw	SCALE		SHEET	1		



REV	DATE	BY	DESCRIPTION
1	08-06-2015	FBO	Preliminary

F-53

ONG Consulting, LLC
735 N. Golden Hills, Wichita, KS 67212

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES

Fortress Control Panel

DRAWN BY FBO	SIZE A	DRAWING NO. City of Denton		REV 2
DATE 07-29-2015				
FILE Quad Enclosure.tcw	SCALE		SHEET 1	

DISCUSSIONS WITH OPERATORS OF EXISTING INSTALLATIONS

Utility Name	City of Emporia, KS
Contact	Phil Cooper (620-340-6371)
Plant Capacity	15 mgd
Impetus for Installing	Velegiers found in nearby reservoirs
Equipment in Place	Macrotech
Number of Years in Operation	2 yrs
Location of Copper Ion Generating System	Raw water
Length of Raw Water Line	0.75 miles
Booster Pumping Required?	No – use raw water pump discharge pressure
Monitoring for Copper in Place?	Yes – at head of WTP and at waste lagoon
Any Issues with Copper Levels?	No
Plans to Replace Equipment	Yes
Other Equipment Issues	Adding a strainer ahead of equipment
Additional Zebra Mussel Controls in Place	Copper mesh screen with 1/8-in openings

Utility Name	City of Wichita, KS
Contact	Eric Meyer (316)-540-3574
System Capacity	80 mgd
Impetus for Installing	Zebra Mussels in sample lines – concern that they would get in air and vacuum release valves along long raw water line
Equipment in Place	Macrotech
Number of Years in Operation	4 yrs
Location of Copper Ion Generating System	Raw Water
Length of Raw Water Line	23 miles
Booster Pumping Required?	No – use raw water pump discharge pressure
Monitoring for Copper in Place?	Yes
Any Issues with Copper Levels?	No
Plans to Replace Equipment	Yes
Other Equipment Issues	Power supply
Additional Zebra Mussel Controls in Place	No – unprotected trach rack upstream

MATERIAL SAFETY DATA SHEETS

SOUTHERN COPPER & SUPPLY COMPANY, INC.

Southern Copper & Supply Company, Inc.
P.O. Box 570 • 875 Yeager Parkway • Pelham, AL 35124
(205) 664-9440 • Fax (205) 664-1365 • 800-289-2728

MATERIAL SAFETY DATA SHEETS

Section I - Material Identification

Copper Development Association (CDA #110) Electrolytic Tough Pitch Copper	Composition - Percent Copper - 99.90% Oxygen - .04%

Section II - Hazardous Ingredients/Identity Information

Hazardous Components (Specific Chemical Identity: Common Names (s)

	1985 OSHA PEL (mg/m^3)	1985 - 1986 ACGIS-TLV (mg/m^3)		Other Limits Recommended	% (Optional)
		TWA	STEL		
Copper					100
Fume	0.1	0.2	NA	NA	
Dust and Mists	1	1	2	NA	

Section III - Physical/Chemical Characteristics

Boiling Point	2300°C	Specific Gravity (H_2O -1)	8.92
Vapor Pressure (mm Hg.) @ 20°C	N/A	Melting Point	1083°C
Vapor Density (AIR-1)	N/A	Evaporation Rate/(Bulyl Acetate-1)	N/A
Solubility in Water: Insoluble			
Appearance and Odor: Yellowish-red Metal; No Odor.			

Section IV - Fire Explosion Hazard Data

Flash Point: Not Applicable	*Flammable Limits:* Not Applicable	*LEL:* N/A	*UEL*: N/A

Extinguishing Media: Use no water, use powdered extinguishing agents: graphite, dolomite, sodium chloride.

Special Fire Fighting Procedures: Powder extinguisher agents should be applied gently on metal fires to avoid breaking any crust which may be formed over metal.

Unusual Fire and Explosion Hazards: Dangerous in dispersed form when exposed to flame or spark. Powdered metal may ignite spontaneously.

Health	2
Fire	1
Reactivity	0
Personal Protection	E

Material Safety Data Sheet
Copper MSDS

Section 1: Chemical Product and Company Identification

Product Name: Copper

Catalog Codes: SLC4939, SLC2152, SLC3943, SLC1150, SLC2941, SLC4729, SLC1936, SLC3727, SLC5515

CAS#: 7440-50-8

RTECS: GL5325000

TSCA: TSCA 8(b) inventory: Copper

CI#: Not available.

Synonym:

Chemical Name: Not available.

Chemical Formula: Cu

Contact Information:

Sciencelab.com, Inc.
14025 Smith Rd.
Houston, Texas 77396

US Sales: **1-800-901-7247**
International Sales: **1-281-441-4400**

Order Online: ScienceLab.com

CHEMTREC (24HR Emergency Telephone), call:
1-800-424-9300

International CHEMTREC, call: 1-703-527-3887

For non-emergency assistance, call: 1-281-441-4400

Section 2: Composition and Information on Ingredients

Composition:

Name	CAS #	% by Weight
Copper	7440-50-8	100

Toxicological Data on Ingredients: Copper LD50: Not available. LC50: Not available.

Section 3: Hazards Identification

Potential Acute Health Effects:
Very hazardous in case of ingestion. Hazardous in case of eye contact (irritant), of inhalation. Slightly hazardous in case of skin contact (irritant).

Potential Chronic Health Effects:
CARCINOGENIC EFFECTS: Not available. MUTAGENIC EFFECTS: Not available. TERATOGENIC EFFECTS: Not available. DEVELOPMENTAL TOXICITY: Not available. The substance is toxic to lungs, mucous membranes. Repeated or prolonged exposure to the substance can produce target organs damage.

Section 4: First Aid Measures

Eye Contact: Check for and remove any contact lenses. Do not use an eye ointment. Seek medical attention.

* * * Section 1 - Chemical Product and Company Identification * * *

Identification Number: KASP-2
Chemical Name: Aluminum
Product Use: Fabricated Parts
Synonyms: None
Manufacturer Information

Kaiser Aluminum
27422 Portola Parkway
Suite 200
Foothill Ranch, CA 92610

24 HR Emergency Telephone: CHEMTREC, call 1-800-424-9300;
International CHEMTREC, call: 001-703-527-3887
For non-emergency assistant Kaiser Aluminum, call: 1-509-927-6444

* * * Section 2 - Hazards Identification * * *

Emergency Overview

Product is solid metallic pieces. Product may form explosive dust/air mixtures if high concentration of product dust is suspended in air. Firefighters should wear full protective clothing and self contained breathing apparatus. Exposure to dust may be irritating to eyes, nose, and throat. Contact with hot metal may cause severe thermal burns. Do not touch or handle cast aluminum or heated materials before determining the temperature. Hot work operation such as welding, torch cutting, etc may potentially generate hexavalent chromium which has been identified as a carcinogen. See Section 15.

Potential Health Effects: Eyes

Dust, fumes or powder may irritate eye tissue. Eye contact with aluminum particles may cause corneal necrosis.

Potential Health Effects: Skin

Dust or powder may irritate the skin. Some products may contain residual coating. Do not touch or handle cast aluminum or heated materials before determining the temperature. Aluminum does not change color on heating. Contact with hot metal may cause severe thermal burns.

Potential Health Effects: Ingestion

Not a likely route of entry. Ingestion of large amounts of dusts or particulates may produce gastrointestinal disturbances including irritation, nausea, and diarrhea.

Potential Health Effects: Inhalation

Dusts of this product may cause irritation of the nose, throat, and respiratory tract.

HMIS Ratings: Health: 1 **Fire:** 1 **Reactivity:** 0 **Pers. Prot.:** Goggles, Gloves, Protective Clothing
Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe * = Chronic hazard
Hazard Label Pictograms:

Explosive

Irritant

Respiratory Sensitizer

* * * Section 3 - Composition / Information on Ingredients * * *

CAS #	Component	Percent[1]
7429-90-5	Aluminum	90-100
	Alloying Elements	
7440-21-3	Silicon	0.1-1, 1-5, 5-10, 10-15
7439-89-6	Iron	0.1-1, 1-5, 5-10
7440-66-6	Zinc	0.1-1, 1-5, 5-10
7440-50-8	Copper	0.1-1, 1-5, 5-10, 10-20
7439-95-4	Magnesium	0.1-1, 1-5, 5-10
7440-31-5	Tin	0.1-1, 1-5, 5-10
7440-69-9	Bismuth	0.1-1, 1-5, 5-10
7440-74-6	Indium	0.1-1, 1-5, 5-10
7440-55-3	Gallium	0.1-1, 1-5, 5-10

Component Related Regulatory Information

This product may be regulated, have exposure limits or other information identified as the following: Iron oxide (1309-37-1), Magnesium oxide fume (1309-48-4), Zinc oxide (1314-13-2).

Component Information/Information on Non-Hazardous Components

This material is considered an "article" under 29 CFR 1910.1200 (Hazard Communication) and the Canadian Workplace Hazardous Materials Information System (WHMIS). The information in this SDS is provided for situations where this material may be deformed creating dusts or fumes which may be potentially hazardous.

* * * Section 4 - First Aid Measures * * *

First Aid: Eyes

Flush immediately with water for at least 15 minutes. Do not rub eyes. If irritation persists get medical attention.

First Aid: Skin

For skin contact, flush with large amounts of water. If irritation persists, get medical attention.

First Aid: Ingestion

Due to the physical nature of this material, ingestion is unlikely to occur. If ingestion of a large amount does occur, seek medical attention.

First Aid: Inhalation

If symptoms are experienced, remove source of contamination or move victim to fresh air. Give oxygen if breathing is difficult. Call a physician if symptoms develop or persist.

* * * Section 5 - Fire Fighting Measures * * *

General Fire Hazards

High concentration of airborne dust may form explosive mixture with air.

Unusual Fire and Explosion Hazards

Fresh, very finely ground aluminum, may be pyrophoric when its particle size is 0.03 um or less. Dust is moderately flammable/explosive by heat, flame or chemical reaction with powerful oxidizers. May ignite on contact with vapors of $AsCl_3$, SCl_2, Se_2Cl_2, PCl_5; on contact with barium peroxide; contact with O_2; mixtures with picric acid + water after a delayed period; exothermic reaction with water + iron powder which emits hydrogen gas; and spontaneously ignites in CS_2 vapors.

[1] Where more than one range for a component is given in the “Percent” column, the range for the component includes all the individual ranges. Thus, if the column lists 0.1-1, 1-5, 5-10, the material is present in the product at a concentration between 0.1 and 10 percent.

May ignite and react violently with mixtures of sodium peroxide and O2+H2O; on contact with halogens and interhalogens. May react violently with hydrochloric acid, hydrofluoric acid, hydrogen chloride gas and disulfur dibromide; non-metals phosphorus, sulfur and selenium; with sulfur, Sb or As when heated; and potential violent reaction with sodium peroxide. May have a violent or explosive reaction when heated with metal oxides, oxosalts (nitrates, sulfates), some halocarbons, sulfides or hot copper oxide worked with an iron or steel tool. May have an explosive reaction with sodium sulfate above 800 oC; in powdered form with KClO4+Ba (NO3) 2+ KNO3+H2O and Ba (NO3)2+KNO3+sulfur+vegetable adhesives+H2O after a delayed period; powder forms sensitive explosive mixture with oxidants; mixtures with powdered AgCl, NH4NO3, or NH4NO3+Ca (NO3)2+formamide+H2O are powerful explosives; mixtures with ammonium peroxodisulfate+water is explosive; and potential explosive reaction with CCl4 during ball milling operations. Many violent or explosive reactions with the following halocarbons have occurred in industry: bromothane, bromotrifluoromethane, CCl4, chlorodifluoromethane, chloroform, chloromethane, chloromethane+2-methylpropane, dichlorodifluoromethane, 1, 2-dichloroethane, dichloromethane, 1, 2-dichloropropane, 1,2, -difluorotetrafluoroethane, fluorotrichloroethane, hexachloroethane alcohol, polytrifluorethylene oils and greases, tetrachlorethylene, tetrachlorethylene, tetrafluoromethane, 1,1,1-trichloroethane, trichloroethylene, 1,1,2-trichlorotrifluoroethane, and trichlorotrifluoroethane-dichlorobenzene. (Sax, Dangerous Properties of Industrial Materials, eighth edition).

Hazardous Combustion Products

Decomposition of base metal product may yield metallic oxides.

Extinguishing Media

Use dry chemical, foam, carbon dioxide, water spray or water fog for oil fires.

Use dry powder, talc, or sand to extinguish metal fires.

Material in or near fires should be cooled with a water spray or fog if compatible with fire fighting techniques for the other materials involved in the fire.

Unsuitable Extinguishing Media

Do NOT use water or halogenated agents.

Fire Fighting Equipment/Instructions

Fire fighters should wear full-face, self contained breathing apparatus and impervious protective clothing. Fire fighters should avoid inhaling any combustion products. Avoid creation of dusts.

NFPA Ratings: Health: 1 **Fire:** 1 **Reactivity:** 0

Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe

* * * Section 6 - Accidental Release Measures * * *

Containment Procedures

Contain the discharged material. Remove sources of ignition.

Clean-Up Procedures

Shovel the material into waste container. Avoid the generation of dusts during clean-up. When dealing with aluminum powder/dust wear appropriate respiratory and protective equipment specified in Section 8. Isolate spill area, provide ventilation and extinguish sources of ignition. Vacuum up spill using a high efficiency particulate absolute (HEPA) air filter and place in a closed container for proper disposal. Use non-sparking tools.

Evacuation Procedures

Isolate area. Keep unnecessary personnel away.

Special Procedures

Wear appropriate personal protective equipment. See Section 8. Follow all Local, State, Federal and Provencial regulations for disposal.

* * * Section 7 - Handling and Storage * * *

Handling Procedures

Do not breathe fumes or dust from this material. Use adequate ventilation. Keep dusts or powders of this product from heat, sparks, or open flame. Use non-sparking tools when opening or closing containers. Do not touch or handle cast aluminum or heated materials before determining the temperature. Aluminum does not change color on heating. Handle with caution and wear appropriate personal protective equipment. Dry metal properly before loading in a melting furnace. Moisture trapped in crevices and occlusions can cause a violent explosion.

Storage Procedures

Keep the container tightly closed and in a cool, well-ventilated place. Store away from incompatible materials. If dusts and powders are formed, use adequate ventilation in storage and do not handle or store dusts or powders of this product near an open flame, heat or other sources of ignition.

Good housekeeping and engineering practices should be employed to prevent the generation and accumulation of dusts. Vacuuming with a HEPA (High Efficiency Particulate Air) equipped vacuum is recommended to clean up any dusts that may be generated during handling and processing. Wash hands and face thoroughly before eating, drinking or smoking.

* * * Section 8 - Exposure Controls / Personal Protection * * *

A: Component Exposure Limits

Consult local authorities for acceptable exposure limits.

Aluminum (7429-90-5)

ACGIH:	10 mg/m3 TWA (metal dust)[2]
OSHA:	15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
CAL-OSHA:	10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
NIOSH:	10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
Alberta:	10 mg/m3 TWA (dust)
British Columbia:	10 mg/m3 TWA (total dust); 3 mg/m3 TWA (respirable fraction)
Manitoba:	10 mg/m3 TWA
New Brunswick:	10 mg/m3 TWA (metal dust)
NW Territories:	10 mg/m3 TWA 20 mg/m3 STEL
Nova Scotia:	10 mg/m3 TWA (metal dust)
Nunavut:	10 mg/m3 TWA 20 mg/m3 STEL
Ontario:	5 mg/m3 TWAEV (powder); 10 mg/m3 TWAEV (metal and oxide dust)
Quebec:	10 mg/m3 TWAEV
Saskatchewan:	10 mg/m3 TWA 20 mg/m3 STEL

[2] The ACGIH has proposed changing the TLV for aluminum from 10 mg/m3 as total dust to 1 mg/m3 as respirable particulate matter.

Silicon (7440-21-3)

OSHA:	15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
CAL-OSHA:	10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
NIOSH:	10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
Alberta:	10 mg/m3 TWA
British Columbia:	10 mg/m3 TWA (total dust); 3 mg/m3 TWA (respirable fraction)
Manitoba:	10 mg/m3 TWA (total dust containing no asbestos and <1% free silica)
New Brunswick:	10 mg/m3 TWA
NW Territories:	5 mg/m3 TWA (respirable mass); 10 mg/m3 TWA (total mass)
Nova Scotia:	10 mg/m3 TWA
Nunavut:	5 mg/m3 TWA (respirable mass); 10 mg/m3 TWA (total mass)
Ontario:	10 mg/m3 TWAEV (total dust)
Quebec:	10 mg/m3 TWAEV (total dust, containing no asbestos and less than 1% crystalline silica)
Saskatchewan:	10 mg/m3 TWA 20 mg/m3 STEL
Yukon:	30 mppcf TWA; 10 mg/m3 TWA 20 mg/m3 STEL

Iron (7439-89-6)

ACGIH:	5 mg/m3 TWA (respirable fraction) (related to Iron oxide (Fe2O3))
OSHA:	10 mg/m3 TWA (fume) (related to Iron oxide)
CAL-OSHA:	5 mg/m3 TWA (fume) (related to Iron oxide)
NIOSH:	5 mg/m3 TWA (dust and fume, as Fe) (related to Iron oxide)
Alberta:	5 mg/m3 TWA (dust and fume, as Fe) (related to Iron oxide)
British Columbia:	5 mg/m3 TWA (dust and fume, as Fe) (related to Iron oxide) 10 mg/m3 STEL (fume, as Fe) (related to Iron oxide)
Manitoba:	5 mg/m3 TWA (as Fe, welding fumes, dust, total particulate) (related to Iron oxide (Fe2O3))
New Brunswick:	5 mg/m3 TWA (particulate matter containing no asbestos and < 1% crystalline silica, dust and fume, as Fe) (related to Iron oxide (Fe2O3))
NW Territories:	5 mg/m3 TWA (respirable mass); 10 mg/m3 TWA (total mass) (related to Rouge)
Nova Scotia:	5 mg/m3 TWA (respirable fraction) (related to Iron oxide (Fe2O3))
Nunavut:	5 mg/m3 TWA (respirable mass); 10 mg/m3 TWA (total mass) (related to Rouge)
Ontario:	5 mg/m3 TWAEV (dust and fume, as Fe) (related to Iron oxide)
Quebec:	5 mg/m3 TWAEV (dust and fume, as Fe) (related to Iron trioxide)
Saskatchewan:	5 mg/m3 TWA (fume, as Fe) (related to Iron oxide) 10 mg/m3 STEL (fume, as Fe) (related to Iron oxide)
Yukon:	5 mg/m3 TWA (fume as Fe2O3) (related to Iron oxide) 10 mg/m3 STEL (fume, as Fe2O3) (related to Iron oxide)

Zinc (7440-66-6)

ACGIH:	2 mg/m3 TWA (respirable fraction) (related to Zinc oxide) 10 mg/m3 STEL (respirable fraction) (related to Zinc oxide)
OSHA:	5 mg/m3 TWA (fume); 15 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction) (related to Zinc oxide)
CAL-OSHA:	5 mg/m3 TWA, 10 mg/m3 STEL (related to Zinc oxide fume) 10 mg/m3 TWA (total dust); 5 mg/m3 TWA (respirable fraction)
NIOSH:	5 mg/m3 TWA (dust and fume) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide) 15 mg/m3 Ceiling (dust) (related to Zinc oxide)
Alberta:	10 mg/m3 TWA (dust); 5 mg/m3 TWA (fume) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide)
British Columbia:	2 mg/m3 TWA (respirable) (related to Zinc oxide) 10 mg/m3 STEL (respirable) (related to Zinc oxide)
Manitoba:	5 mg/m3 TWA (fume); 10 mg/m3 TWA (total dust containing no asbestos and <1% crystalline silica) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide)
New Brunswick:	5 mg/m3 TWA (fume); 10 mg/m3 TWA (particulate matter containing no asbestos and < 1% crystalline silica, dust) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide)
NW Territories:	5 mg/m3 TWA (fume); 5 mg/m3 TWA (dust, respirable mass); 10 mg/m3 TWA (dust, total mass) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide)
Nova Scotia:	2 mg/m3 TWA (respirable fraction) (related to Zinc oxide) 10 mg/m3 STEL (respirable fraction) (related to Zinc oxide)
Nunavut:	5 mg/m3 TWA (fume); 5 mg/m3 TWA (dust, respirable mass); 10 mg/m3 TWA (dust, total mass) (related to Zinc oxide) 10 mg/m3 STEL (fume) (related to Zinc oxide)
Ontario:	2 mg/m3 TWAEV (respirable) (related to Zinc oxide) 10 mg/m3 STEV (respirable) (related to Zinc oxide)
Quebec:	5 mg/m3 TWAEV (fume); 10 mg/m3 TWAEV (dust) (related to Zinc oxide) 10 mg/m3 STEV (fume) (related to Zinc oxide)
Saskatchewan:	5 mg/m3 TWA (fume); 10 mg/m3 TWA (dust) (related to Zinc oxide) 10 mg/m3 STEL (fume); 20 mg/m3 STEL (dust) (related to Zinc oxide)
Yukon:	5 mg/m3 TWA (fume); 30 mppcf TWA (dust); 10 mg/m3 TWA (dust) (related to Zinc oxide) 10 mg/m3 STEL (fume); 20 mg/m3 STEL (dust) (related to Zinc oxide)

Copper (7440-50-8)

ACGIH:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu)
OSHA/CAL-OSHA:	0.1 mg/m3 TWA (fume), 1.0 mg/m3 (dust and mist)
NIOSH:	1 mg/m3 TWA (dust and mist); 0.1 mg/m3 (respirable fume)
Alberta:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu)
British Columbia:	1 mg/m3 TWA (dust and mist, as Cu); 0.2 mg/m3 TWA (fume, as Cu)
Manitoba:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu)
New Brunswick:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu)
NW Territories:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist) 0.6 mg/m3 STEL (fume); 2 mg/m3 STEL (dust and mist)
Nova Scotia:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu)
Nunavut:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu) 0.6 mg/m3 STEL (fume); 2 mg/m3 STEL (dust and mist, as Cu)
Ontario:	0.2 mg/m3 TWAEV (fume, as Cu); 1 mg/m3 TWAEV (dust and mist, as Cu)
Quebec:	0.2 mg/m3 TWAEV (fume, as Cu); 1 mg/m3 TWAEV (dust and mist, as Cu)
Saskatchewan:	0.2 mg/m3 TWA (fume, as Cu); 1 mg/m3 TWA (dust and mist, as Cu) 0.6 mg/m3 STEL (fume, as Cu); 2 mg/m3 STEL (dust and mist, as Cu)
Yukon:	0.2 mg/m3 TWA (fume); 1 mg/m3 TWA (dust and mist, as Cu) 0.2 mg/m3 STEL (fume); 2 mg/m3 STEL (dust and mist, as Cu)

Magnesium (1309-48-4)

ACGIH:	10 mg/m3 TWA (inhalable fraction) (related to Magnesium oxide)
OSHA:	10 mg/m3 TWA (total particulate) (related to Magnesium oxide fume)
CAL-OSHA:	10 mg/m3 TWA (fume)
Alberta:	10 mg/m3 TWA (fume) (related to Magnesium oxide)
British Columbia:	10 mg/m3 TWA (fume, inhalable, as Mg); 3 mg/m3 TWA (respirable dust and fume, as Mg) (related to Magnesium oxide) 10 mg/m3 STEL (respirable dust and fume, as Mg) (related to Magnesium oxide)
Manitoba:	10 mg/m3 TWA (fume) (related to Magnesium oxide)
New Brunswick:	10 mg/m3 TWA (fume) (related to Magnesium oxide)
NW Territories:	10 mg/m3 TWA (fume, as Mg) (related to Magnesium oxide) 20 mg/m3 STEL (fume, as Mg) (related to Magnesium oxide)
Nova Scotia:	10 mg/m3 TWA (inhalable fraction) (related to Magnesium oxide)
Nunavut:	10 mg/m3 TWA (fume, as Mg) (related to Magnesium oxide) 20 mg/m3 STEL (fume, as Mg) (related to Magnesium oxide)
Ontario:	10 mg/m3 TWAEV (inhalable) (related to Magnesium oxide)
Quebec:	10 mg/m3 TWAEV (fume, as Mg) (related to Magnesium oxide)
Saskatchewan:	10 mg/m3 TWA (fume) (related to Magnesium oxide) 20 mg/m3 STEL (fume) (related to Magnesium oxide)
Yukon:	10 mg/m3 TWA (fume as Mg) (related to Magnesium oxide) 10 mg/m3 STEL (fume, as Mg) (related to Magnesium oxide)

Tin (7440-31-5)

ACGIH:	2 mg/m3 TWA
OSHA:	2 mg/m3 TWA (inorganic compounds except oxides)
	0.1 mg/m3 TWA (organic compounds)
CAL-OSHA:	0.1 mg/m3 TWA, 0.2 mg/m3 STEL (organic compounds)
Alberta:	2 mg/m3 TWA
British Columbia:	2 mg/m3 TWA
Manitoba:	2 mg/m3 TWA
New Brunswick:	2 mg/m3 TWA
Nova Scotia:	2 mg/m3 TWA
Ontario:	2 mg/m3 TWAEV
Quebec:	2 mg/m3 TWAEV
Saskatchewan:	2 mg/m3 TWA
	4 mg/m3 STEL

Indium (7440-74-6)

ACGIH:	0.1 mg/m3 TWA
NIOSH:	0.1 mg/m3 TWA
Alberta:	0.1 mg/m3 TWA
British Columbia:	0.1 mg/m3 TWA
Manitoba:	0.1 mg/m3 TWA
New Brunswick:	0.1 mg/m3 TWA
NW Territories:	0.1 mg/m3 TWA
	0.3 mg/m3 STEL
Nova Scotia:	0.1 mg/m3 TWA
Nunavut:	0.1 mg/m3 TWA
	0.3 mg/m3 STEL
Ontario:	0.1 mg/m3 TWAEV
Quebec:	0.1 mg/m3 TWAEV
Saskatchewan:	0.1 mg/m3 TWA
	0.3 mg/m3 STEL
Yukon:	0.1 mg/m3 TWA
	0.3 mg/m3 STEL

Engineering Controls

Use local exhaust ventilation.

PERSONAL PROTECTIVE EQUIPMENT

Personal Protective Equipment: Eyes/Face

Wear safety glasses with side shields.

Personal Protective Equipment: Skin

Wear leather or other appropriate work gloves, if necessary for type of operation.

Personal Protective Equipment: Respiratory

If ventilation is not sufficient to effectively control exposures, appropriate NIOSH approved respirators should be used. Respirators should be selected and used under the direction of trained health and safety professionals in accordance with all applicable health, safety, and environmental regulations.

Personal Protective Equipment: General

Wear appropriate protective clothing.

* * * Section 9 - Physical & Chemical Properties * * *

Appearance:	Solid metallic pieces	**Odor:**	None
Physical State:	Solid	**pH:**	Not Available
Vapor Pressure:	Not Available	**Vapor Density:**	Not Available
Boiling Point:	Not Available	**Melting Point:**	1215°F (660°C)
Solubility (H2O):	Insoluble	**Specific Gravity:**	2.5-2.9 g/cc

* * * Section 10 - Chemical Stability & Reactivity Information * * *

Chemical Stability

Stable under normal conditions.

Chemical Stability: Conditions to Avoid

Avoid ignition sources where dust is produced. Avoid incompatible materials. May react with chlorinated solvents to produce toxic hydrogen chloride. Hot aluminum may react with chlorinated solvents to produce phosgene, a highly irritating and toxic gas.

Special Sensitivity: When melting aluminum, aluminum alloys, or aluminum scrap, care must be taken to exclude water or moisture. Water or moisture trapped under hot or molten metal can result in a violent explosion. Strong oxidizing agents must be excluded during heating and melting operations to prevent the possibility of an explosion. Finely divided aluminum dusts may form explosive mixtures in air. Care should be taken to employ effective dust control measures.

Incompatibility

This product may react with strong acids, bases and oxidizing agents to produce hydrogen gas, which is highly flammable. Contact with chlorinated solvents may release toxic and corrosive hydrogen chloride gas. Hot aluminum may react with chlorinated solvents to produce phosgene, a highly irritating and toxic gas.

Hazardous Decomposition

Decomposition of this product may yield metallic oxides, such as aluminum oxide. Hydrogen may also be produced when reacted with some acids and caustic solutions.

Possibility of Hazardous Reactions

Will not occur.

* * * Section 11 - Toxicological Information * * *

Acute Dose Effects

A: General Product Information

Inhalation of metal fumes may cause metal fume fever, a flu-like illness generally lasting 24 hours or less.

Aluminum: Chronic overexposure to aluminum can result in lung damage and has been associated with asthma-like syndrome. Accumulation of aluminum in the body may result in neurological damage, anemia and bone softening. Repeated overexposure to high levels of aluminum oxide may lead to pulmonary fibrosis, a progressive lung disorder.

Silicon: Silicon dust seems to have little adverse effect on lungs and does not appear to produce significant organic disease or toxic effects when exposures are kept under reasonable control.

Iron: Chronic inhalation of iron has resulted in mottling of the lungs, a condition referred to as siderosis. This is considered benign pneumoconiosis and does not ordinarily cause significant physiologic impairment.

Zinc: Zinc poisoning can cause anemia, lethargy and dizziness. Inhalation of zinc fumes may cause metal fume fever, a flu-like illness generally lasting 24 hours or less.

Copper: Acute poisoning from ingestion of excessive copper can cause temporary gastrointestinal distress with symptoms such as nausea, vomiting, and abdominal pain. High levels of exposure to copper can cause destruction of red blood cells, possibly resulting in anemia.

Tin: Prolonged exposure to high concentration of tin-containing dusts and/or fumes may result in the development of Stannosis, which is a rare benign pneumoconiosis. The maximum concentration of tin in the product is such that Stannosis should not present a potential hazard.

B: Component Analysis - LD50/LC50

Silicon (7440-21-3)
Oral LD50 Rat: 3160 mg/kg

Iron (7439-89-6)
Oral LD50 Rat: 984 mg/kg

Zinc (7440-66-6)
Oral LD50 Rat: >5000 mg/kg (related to Zinc oxide)

Magnesium (7439-95-4)
Oral LD50 Rat: 230 mg/kg

Bismuth (7440-69-9)
Oral LD50 Rat: 5 g/kg

Repeated Dose Effects

Exposure to metal dusts and oxides may cause fume fever. Fume fever is a temporary flu-like condition characterized by chills, fever, muscle aches and pains, nausea and vomiting. Typically the symptoms appear within a few hours after exposure and subside within 2-3 days with no permanent effects.

Carcinogenicity

A: General Product Information

No carcinogenicity data available for this product.

B: Component Carcinogenicity

Iron (7439-89-6)

ACGIH: A4 - Not Classifiable as a Human Carcinogen (dust and fume) (related to Iron oxide)
IARC: Supplement 7 [1987], Monograph 1 [1972] (related to Ferric oxide) (Group 3 (not classifiable))

Magnesium (7439-95-4)

ACGIH: A4 - Not Classifiable as a Human Carcinogen (related to Magnesium oxide)

* * * Section 12 - Ecological Information * * *

Ecotoxicity

A: General Product Information

No data available for this product. Product is not expected to present an environmental hazard to aquatic and terrestrial flora and fauna.

B: Component Analysis - Ecotoxicity - Aquatic Toxicity

Iron (7439-89-6)

Test & Species		Conditions
96 Hr LC50 Morone saxatilis	13.6 mg/L	static

Zinc (7440-66-6)

Test & Species		Conditions

96 Hr LC50 Pimephales promelas	6.4 mg/L	
96 Hr EC50 Selenastrum capricornutum	30 µg/L	
72 Hr EC50 water flea	5 µg/L	

Copper (7440-50-8)

Test & Species		Conditions
96 Hr LC50 Pimephales promelas	23 µg/L	
96 Hr LC50 Oncorhynchus mykiss	13.8 µg/L	
96 Hr LC50 Lepomis macrochirus	236 µg/L	
72 Hr EC50 Scenedesmus subspicatus	120 µg/L	
96 Hr EC50 water flea	10 µg/L	
96 Hr EC50 water flea	200 µg/L	

Environmental Fate

No data available for this product.

* * * Section 13 - Disposal Considerations * * *

US EPA Waste Number & Descriptions

A: General Product Information

Material, if discarded, is not expected to be a characteristic hazardous waste under RCRA.

B: Component Waste Numbers

No EPA Waste Numbers are applicable for this product's components.

Disposal Instructions

Dispose of waste material according to Local, State, Federal, and Provincial Environmental Regulations.
See Section 7 for Handling Procedures. See Section 8 for Personal Protective Equipment recommendations.

* * * Section 14 - Transportation Information * * *

US DOT Information

Shipping Name: Not regulated.
Additional Info.: Aluminum and aluminum alloys are not regulated for transportation. Aluminum powder is regulated: Aluminum Powder, Class 4.3, UN 1396, PG II.

TDG Information

Shipping Name: Not regulated.
Additional Info.: Aluminum and aluminum alloys are not regulated for transportation. Aluminum powder is regulated: Aluminum Powder, Class 4.3, UN 1396, PG II.

* * * Section 15 - Regulatory Information * * *

US Federal Regulations

A: General Product Information

Components of this product have been checked against the non-confidential TSCA inventory by CAS Registry Number. Components not identified on this non-confidential inventory are either exempt from listing (i.e. polymers, hydrates) or are listed on the confidential inventory as declared by the supplier.

B: Component Analysis

This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4).

Aluminum (7429-90-5)

SARA 313: 1.0 % de minimis concentration (dust or fume only)

Zinc (7440-66-6)

SARA 313: 1.0 % de minimis concentration (dust or fume only)

CERCLA: 1000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 0.004 inches); 454 kg final RQ (no reporting of releases of this hazardous substance is required if the diameter of the solid metal released is equal to or exceeds 0.004 inches)

Copper (7440-50-8)

SARA 313: 1.0 % de minimis concentration

CERCLA: 5000 lb final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 0.004 inches); 2270 kg final RQ (no reporting of releases of this hazardous substance is required if the diameter of the pieces of the solid metal released is equal to or exceeds 0.004 inches)

Chromium (7440-47-3)

The product contains less than 0.1 % chromium. Hot work operations such as welding, torch cutting, etc. will generate metal oxides, which can include hexavalent chromium. OSHA has enacted a standard for exposure to hexavalent chromium [29 CFR 1910.1026], which mandates very stringent exposure limits. Users of the product are urged to read this standard and determine how it might affect their operations.

C: Component Marine Pollutants

This material contains one or more of the following chemicals required by US DOT to be identified as marine pollutants.

Component	CAS #	
Copper	7440-50-8	DOT regulated severe marine pollutant

Acute Health: Yes **Chronic Health:** No **Fire:** No **Pressure:** No **Reactive:** No

State Regulations

A: General Product Information

Other state regulations may apply. Check individual state requirements.

Aluminum and its alloys may contain up to 0.005% beryllium, 0.05% cadmium, <0.1% chromium, and 0.05% lead as impurities if these elements are not listed in Section 3. Beryllium, cadmium, chromium, lead, and nickel have been identified as carcinogens or having developmental or reproductive toxicity by the State of California, as Special Health Hazard Substances by the States of New Jersey and Pennsylvania, and as Extraordinarily Hazardous Substances by the State of Massachusetts.

B: Component Analysis - State

The following components appear on one or more of the following state hazardous substances lists:

Component	**CAS**	**CA**	**MA**	**MN**	**NJ**	**PA**	**RI**
Aluminum	7429-90-5	Yes	Yes	Yes	Yes	Yes	Yes
Copper	7440-50-8	Yes	Yes	Yes	Yes	Yes	Yes
Silicon	7440-21-3	No	Yes	Yes	Yes	Yes	Yes
Iron ([1]related to Iron oxide) ([2]related to Iron oxide fume)	7439-89-6	Yes	Yes[1]	Yes[2]	Yes[1]	Yes[1]	Yes[1]
Zinc ([1]related to Zinc oxide)	7440-66-6	Yes	Yes	Yes[1]	Yes	Yes	Yes
Magnesium ([1]related to Magnesium oxide fume)	7439-95-4	Yes	Yes	Yes[1]	Yes	Yes	Yes
Tin	7440-31-5	Yes	Yes	Yes	Yes	Yes	Yes
Gallium	7440-55-3	No	No	Yes	Yes	No	No
Indium	7440-74-6	Yes	Yes	Yes	Yes	Yes	Yes

Canadian WHMIS Information

A: General Product Information

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the SDS contains all information required by CPR.

B: Component Analysis - WHMIS IDL

The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	Minimum Concentration
Aluminum	7429-90-5	1 %
Iron	7439-89-6	1 % (related to Ferric oxide)
Zinc	7440-66-6	1 % (related to Zinc oxide)
Copper	7440-50-8	1 %
Magnesium	7439-95-4	1 % (related to Magnesium oxide)
Tin	7440-31-5	1 %
Gallium	7440-55-3	1 %
Indium	7440-74-6	1 %

C: WHMIS Classification

D2B- Irritating to eyes and skin when dusts formed.

Additional Regulatory Information

A: General Product Information

No additional information available.

B: Component Analysis - Inventory

Component	CAS #	TSCA	CAN	EEC
Aluminum	7429-90-5	Yes	DSL	EINECS
Silicon	7440-21-3	Yes	DSL	EINECS
Iron	7439-89-6	Yes	DSL	EINECS
Zinc	7440-66-6	Yes	DSL	EINECS
Copper	7440-50-8	Yes	DSL	EINECS
Magnesium	7439-95-4	Yes	DSL	EINECS
Tin	7440-31-5	Yes	DSL	EINECS
Bismuth	7440-69-9	Yes	DSL	EINECS
Gallium	7440-55-3	Yes	DSL	EINECS
Indium	7440-74-6	Yes	DSL	EINECS

* * * Section 16 - Other Information * * *

Other Information

Exercise caution when cutting the containment strapping that may secure some products, particularly wrought materials, during transportation. It may rebound and cause serious injury.

Reasonable care has been taken in the preparation of this information, but the manufacturer makes no warranty of merchantability or any other warranty, expressed or implied, with respect to this information. The manufacturer makes no representations and assumes no liability for any direct, incidental or consequential damages resulting from its use.

Key/Legend

ACGIH = American Conference of Governmental Industrial Hygienists. AICS = Australian Inventory of Chemical Substances. CAS = Chemical Abstract Service. CERCLA = Comprehensive Environmental Response, Compensation and Liability Act. CFR = Code of Federal Regulations. CHEMTREC = Chemical Transportation Emergency Center. DSL = Canadian Domestic Substance List. EINECS = European Inventory of New and Existing Chemical Substances. ELINCS = European List of Notified Chemical Substances. EPA = Environmental Protection Agency. HEPA = High Efficiency Particulate Air. HMIS = Hazardous Material Information System. IARC = International Agency for Research on Cancer. IDLH = Immediately Dangerous to Life and Health. MITI = Japanese Ministry of International Trade and Industry. NDSL = Canadian Non-Domestic Substance List. NFPA = National Fire Protection Association. NIOSH = National Institute of Occupational Safety and Health. NJTSR = New Jersey Trade Secret Registry. NTP = National Toxicology Program. OSHA = Occupational Safety and Health Administration. NA = Not available or Not Applicable. SARA = Superfund Amendments and Reauthorization Act. TDG = Transportation of Dangerous Goods. TLV = Threshold Limit Value. TSCA = Toxic Substances Control Act. WHMIS = Workplace Hazardous Materials Information System.

End of Sheet KASP-2

Section V - Reactivity Data

Stability	Unstable		Conditions to Avoid: In moist air, copper gradually becomes coated with green basic carbonate.
	Stable	X	

Incompatibility *(Materials to Avoid)*:
Copper reacts violently with sodium azide. Avoid contact of powdered metal with oxidizers.

Hazardous Decomposition or Byproducts: No Data

Hazardous Polymerization	May Occur		Conditions to Avoid:
	Will not Occur	X	

Section VI - Health Hazard Data

Route(s) of Entry:
✓Inhalation? of dust, fumes and mists Skin? Ingestion?

Effects of Overexposure:
Acute:
Inhalation: Irritation of upper respiratory tract, metal fume fever (flue-like systems including fever, chills, fatigue, aches, nausea); metallic taste in mouth; skin or hair discoloration
Ingestion: Acute gastrointestinal irritation with possible nausea, vomiting, diarrhea, gastritis.
Other: Hemolytic anemia from copper-tubing hemodialysis equipment
Chronic: Skin, hair and gum discoloration; one study of workers grinding or sieving copper dusts showed symptoms of copper poisoning with effects on the blood, liver, lungs and gastrointestinal tract.

Carcinogenicity: NIP? No IARC Monographs? No OSHA Regulated? No

Medical Conditions Generally Aggravated by Exposure: Persons with Wilson's disease, G6OPD deficiency or chronic respiratory problems.

Emergency and First Aid Procedures:
Inhalation: Remove to fresh air. Establish respiration. Seek medical attention.
Ingestion: Dilute with water. Induct Vomiting, if conscious. Seek medical attention.
Eye: For fumes and mists, flush with large amounts of water. Seek medical attention. For dust particles in eye, have trained medical personnel remove the foreign body.
Skin: Flush with large amounts of water.

Skin Contact:
After contact with skin, wash immediately with plenty of water. Gently and thoroughly wash the contaminated skin with running water and non-abrasive soap. Be particularly careful to clean folds, crevices, creases and groin. Cover the irritated skin with an emollient. If irritation persists, seek medical attention. Wash contaminated clothing before reusing.

Serious Skin Contact: Not available.

Inhalation: Allow the victim to rest in a well ventilated area. Seek immediate medical attention.

Serious Inhalation: Not available.

Ingestion:
Do not induce vomiting. Loosen tight clothing such as a collar, tie, belt or waistband. If the victim is not breathing, perform mouth-to-mouth resuscitation. Seek immediate medical attention.

Serious Ingestion: Not available.

Section 5: Fire and Explosion Data

Flammability of the Product: May be combustible at high temperature.

Auto-Ignition Temperature: Not available.

Flash Points: Not available.

Flammable Limits: Not available.

Products of Combustion: Some metallic oxides.

Fire Hazards in Presence of Various Substances: Not available.

Explosion Hazards in Presence of Various Substances:
Risks of explosion of the product in presence of mechanical impact: Not available. Risks of explosion of the product in presence of static discharge: Not available.

Fire Fighting Media and Instructions:
SMALL FIRE: Use DRY chemical powder. LARGE FIRE: Use water spray, fog or foam. Do not use water jet.

Special Remarks on Fire Hazards: Not available.

Special Remarks on Explosion Hazards: Not available.

Section 6: Accidental Release Measures

Small Spill:
Use appropriate tools to put the spilled solid in a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and dispose of according to local and regional authority requirements.

Large Spill:
Use a shovel to put the material into a convenient waste disposal container. Finish cleaning by spreading water on the contaminated surface and allow to evacuate through the sanitary system. Be careful that the product is not present at a concentration level above TLV. Check TLV on the MSDS and with local authorities.

Section 7: Handling and Storage

Precautions:
Keep away from heat. Keep away from sources of ignition. Empty containers pose a fire risk, evaporate the residue under a fume hood. Ground all equipment containing material. Do not breathe dust. Avoid contact with eyes Wear suitable protective clothing In case of insufficient ventilation, wear suitable respiratory equipment If you feel unwell, seek medical attention and show the label when possible.

Storage:
Keep container dry. Keep in a cool place. Ground all equipment containing material. Keep container tightly closed. Keep in a cool, well-ventilated place. Combustible materials should be stored away from extreme heat and away from strong oxidizing agents.

Section 8: Exposure Controls/Personal Protection

Engineering Controls:
Use process enclosures, local exhaust ventilation, or other engineering controls to keep airborne levels below recommended exposure limits. If user operations generate dust, fume or mist, use ventilation to keep exposure to airborne contaminants below the exposure limit.

Personal Protection:
Splash goggles. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Gloves.

Personal Protection in Case of a Large Spill:
Splash goggles. Full suit. Dust respirator. Boots. Gloves. A self contained breathing apparatus should be used to avoid inhalation of the product. Suggested protective clothing might not be sufficient; consult a specialist BEFORE handling this product.

Exposure Limits:
TWA: 1 (mg/m3) from ACGIH [1990] Consult local authorities for acceptable exposure limits.

Section 9: Physical and Chemical Properties

Physical state and appearance: Solid.

Odor: Not available.

Taste: Not available.

Molecular Weight: 63.54 g/mole

Color: Not available.

pH (1% soln/water): Not applicable.

Boiling Point: 2595°C (4703°F)

Melting Point: 1083°C (1981.4°F)

Critical Temperature: Not available.

Specific Gravity: 8.94 (Water = 1)

Vapor Pressure: Not applicable.

Vapor Density: Not available.

Volatility: Not available.

Odor Threshold: Not available.

Water/Oil Dist. Coeff.: Not available.

Ionicity (in Water): Not available.

Dispersion Properties: Not available.

Solubility: Insoluble in cold water.

Section 10: Stability and Reactivity Data

Stability: The product is stable.

Instability Temperature: Not available.

Conditions of Instability: Not available.

Incompatibility with various substances: Not available.

Corrosivity: Non-corrosive in presence of glass.

Special Remarks on Reactivity: Not available.

Special Remarks on Corrosivity: Not available.

Polymerization: No.

Section 11: Toxicological Information

Routes of Entry: Absorbed through skin. Eye contact. Inhalation. Ingestion.

Toxicity to Animals:
LD50: Not available. LC50: Not available.

Chronic Effects on Humans: The substance is toxic to lungs, mucous membranes.

Other Toxic Effects on Humans:
Very hazardous in case of ingestion. Hazardous in case of inhalation. Slightly hazardous in case of skin contact (irritant).

Special Remarks on Toxicity to Animals: Not available.

Special Remarks on Chronic Effects on Humans: Human: passes through the placenta, excreted in maternal milk.

Special Remarks on other Toxic Effects on Humans: Not available.

Section 12: Ecological Information

Ecotoxicity: Not available.

BOD5 and COD: Not available.

Products of Biodegradation:
Possibly hazardous short term degradation products are not likely. However, long term degradation products may arise.

Toxicity of the Products of Biodegradation: The products of degradation are as toxic as the original product.

Special Remarks on the Products of Biodegradation: Not available.

Section 13: Disposal Considerations

Waste Disposal:

Section 14: Transport Information

DOT Classification: Not a DOT controlled material (United States).

Identification: Not applicable.

Special Provisions for Transport: Marine Pollutant

Section 15: Other Regulatory Information

Federal and State Regulations:
Pennsylvania RTK: Copper Massachusetts RTK: Copper TSCA 8(b) inventory: Copper CERCLA: Hazardous substances.: Copper

Other Regulations: OSHA: Hazardous by definition of Hazard Communication Standard (29 CFR 1910.1200).

Other Classifications:

WHMIS (Canada): CLASS D-2A: Material causing other toxic effects (VERY TOXIC).

DSCL (EEC): R36- Irritating to eyes.

HMIS (U.S.A.):

Health Hazard: 2

Fire Hazard: 1

Reactivity: 0

Personal Protection: E

National Fire Protection Association (U.S.A.):

Health: 2

Flammability: 1

Reactivity: 0

Specific hazard:

Protective Equipment:
Gloves. Lab coat. Dust respirator. Be sure to use an approved/certified respirator or equivalent. Wear appropriate respirator when ventilation is inadequate. Splash goggles.

Section 16: Other Information

References: Not available.

Other Special Considerations: Not available.

Created: 10/09/2005 04:58 PM

Last Updated: 05/21/2013 12:00 PM

APPENDIX G: MEMORANDUM ON MANGANESE PROFILING

Mamun Yusuf, P.E.
Senior Engineer – Water Production
City of Denton
9401 Lake Ray Roberts Dam Road
Aubrey, TX 76227

Subject:
Manual for the Control, Operation and Maintenance of Zebra Mussels;
Manganese Profile Sampling

WATER

Date:
January 4, 2016

Contact:
Gail Charles, P.E.

Phone:
972-419-0333

Email:
Gail.Charles@arcadis.com

Our ref:
05673009.0000

Dear Mr. Yusuf:

A second trial run of increased permanganate addition at the LLWTP intake was recommended by Arcadis during the Manual Review Meeting held on September 23rd, 2015 to better understand and quantify the magnitude of increased turbidity through the treatment processes observed by plant staff during the prior trial run of increased permanganate to 1 mg/L. The proposed sampling was completed according to the sampling plan described below between October 26 and November 3, 2015 by City staff. This letter provides (1) a summary of the sampling approach, (2) a summary and discussion of the results and (3) recommendations regarding the potential use of permanganate for zebra mussel control.

Sampling Approach

Four rounds of sampling were conducted:

- At the typical permanganate dose of 0.3 mg/L (two sampling events, each on a different day), and
- At a higher permanganate dose of 1 mg/L[1] (two sampling events, each on a different day).

Sampling was timed to allow sufficient time for the system to reach equilibrium across the plant after making permanganate dose changes. For each sampling event, samples were collected at the following locations and analyzed for the parameters listed in Table G-1:

- Raw Water (before permanganate addition)
- Plant influent (upstream of rapid mix)
- Post Coagulation / Sedimentation
- Ozone Cell 1
- Ozone Cell 4
- Filter Influent

[1] Doses as high as 5.3 mg/L could be required to prevent settlement of veligers in the LLWTP raw water system, depending on the water temperature and background water demand. The applied dose of 1 mg/L is approximately that predicted by prior demand testing based upon the flow rate and water temperature for this day. The average permanganate residual measured in the plant influent (i.e., 0.3 mg/L) on the sampling dates is consistent with that required to prevent settlement of veligers.

- Filter Effluent
- Post Chlorination (just prior to the addition of ammonia)
- Finished Water

Table G-1: Parameters Analyzed in Samples Collected between October 26 and November 3, 2015

Parameter	Methods
Manganese, Total	EPA 200.7 (U.S. EPA Method 200.8 suggested)
Manganese, Dissolved[1]	EPA 200.7 Rev. 4.4 (U.S. EPA Method 200.8 suggested)
Permanganate Residual	HACH Method 8021 (USEPA DPD Method)
Oxidation-Reduction Potential (ORP)	HACH Model HQ40d MTC101 / Direct Measurement Method 10228
pH	HACH Model HQ40d PHC101 / pH Meter Electrode Method 8156
Temperature	HACH Model HQ40d MTC101 and PHC101
Turbidity	Standard Methods 21030B

[1] Dissolved manganese was filtered through a 0.45 µm filter prior to analysis.

Results and Conclusions of City Trial

The City collected baseline data on October 26 and October 27, 2015, and test data when an elevated permanganate dose was being applied to the raw water on November 2 and November 3, 2015. The target applied permanganate dose was 0.3 to 0.5 mg/l on baseline days, and 1 mg/l on test days. Based upon the data provided by the City to Arcadis, a series of graphs (i.e., Figures 1 – 4) was developed to analyze trends in the data.

Figure G-1 shows the total (solid symbols) and dissolved (open symbols) manganese concentrations measured during baseline sampling (blue and grey symbols) and then when 1 mg/L permanganate was applied (green and purple symbols). **Overall, it appears that the increased permanganate dose did result in increased manganese in the filter effluent, but the chlorinated and finished water total manganese concentrations were below the 0.05 mg/L secondary maximum contaminant limit (SMCL).** Specific observations include:

- The raw water total manganese was below the SMCL for three of the four samples collected.
- The total manganese generally increased after addition of permanganate.
- Coagulation and sedimentation decreased the total manganese but not to the extent expected. Generally, coagulation and sedimentation removes greater than 80% of particulate manganese, which was not the case based upon these data. Dissolved manganese increased through the coagulation and sedimentation process during application of the higher permanganate dose.
- Ozone generally resulted in increased total manganese of 90 µg/L, on average, in half of the samples. ORP increases through the ozonation process often shift the manganese speciation (see Figure 4 for more discussion).

- At high doses, ozone may result in the formation of colloidal particles that are not filterable. As the filter influent (just downstream of ozone) total manganese was below the SMCL, these data suggest that colloidal particles are not a concern. However, the filter effluent total and dissolved manganese levels were above the SMCL during the higher permanganate dose, suggesting either the data are suspect or there was manganese release occurring through the filters.
- During the sampling event, breakthrough of particulate and dissolved manganese above the SMCL was measured in the filter effluent. However, the chlorinated and finished water samples were all below the SMCL. Additionally, these data suggest that the filters are not removing significant levels of dissolved manganese at the higher permanganate dose. The effectiveness of removal of dissolved manganese during the baseline samples is unclear. As a comparison, on average 95% total manganese removal across the biofilters has been noted since June 2014 through the biofilter innovation project. The limited data collected during this trial do not support that conclusion.

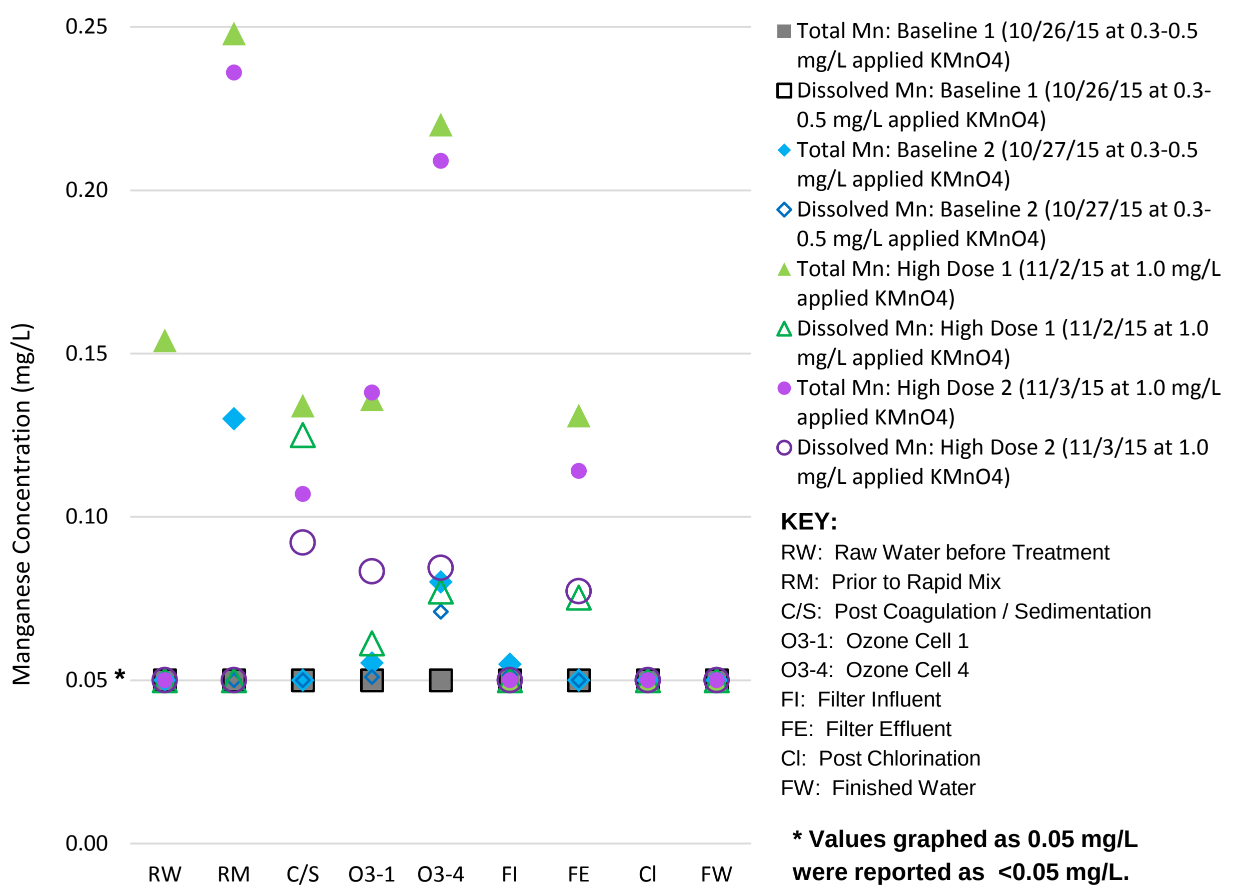


Figure G-1: Total and Dissolved Manganese Profile

Figure G-2 presents the profile for turbidity (squares) and total manganese (triangles). These data show that the total manganese and turbidity generally increased upstream of rapid mix (downstream of permanganate addition. However, the turbidity decreased by approximately 10 NTU or 91% on average through the coagulation and sedimentation process. The ozonation process did result in a slight increase in the turbidity of the water in the filter influent compared to the ozone influent. However, the turbidity in the filter influent increased by less than 0.5 NTU on average with the higher permanganate dose compared to the baseline, and the turbidity was 0.05 NTU in the filter effluent for all samples collected.

These results differ from those reported by the City in June 2015 when a similar trial of increased permanganate was conducted and filter influent turbidities above 2.5 NTU were noted. These differences highlight the importance of multiple sampling events in distinguishing long-term manganese control issues from isolated events caused by influent water quality or treatment process changes. However, both events did highlight increased discoloring of ozone probes and cells. This correlates with an increased turbidity through the ozone process, likely cause by the oxidation of manganese. Optimization of the upstream coagulation and sedimentation process to maximize manganese removal prior to ozonation will minimize the impact of colored water through the ozone process.

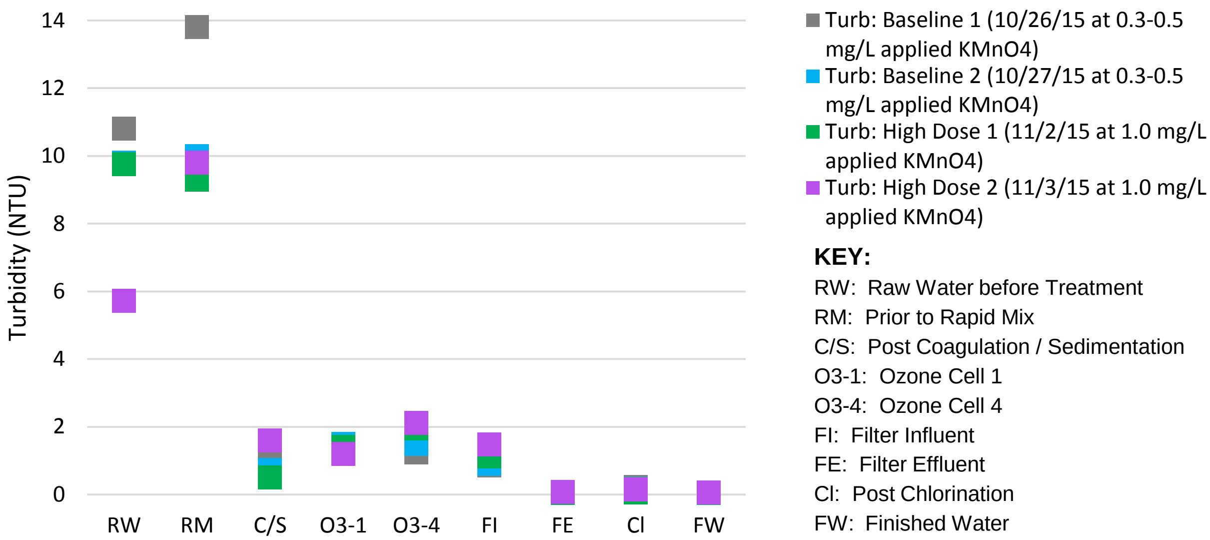


Figure G-2: Total Manganese and Turbidity Profile

Figure G-3 shows a profile of the ORP (squares) and pH (circles) measured during the trial through the plant. The ORP and pH were generally similar during the two sampling phases. From the raw water through coagulation and sedimentation, the ORP increased and the pH decreased. The ORP and pH measured from that point on was fairly consistent at about 300 mV, and 7 pH units until the chlorination process where the pH and ORP both increased significantly. The ORP was also expected to increase significantly during the ozonation process, but as ozone decays very rapidly the ORP in the samples may have dropped before the measurements were complete.

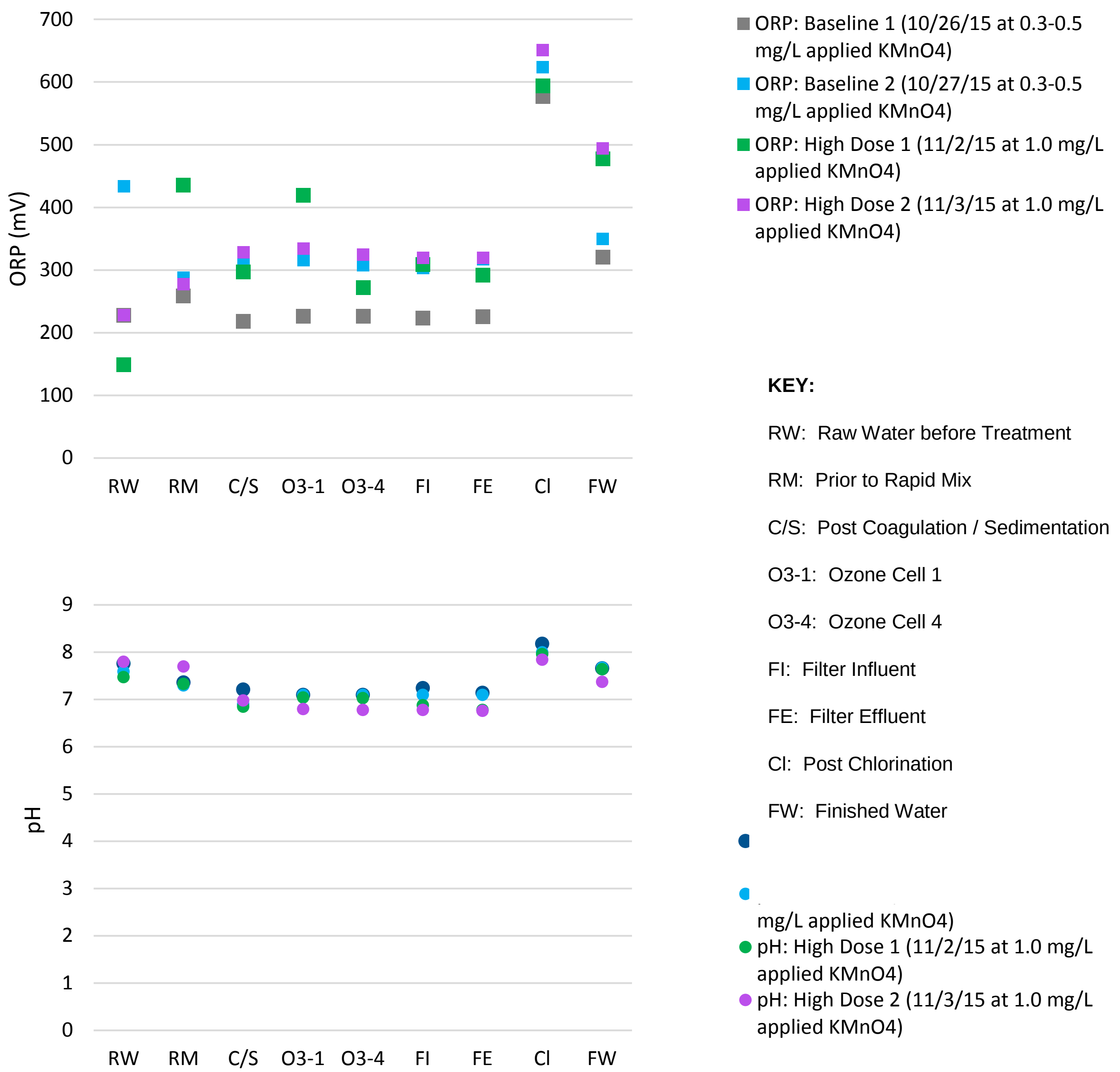


Figure G-3: pH and ORP Profile

Figure 4 is a Pourbaix diagram overlaid with the average ORP and pH measured at each location during the higher permanganate dose. Based on these limited data, it appears that the manganese in the LLWTP source and treated water is generally favorable for formation of particulate manganese. However, thermodynamics and kinetics also play key roles in manganese speciation. The graph illustrates the use of the Pourbaix diagram along with ORP and pH data to discern trends in manganese speciation and removal in response to treatment or water quality changes at the LLWTP.

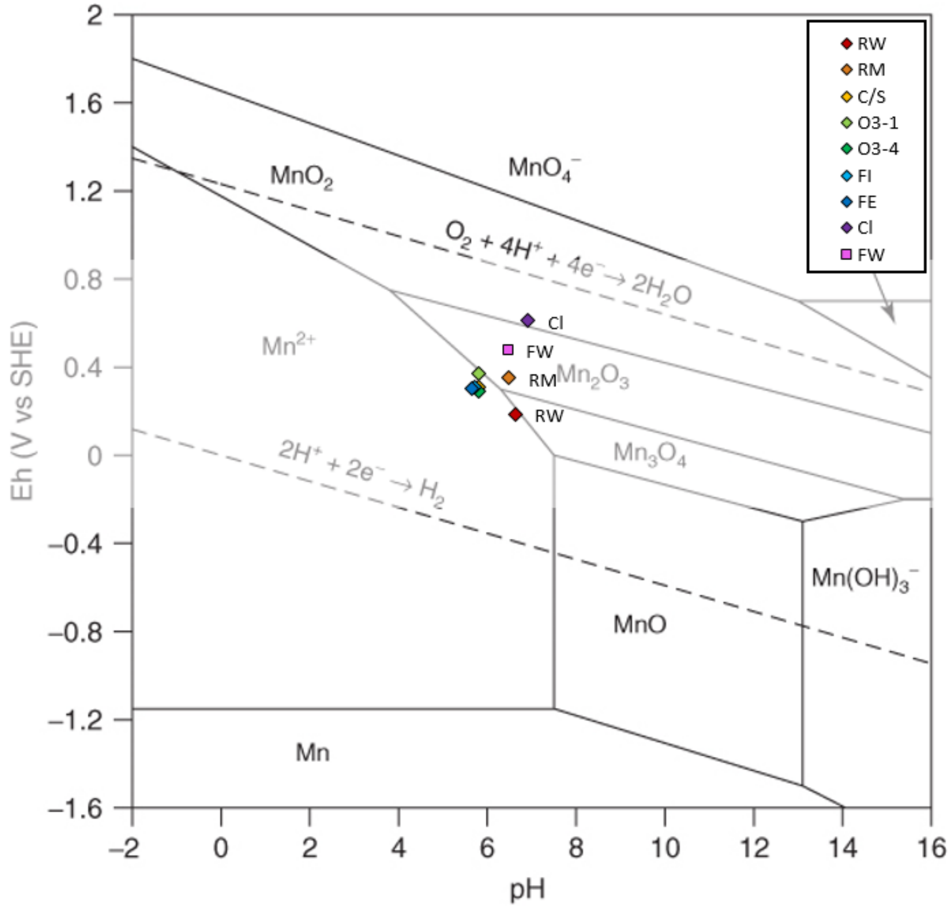


Figure G-4: Pourbaix Diagram for Manganese with the Average ORP and pH of Samples Collected at a 1 mg/L Permanganate Dose

As the primary purpose of increasing the permanganate dose is to prevent the settlement of zebra mussel veligers, it is important to maintain a small permanganate residual (e.g. 0.25 mg/L) through the entire raw water pipeline. At the plant influent upstream of rapid mix, an average permanganate residual of 0.0 mg/L was noted during the baseline sampling events at 0.3-0.5 mg/L of applied permanganate, and an average permanganate residual of 0.3 mg/L was measured during application of 1.0 mg/L permanganate. Likely (as shown in prior bench testing), a higher dose will be required to achieve the same residual during warmer months, with higher background water demand, or with longer pipeline residence times. Recommendations have been developed to monitor for and mitigate any impacts of increased permanganate dose on finished water turbidity and manganese concentrations.

Recommended Next Steps

Based upon limited grab samples collected during this sampling event, an increase in permanganate dose (i.e. 1 mg/L) at the intake resulted in conditions where the filtered water total manganese concentration was above the SMCL. However, the chlorinated and finished water samples were all below the SMCL. The filter influent turbidity was increased on average by 0.5 NTU when the permanganate dose was increased. However, the filter effluent turbidity of all samples was below 0.05 NTU. Generally, the ORP and pH are favorable for formation of particulate manganese, which is easy to remove with physical processes. Considering the limited data reviewed and summarized above, Arcadis recommends that the City continue to consider permanganate as an alternative for zebra mussel control, and complete additional manganese profiling to confirm the trends noted during this event. The following next steps are recommended:

1) **Conduct additional manganese profiling –** Only limited confidence can be placed in results from two grab samples. Complete additional manganese profiling (as described in the Sampling Plan provided in separate correspondence) with a few modifications as outlined below.
   a) Consider testing a higher potassium permanganate dose of 2-5 mg/L (maximum dose may be limited by the current chemical feed pumps depending on the plant flow rate) during seasons with higher background water demand.
   b) Collect at least two grab samples during the baseline sampling and at least three grab samples at the higher permanganate dose
   c) Use a different laboratory for manganese analysis which can provide results below the SMCL. Eurofins Eaton has been used successfully in previous projects, and will report manganese concentrations as low as 2.0 µg/L. Industry experts[2] recommend a goal of 1.5-2.0 µg/L to prevent water discoloration.
   d) Conduct sampling during a period when the recycle stream is in service to understand the influence of the recycle stream on the concentration of manganese in the influent water.
   e) Determine whether the current coagulant (i.e., ferric) in use is adding manganese into the treatment stream and quantify the concentration of manganese added compared to the amount of manganese in the raw water.

2) **If the additional manganese profile indicates that there is a potential challenge to achieving finished water manganese goals at a higher permanganate dose, then consider one of the following options:**
   a) Permanganate may still be a good candidate for zebra mussel control. However, as outlined in the Draft Manual, additional monitoring will be critical to meeting the plant's finished water goals. Develop a zebra mussel monitoring standard operating procedure (SOP), as outlined in Draft Manual Section 4.3.2.1, to minimize the dose of permanganate that must be fed to maintain control of zebra mussels through the LLWTP raw water system. Additionally, develop a manganese SOP, as outlined in Draft Manual Section 4.3.2.8, to monitor manganese concentrations through the plant continually including implementation of treatment process optimization strategies for manganese removal. Based upon the limited data reviewed from this sampling event, it may be especially important to evaluate potential improvements to the

[2] Knocke, W. (2015). *Key Aspects of Manganese Control in Drinking Water Treatment*, American Water Works Association Annual Conference and Exposition, Anaheim, CA.

coagulation and sedimentation process to achieve the 80% removal of particulate manganese that is generally observed through this process. If ferric is determined to contribute additional manganese to the treatment process, consider alternative coagulants. Additionally, with increased removal through sedimentation, optimization of the sludge blowdown frequency will be increasingly important.

b) If the additional monitoring and optimization of treatment processes to achieve increased manganese removal is not preferred, the City could consider alternative strategies for zebra mussel control.

Sincerely,

Arcadis U.S., Inc.

Gail Charles, P.E.
Project Manager

Copies:

Ashley Evans, E.I.T.
Randy McIntyre, P.E.
Ben Kuhnel, P.E.