US Army Corps of Engineers®

ZEBRA MUSSEL RESOURCE DOCUMENT

Trinity River Basin, Texas

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GSRC

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Tarrant Regional Water District

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Trinity River Basin, Texas

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TBPE Firm Registration No. 13

This Zebra Mussel Resource Document was prepared at the direction of the Fort Worth District, U.S. Army Corps of Engineers, under authority of Section 22 of the Water Resources Development Act (WRDA) of 1974 (Public Law 93-251), as amended. Section 22 authorizes the Secretary of the Army, acting through the Chief of Engineers, to assist the states in preparing comprehensive plans for the development, utilization, and conservation of water and related resources of drainage basins, watersheds, or ecosystems located within the boundaries of such states. The non-federal sponsor of this project was the Trinity River Authority of Texas, supported by the city of Dallas, city of Houston, North Texas Municipal Water District, and Tarrant Regional Water District. These entities contributed a total of fifty percent of the project cost. This document is a resource to help assess risks, detect early, and prepare effectively for the threat of zebra mussel infestation. It is not intended for regulatory purposes.

*Cover photograph: In July 2012, zebra mussels were discovered in Ray Roberts Lake, on the Elm Fork of the Trinity River, near the headwaters of the Trinity River Basin.

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1 Introduction

1.1 PURPOSE

The zebra mussel, *Dreissena polymorpha*, is believed to have been introduced to the Great Lakes region in the late 1980s from ballast water of transoceanic ships, and since has expanded its range southward to Louisiana and westward to California. High summer temperatures were once thought to create unsuitable habitat for zebra mussels in Texas; however, in April 2009, this invasive species was detected in Lake Texoma, located on the Texas-Oklahoma border. Since then, efforts have been made by various agencies to prevent the spread of these mussels to surrounding waters. In spite of these efforts, zebra mussels were found in Sister Grove Creek in summer 2009 and in Ray Roberts Lake in July 2012, both in the Trinity River basin. Arrival of zebra mussels elevates concerns of many municipal water providers over the potential treatment costs and impacts to daily operations that may result. Because zebra mussels were established only recently in Texas, many water providers and citizens in the state have limited knowledge of their biology, impacts, and potential control methods.

Quagga mussels, *Dreissena rostriformis bugensis*, were also introduced to the Great Lakes region in the late 1980s. Established populations are mainly limited to the Great Lakes region and drainages in the southwest United States. Quagga and zebra mussels are similar in biology, reproductive behavior, and impacts to infrastructure and the environment. Quagga mussels are more versatile than zebra mussels because they can tolerate cooler temperatures, deeper water depths, and a variety of substrates including mud or sand. Quagga and zebra mussels coexist in some watersheds in the United States; however, quagga mussels generally out-compete zebra mussels. Since quagga mussel populations are not established in Texas or any adjacent states, this document will only address zebra mussels. However, many impacts and control methods described in this document are also applicable to quagga mussels.

This resource document is intended to educate the reader on many aspects of zebra mussels, from biology and control methods to regulations and treatment costs. Experiences and lessons learned from the infestation at Lake Texoma as well as other areas of the country will be presented where pertinent. The objective is to provide knowledge needed to make informed decisions regarding the monitoring, treatment, and anticipated cost of zebra mussels. This document was prepared in collaboration with the United States Army Corps of Engineers, Tarrant Regional Water District, City of Dallas, North Texas Municipal Water District, City of Houston, and Trinity River Authority. The risk analysis and interbasin transfer sections focus on water sources selected by project sponsors. These sources are located primarily within the Trinity River basin but some outside of this river basin were included where they serve as current or potential future sources for water transfer into the Trinity River basin.

1.2 SCOPE

Zebra mussel biology, risks, treatment options, regulations, monitoring techniques, and cost considerations are summarized in this document. The capabilities of selected water sources in Texas to sustain zebra mussel populations are assessed. The types of facilities at risk are identified and control methods suitable for each facility are presented. Monitoring techniques are recommended that can be implemented before and after infestation. Public outreach is also addressed as boat inspections and public education are major factors in controlling the spread of zebra mussels. Finally, the document describes past and current regulations related to zebra mussels and invasive species.

2 Background

2.1 IDENTIFICATION

Zebra mussels are not the only freshwater bivalves in North America, nor are they the only introduced species of freshwater bivalves. For this reason, it is important to be able to distinguish zebra mussels from other bivalves. Zebra mussels are small triangularly-shaped bivalves, with one side of the triangle being broadly flattened (Lubner, 1995). A zebra mussel can sit flat on the ventral side, which distinguishes it from other mussels, such as the quagga mussel, which will generally fall over when placed on a flat surface. Shell color ranges from tan to cream to dark brown, usually with alternating light and dark bands (Lubner, 1995). Figure 2-1 shows a tan to cream zebra mussel, and Figure 2-2 shows dark brown zebra mussels observed in Lake Texoma. Adult mussels are approximately one inch in length but can grow up to two inches.

Figure 2-1- Zebra Mussel
(Source: Amy Benson, USGS)

Figure 2-2 Zebra Mussels from Lake Texoma

2.2 ZEBRA MUSSEL BIOLOGY

Before selecting a treatment method or control strategy it is imperative that the life stages and reproductive behavior of zebra mussels be understood as they may impact the methods and dosages that should be considered. For instance, ultraviolet radiation (UV) is successful at killing veligers but has little impact on adult mussels. This section provides a brief overview of zebra mussel biology and describes the process by which zebra mussels are able to attach and detach from objects.

2.2.1 <u>Life Cycle</u>

The life cycle of zebra mussels begins with external fertilization of gametes from which fertilized eggs are formed. At this stage, fertilized eggs are approximately 70-80 microns in diameter (Sprung, 1993). Fertilized eggs develop into embryos and are nourished from the yolk. Within 6-20 hours, the embryo develops into a trochophore (Mackie and Claudi, 2010). At this stage, the zebra mussel is approximately 100 microns in size (Sprung, 1993).

Several days after fertilization, the trochophore grows into a veliger with the development of a velum and begins to form the first larval shell. The velum is a ciliated structure that aids in swimming and feeding. At this stage they develop some resistance to chemical controls but are still far more susceptible than adults to chemicals. Veligers progress to the D-shaped form, followed by the umbonal stage. In the umbonal stage, the velum is reabsorbed, the siphons develop from a fusion of the posterior margins of the mantle, the foot lengthens, and blood and some organ systems begin to develop (Mackie and Claudi, 2010). During the veliger stage, zebra mussels are small and free swimming and can be spread easily by water currents. Zebra mussels enter the pediveliger stage with further development of the foot and begin to enter the settling phase. The foot is located on the ventral side of the mussel, provides means for crawling, and houses the byssal gland. Pediveligers typically have byssal threads which are used to attach to substrate. Zebra mussel larvae typically settle when they are over 200 microns in diameter (Stanczykowska and Lewandowski, 1993). The life cycle of zebra mussels, from fertilized egg to the settling phase, usually takes about 18-30 days to complete (Mackie and Claudi, 2010), but is highly temperature-dependent.

If mussels do not attach in the pediveliger stage, they will usually attach after settling. However, if substrate is not suitable for attachment, mussels can delay byssal attachment and metamorphosis (Mackie and Claudi, 2010). After attachment, mussels undergo metamorphosis and transform into a juvenile. Metamorphosis includes development of gills and secretion of the adult bivalve shell. Adults often remain attached to substrate but can release to find more suitable conditions. Zebra mussels rely on water currents and gravity to relocate since they are unable to swim. Zebra mussels have a lifespan of about three to five years; however, Mackie and Claudi (2010) report up to 99% mortality rate of larvae during planktonic and settlement phases. This may be attributed to any number of factors including predation, lack of suitable substrate, a natural development bottleneck during metamorphosis, and unfavorable oxygen and thermal conditions.

2.2.2 <u>Reproduction</u>

Zebra mussels reproduce by external fertilization, where coordinated release of eggs and sperm is important for successful reproduction. Depending on size, a single female zebra mussel can produce 10,000- up to 300,000 eggs per year (Stoeckel et al., 2004b). Although the onset of spawning is impacted by external and internal factors, temperature is reported to be primary (Sprung, 1993; Ram et al., 1996). Neumann et al. (1993) found that eggs and sperm usually begin appearing when water temperatures reach 12°C; however, typical spawning in North American mussels begins at 16-18°C and ceases at 24-27°C (Robert McMahon, personal communication, March 1, 2013). Sampling conducted at Lake Texoma by the United States Geological Survey (USGS) suggests that veligers are first detected when springtime surface water temperatures are approximately 18 °C. Continuous water temperature data collection coupled with weekly to biweekly plankton tow sampling has enabled the USGS to determine onset and peak spawning water temperatures for zebra mussels. Zebra mussels typically breed one to two times a year depending on climate.

Since zebra mussels infested Lake Texoma in 2009, there are limited data on spatial variation and population densities in the lake. Sampling was conducted by the USGS in 2010-2012 utilizing plankton tow nets and passive sampling methods. Veliger sampling indicated that two spawning events were observed in 2010 and 2012, but only one in 2011. The spring spawning event occurred by late April in 2010 and 2011, with the highest density of veligers occurring in late May to middle June of both years. Fall spawning events occurred in late September 2010 and 2012, with the highest number of veligers detected by early October. It is possible that summer heat impacted the mussels' ability to spawn in fall 2011. The year 2011 was the driest year on record in Texas and included over 70 days of 100+ °F weather.

Sampling has indicated a steady decline in the numbers of spring and fall season veligers in Lake Texoma from 2010 to 2012. In spring sampling, a 92 percent reduction of veligers was detected in 2012 as compared to 2010. Similarly, fall veliger counts declined by approximately 79 percent from 2010 to 2012. As heat and drought caused lake levels to recede, adult mussels on the shoreline were exposed to air and desiccated. This desiccation may have reduced the adult population and impacted veliger densities in 2012. Life cycle studies at Lake Texoma indicate that fertilized eggs which are released during the spring spawning event can develop into adults and reproduce in fall (Christopher Churchill, personal communication, March 1, 2013). This is attributed to long growing seasons in Texas and is consistent with the findings of Mackie and Claudi (2010) who suggest that, to a point, rate of development increases with temperature.

Based on studies in Lake Texoma, maximum mussel densities were reached during spring 2011, 1.5 years after initial discovery. This was likely due to the very high growth rates recorded for zebra mussels in Lake Texoma during 2011-2012 with maximum size achieved (approximately 25 mm shell length) within a very short 14-month life span 2011-2012 (Robert McMahon unpublished data). This result suggests that massive zebra mussel infestations may develop much more quickly in Texas water bodies than has previously occurred in northeastern US lakes.

2.2.3 Variation From Other Aquatic Organisms

Water quality characteristics outside favorable ranges for zebra mussels may limit their ability to survive in waters that are inhabited by other mussel and clam species. In general, zebra mussels require higher levels of calcium, hardness, and alkalinity than many other clams and mussels in order to survive and reproduce. Therefore, presence of native or other invasive mussel species does not necessarily indicate that zebra mussels could also establish a sustainable population. For example, freshwater Asian clams have invaded many lakes and pipelines in Texas. Asian clams can sustain populations when calcium concentration is as low as 2 mg/L (Mackie and Claudi, 2010). By contrast, adult zebra mussels require a minimum calcium concentration of approximately 12 mg/L for survival. In addition, Asian clams have a lower minimum requirement for alkalinity and hardness (7 mg/L) as compared to zebra mussels (55 mg/L). Asian clams have a larger range of tolerance for pH and dissolved oxygen as well.

2.2.4 Mussel Attachment

Zebra mussels are one of the freshwater mussels in the United States that can attach to objects. They use strands of proteins called byssal threads to attach to hard substrate, including structures such as intake screens or pipelines, and can create a biofouling problem. Figure 2-3 shows byssal threads extended from the ventral side of a zebra mussel.

Figure 2-3 Zebra Mussel Byssal Threads
(Source: California Department of Water Resources)

Zebra mussels have a muscular foot on their ventral side that provides means for crawling, and houses the byssal gland that is responsible for secretion of byssal threads. Byssal threads are formed one at a time and are composed of proteins (Mackie and Claudi, 2010). Rate of byssal secretion can vary based on temperature, age, and water quality, but generally ranges from one to nine per day (Ekroat et al., 1993; Mackie and Claudi, 2010).

Both juvenile and adult zebra mussels can release or detach from their byssal threads by secreting enzymes at the base of the byssal mass, and can relocate, and reattach in a new location if they are not restrained by threads of other zebra mussels (Mackie and Claudi, 2010). This appears to be more common in younger mussels and can occur vertically within the water column as well as horizontally with the aid of water currents. This ability enables mussels to detach and find more suitable conditions upon detecting chemical treatments in pipelines and other structures.

Adhesion of zebra mussels to infrastructure not only causes bio-fouling problems, but byssal threads left behind can also increase corrosion of iron and steel beneath attachment points (Mackie and Claudi, 2010). Mackie and Claudi (2010) estimate a mussel 2.5 cm in length can produce approximately 500 threads. Figure 2-4 shows remnants of byssal threads on a concrete pipeline wall after mussels were removed.

Figure 2-4- Byssal Threads Remaining on a Concrete Pipe Wall

2.3 MOVEMENTS AND INFESTATIONS

Zebra mussels are native to the drainage basins of the Aral, Black, and Caspian Seas of Europe and Asia and are considered one of the most damaging invasive species introduced to North America. Zebra mussels were detected in Lake Erie and Lake St. Clair in 1988 and one year later were detected in all five Great Lakes. In 1991, they spread beyond the Great Lakes via man-made canals into the Illinois River and subsequently the Mississippi River (USGS-A, 2011). At the same time, mussels spread further east into the Hudson River. The rapid spread of zebra mussels in the Mississippi basin is attributed to extensive commercial barge traffic (Kozlowski et al., 2002). By 1993, zebra mussels were found near New Orleans and had moved up the Arkansas River into Eastern Oklahoma likely by attachment to barges. Barges have spread zebra mussels up and down large navigable waterways including the Mississippi, Ohio, Tennessee, and Arkansas (USGS-A, 2011).

In 2003, mussels were detected in Kansas at El Dorado Lake. Also in 2003, veligers were collected above and below Lewis and Clark Lake on the Missouri River. In 2006, zebra mussels were detected on a contaminated boat that was transported to a marina on Lake Texoma from the Upper Midwest. In 2008, zebra mussels were discovered in California, Utah and Colorado. Finally, in 2009, zebra mussels were detected in Texas and Massachusetts. Zebra mussels detections do not always result in established populations. Figure 2-5 shows the range of zebra mussel populations as of December 2012. The spread of zebra mussels in the United States illustrates the ability of this species to tolerate a wide range of habitat conditions. Zebra mussels have adapted to environments well-beyond conditions in their native areas (Kozlowski et al., 2002). Figure 2-5 also shows the significance of connected waterways, barge and boat traffic, and overland boat movements to the expansion of zebra mussels in this country.

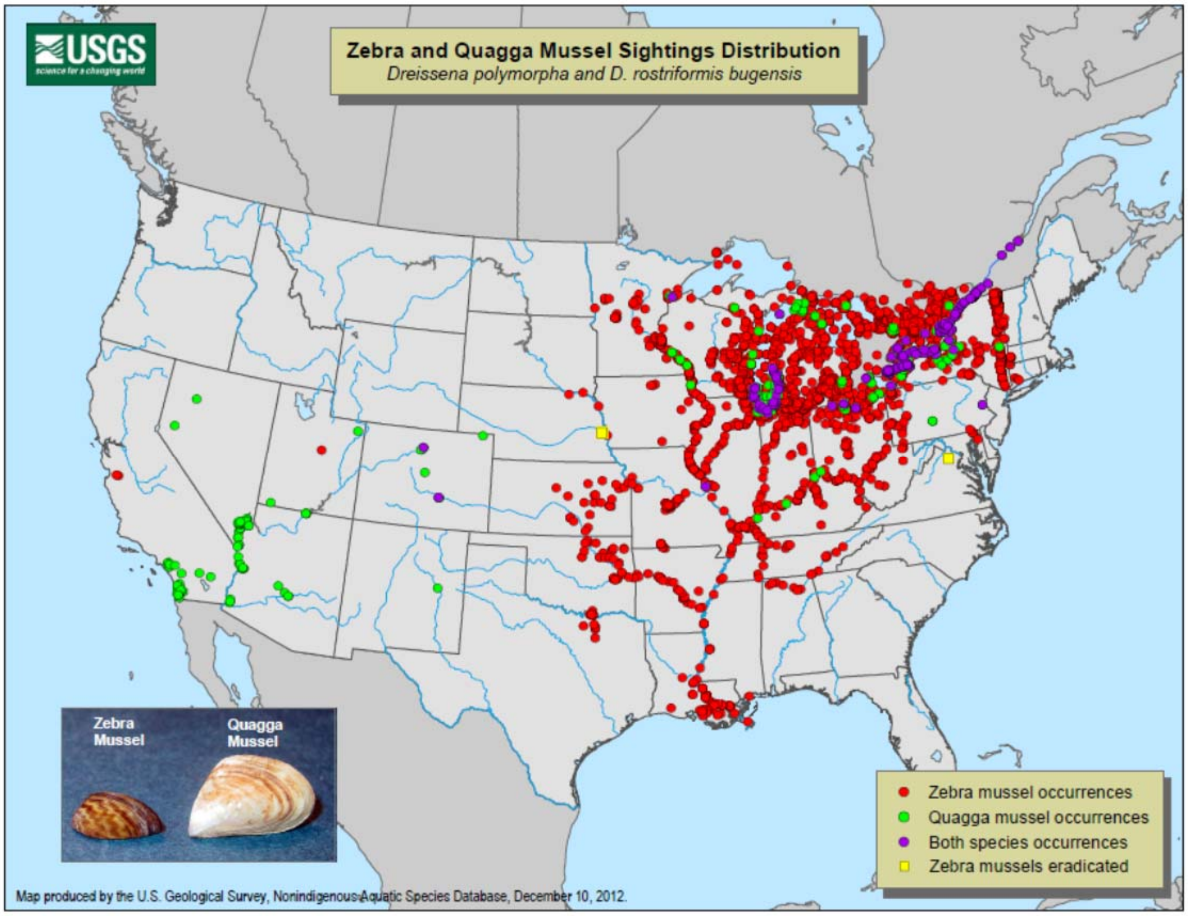

Figure 2-5- Zebra Mussel Distribution from December 2012
(Source: USGS)

2.4 INFESTATION IMPACTS

Zebra mussels can alter water quality, out-compete native species, and foul infrastructure. The economic impacts can be extensive as water utilities and their customers become burdened with costs of treatment and additional maintenance. This section summarizes the biological, operational, and economic impacts associated with zebra mussels.

2.4.1 Biological Impacts

Zebra mussels not only affect infrastructure and plant operations, but they also have deleterious effects on local ecosystems. Zebra mussels are filter feeders and can filter quantities of water as high as 0.4 liter/mussel/hour (Wu et al. 2010). During feeding, particles suspended in the water are bound in mucus and egested as feces if ingested or bound into and rejected as pseudofeces if not ingested (USGS-B, 2011). This filtering process increases the clarity of the water column. The USGS (A-2011) states that since the mussels were established in Lake Erie, water clarity has increased from 6 inches to 30 feet in some areas. As water clarity increases, light penetration through the water column can create conditions favoring growth of aquatic plants in areas where conditions were previously not conducive for vegetation growth. Increased vegetative growth can be beneficial to fish; however, plants can cause problems for recreational boaters and can also result in taste and odor issues for water providers. In water bodies already impacted by invasive aquatic plants, the increase in light penetration to lower depths can significantly escalate the growth and spread of nuisance plants.

Large populations of zebra mussels can also out-compete native mussels and other aquatic species for food. Zebra mussels are aggressive filter feeders and can alter the food chain by removing vital phytoplankton and small forms of zooplankton which young sport and forage fish depend on for survival. Reduction in zooplankton and phytoplankton biomass can increase competition and decrease survival among certain fish species. As mussels feed, they deposit feces which become food for bottom-dwelling worms, insect nymphs and larvae. This can increase the benthic feeding of fish or favor benthic feeding prey. Impacts to the food chain caused by zebra mussels may result in behavioral shifts from pelagic to benthic-feeding (Benson et al., 2012). Many zebra mussels can attach to a single native mussel, which can be lethal by reducing its ability to feed, move and breed. Figure 2-6 shows zebra mussels attached to a native mussel. In Lake St. Clair, the invasion of zebra mussels resulted in near extinction of native unionid mussels (USGS-A, 2011).

Figure 2-6- Zebra Mussels Attached to a Native Mussel
(Source: USGS)

Another potential biological impact of zebra mussels is an increase in blue-green algae levels. Blue-green algae are naturally present in lakes and streams and reproduce rapidly in areas with high temperatures, nutrients, and light levels. During the filtering process, zebra mussels consume more desirable forms of green algae and often reject blue-green algae which can increase ambient concentrations of blue-green algae. This may increase the severity, duration or frequency of toxic blue-green algae blooms within a water source. Not all species of blue-green algae are toxic and it is not well understood why the toxins are produced. If blue-green algae levels become high enough, a lake could be closed to all water traffic and swimming until the levels subside. Lake Erie and Lake Huron have incurred higher frequencies of blue-green algal blooms since the zebra mussels arrived (Indiana DNR, 2005).

In 2011, toxic blue-green algae levels in Lake Texoma were high enough to result in closure of the lake to swimming and other activities that involved direct exposure to lake water for over six months. It is not known whether the presence of zebra mussels impacted the extent of the blue-green algae bloom in Lake Texoma. However, as a result of the bloom, boaters that typically utilized Lake Texoma for recreational purposes did move their boats to other lakes, potentially transporting zebra mussels to other waters.

Zebra mussels bioaccumulate contaminants that are filtered during the feeding process. Zebra mussels can concentrate toxic contaminants to as much as 100,000 times the concentration of the surrounding water (De Kock and Bowmer, 1993; Wu et al., 2010). Contaminants that could be of concern include dichlorodiphenyldichloroethylene (DDE), hexachlorobenzene, lead, copper and mercury. Tatem (1994) reported that zebra mussels can accumulate contaminants because of their high lipid content, reported to be as high as 15 percent. These toxins can then be passed through the food chain impacting waterfowl and other organisms. Wu et al. (2010) stated that waterfowl that consume contaminated zebra mussels show elevated concentrations of metals, organic pesticides, and polychlorinated biphenyl compounds. In addition, zebra mussels will deposit unconsumed contaminated material in sediment, increasing the potential for food chain transfer to benthic organisms.

2.4.2 Operational and Treatment Process Impacts

Zebra mussels can attach to interior walls of pipelines that incur periods of low velocity (below 6.5 ft/s). This attachment will increase friction with the fluid and subsequently increase pumping cost. In small diameter pipelines, attachment could ultimately plug the pipeline if left untreated. Figure 2-7 shows zebra mussels attached to the inside of a large diameter concrete pipe. Since zebra mussels are able to attach to each other, the accumulation of mussel shells can be inches thick and can result in an effective decrease in the internal diameter of a pipeline. For longer, high flow rate pipelines, increased pumping cost and reduced hydraulic capacity could impact the ability to maintain a sufficient water supply.

Figure 2-7 Zebra Mussels Attached to a Pipeline

Water treatment is vital to public health and safety, and any disruption in service could be critical. There is concern from municipal water providers over how zebra mussels will impact water treatment plants which usually involve small onsite process piping, instrumentation, and ports. Plant shutdown cannot be tolerated, especially during summer month peak demands.

The greatest macro-fouling problem in most water treatment plants occurs at the intake structure (Mackie and Claudi, 2010).

Zebra mussels can attach to trash racks, intake screens, valves, gates and instrumentation. They can accumulate in canals and balancing reservoirs which can serve as breeding grounds for further infestations. Hydroelectric power plants are at risk for zebra mussel attachment in the penstocks, turbines, and cooling water system when they do not operate continuously. Zebra mussels will attach to boat docks and recreational water craft. A complete infrastructure assessment is provided in Section 9.

2.4.3 Economic Impacts

Control of zebra mussels can create additional capital costs and yearly operational and maintenance costs. U.S. Fish and Wildlife Service estimates that zebra mussels in the Great Lakes region alone, within the United States and Canadian waters, had an economic impact of $5 billion from 2000-2010 (USGS-B, 2011). This cost included impacts to the commercial fishery industry. A 1995 study found that zebra mussel related expenses in North America totaled $69 million for 339 facilities and greatest economic impacts occurred at electric power plants ($35 million) followed by water treatment plants ($21 million)(Kozlowski et al., 2002). Costs will vary depending on factors, such as level of infestation, treatment method, and size of treated system.

3 The Threat to Texas

When zebra mussels were first detected in the Great Lakes region, scientists predicted that higher water temperatures in the southern regions of the United States would prohibit colonization there. But by the middle 1990s, zebra mussels had infested the Mississippi River as far south as Louisiana (Kozlowski, 2002). Figure 2-5 shows the current infestation of many Oklahoma lakes including Lake Texoma on the Oklahoma-Texas border. Expansion of the zebra mussel range is greatly influenced by boat and other vessel traffic, natural connectivity of water sources, and interbasin transfers.

Zebra mussel infestation has restricted transfer of raw water from Lake Texoma to other water sources due to the threat of further infestations. Adult zebra mussels were detected in Ray Roberts Lake in July 2012. As zebra mussel infestations continue to spread in Texas, water supply operations and recreation could be seriously burdened, and the quality of water and the health of native species in Texas lakes could be threatened.

3.1 INTERBASIN TRANSFERS

Interbasin transfers have the potential to threaten intermediate and terminal storage reservoirs and all waters and reservoirs downstream by transporting zebra mussels into previously non-infested waters. They provide direct connections of water sources across watersheds and minimize factors such as climate and human behavior that influence other modes of transport. Untreated interbasin transfers can potentially transport overwhelming numbers of veligers to intermediate and terminal waters and increase risks of developing viable populations.

Transfers addressed in this document include not only transport of water across major river basins, but also across watersheds within the same basin. Issues arise as agencies and utilities strive to prevent the spread of invasive species while they exercise their responsibilities to satisfy critical needs for water supply. There are numerous state and federal laws and regulations pertaining to zebra mussels. A more complete discussion of these laws and regulations is presented in Section 14. The two that most directly impact interbasin transfers are Executive Order (EO) 13112 and the Lacey Act. EO 13112 was issued in 1999 to improve government effectiveness in dealing with invasive species. The EO states that each federal agency has the duty to “prevent the introduction of invasive species.” Therefore, federal agencies involved in permitting the flow of water from infested to non-infested sources must act to prevent the further expansion of zebra mussels “to the extent practicable and permitted by law.” Although the EO only directs the actions of federal agencies, it can impact other public and private entities when they apply for federal permits. The Lacey Act of 1900, as amended, prohibits the interstate transport of invasive species, including zebra mussels which were listed in 2000. It should be noted that the Lacey Act only impacts interstate transport of infested water, while Executive Order 13112 applies to all actions that could spread invasive species. Any potential water transfers from infested Oklahoma lakes to Texas, including those from the Oklahoma side of Lake Texoma, would face regulation under both EO 13112 and the Lacey Act.

In addition to potential infestation of intermediate and terminal storage sites, infested infrastructure components of pipelines could potentially contaminate areas along the alignment.

Blow off valves are located at low points of pipelines and typically drain into creeks. Pipeline drainage could result in infestation of these creeks and further downstream surface waters. Leakage of water from pipelines is also a concern if the volume exceeds the filtering capability of adjacent soil.

The following sub-sections describe interbasin and inter-watershed transfers currently in place or planned by the sponsors of this document. The sponsors who use interbasin transfers are North Texas Municipal Water District and the City of Dallas. Tarrant Regional Water District currently transfers water across watershed boundaries but within the same river basin. A map of the sources and schematic representation of the transfers are shown in Figure 3-1. Only transfers between raw water supplies are shown in this figure. Threats resulting from transfers direct to water treatment facilities are mitigated by treatment process, and those transfers are not included in Figure 3-1.

3.1.1.1 Tarrant Regional Water District

Tarrant Regional Water District (TRWD) owns and operates four major reservoirs including Richland-Chambers Reservoir, Cedar Creek Reservoir, Eagle Mountain Lake, and Lake Bridgeport. TRWD has constructed over 150 miles of pipeline and provides water to more than 1.7 million people. TRWD has the ability to pump raw water to Benbrook Lake and Eagle Mountain Lake from Richland-Chambers Reservoir and Cedar Creek Reservoir. Along the pipeline, there is also an outfall that delivers water to Village Creek, a tributary of Lake Arlington. The Integrated Pipeline Project (IPL) is a coordinated effort between TRWD and the City of Dallas that will connect Lake Palestine, Richland-Chambers Reservoir, and Cedar Creek Reservoir to Lake Arlington, Benbrook Lake, and Eagle Mountain Lake.

TRWD also uses the Trinity River as the water source for the constructed wetland near Richland Chambers Reservoir. Trinity River water is pumped into the Richland-Chambers wetland for natural treatment and is subsequently pumped into the Richland-Chambers Reservoir. In the future, TRWD plans to construct a sister wetland near the Trinity River that will treat water before pumping it to Cedar Creek Reservoir.

Future interbasin water sources listed in the Region C plan for TRWD include Marvin Nichols Reservoir, Toledo Bend Reservoir, and Oklahoma.

3.1.1.2 North Texas Municipal Water District

North Texas Municipal Water District (NTMWD) provides water to over 1.6 million people. NTMWD draws raw water from the conservation pool of Lavon Lake where waters pumped from Lake Texoma and Jim Chapman Lake (also known as Cooper Dam) are mixed prior to being pumped to NTMWD's water treatment plant (WTP) located in Wylie. NTMWD has a pipeline to transport water from Lake Texoma to Sister Grove Creek, a tributary of Lavon Lake. After zebra mussels were detected in Lake Texoma, NTMWD discontinued pumping to Sister Grove Creek. However, zebra mussels were detected in Sister Grove Creek in 2009. NTMWD also operates a pipeline from Jim Chapman Lake to Lavon Lake. A pipeline extension from the Sister Grove Creek pipeline to the NTMWD's WTP located in Wylie is currently under construction and should be completed by end of 2013. This pipeline extension will connect Lake Texoma directly to the WTP, bypassing Lavon Lake. The pipeline extension will also have a connection to the

Jim Chapman Lake pipeline so raw water from Jim Chapman Lake could be transported directly to the WTP if needed. To enable resumed pumping from Lake Texoma, NTMWD also obtained an amendment to the injurious wildlife provisions of the Lacey Act to avoid violation of federal law since their pipeline crosses the Texas-Oklahoma state line. NTMWD also operates a constructed wetland near the East Fork Trinity River where the finished water from the wetland is pumped to Lavon Lake. Water from Lake Tawakoni also enters this pipeline and is transferred with water from the wetland to Lake Lavon.

Future interbasin water sources listed in the Region C plan for NTMWD include Marvin Nichols Reservoir, Lower Bois d'Arc Creek Reservoir, Toledo Bend, and Oklahoma.

3.1.1.3 City of Dallas

The City of Dallas currently obtains water from Lake Ray Hubbard, Lake Tawakoni, Lake Fork, Ray Roberts Lake, Lewisville Lake, and Grapevine Lake, and has plans to use Lake Palestine in the future. Lake Fork Reservoir is connected to Lake Tawakoni via a pipeline, and Lake Tawakoni water is delivered directly to the Dallas Eastside WTP. The City of Dallas is also a stakeholder (with TRWD) in the IPL project described above. In addition, a pipeline shared by the Upper Trinity Regional Water District and the City of Irving connects Jim Chapman Lake and Lewisville Lake. Since Dallas holds storage space and water rights in Lewisville Lake, this transfer could impact City of Dallas infrastructure if zebra mussels were introduced into the lake from pipeline flow. However, it is more likely that mussels will be introduced into Lewisville Lake from Ray Roberts Lake, immediately upstream, via natural river flow and migration. Future water sources listed in the Region C plan for Dallas are Wright Patman Lake and a replacement for Lake Fastrill[1].

[1] Lake Fastrill is no longer an option due to conflicting fish and wildlife issues and subsequent litigation.

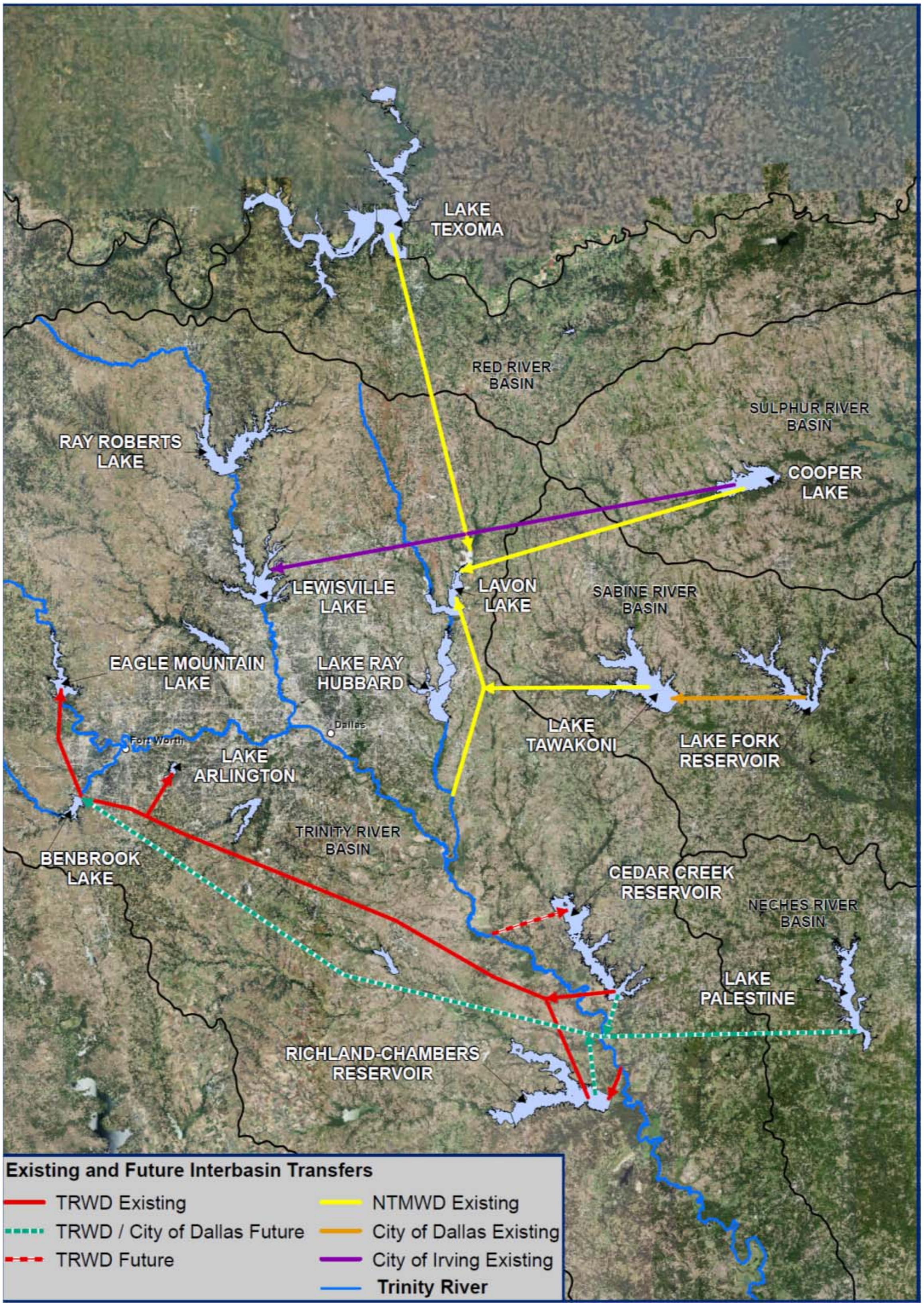

Figure 3-1 Map of Interbasin Transfers by Participating Sponsors.

3.2 BOAT TRAFFIC

Studies suggest that boating is a significant and widely investigated zebra mussel transport vector (Timar and Phaneuf, 2009). The potential for infestation depends on the frequency of movements (both waterborne and overland) between infested and uninfested waters, the numbers of zebra mussels transported by vessels, as well as the effectiveness of cleaning and disinfection efforts. Juvenile and adult mussels can attach to boat motors, hulls, and trailers. Veligers can be transported in ballast water, live wells, and bait buckets. Johnson and Carlton (1996) concluded that zebra mussels on entangled macrophytes and in live wells appear to be the most common means of transporting zebra mussels. They used data from boat surveys collected in 1992 on boats exiting Lake St. Clair. Factors such as weather, proximity of infested water sources, and boater habits impact mussel survival on recreational boats and subsequent infestation of previously uninfested water bodies.

In 2011, there were over 600,000 registered boaters in Texas (TPWD, 2011). Many of the Texas water sources near Lake Texoma are relatively close to a large metropolitan area and experience high boat traffic during the summer months. In addition, the warm spring, summer, and fall temperatures in Texas result in an extended boating season compared to northern states, increasing the risk.

3.3 NATURALLY-CONNECTED WATER SOURCES

Although boat traffic and interbasin transfers are significant transport vectors for zebra mussels, natural streams also transport zebra mussels to downstream waters without the aid of human actions. The potential for zebra mussels to spread from an infested lake, establish an in-stream population, and invade a downstream water source has been far less studied than boat traffic (Bobeldyk et al., 2005). It is apparent that stream connectivity has contributed to the spread of zebra mussels, as many water sources downstream of infested lakes have subsequently become infested. In-stream zebra mussel populations are unlikely to be self-sustaining as they require continuous recruitment from source populations of the upstream water source (Bodamer and Bossenbroek, 2008). Since the net flow in rivers is unidirectional, most larvae produced by riverine populations will be carried downstream and do not contribute to recruitment within the population that produced them (Stoeckel et al., 2004a). Nonetheless, upstream lakes could supply river systems with a consistent supply of veligers during the breeding season and contribute to the persistence of downstream populations. Zebra mussel populations within river sections that are able to retain mussels may self-recruit, eliminating or greatly decreasing their dependency on upstream water sources (Stoeckel et al., 2004a). This includes habitat areas with high residence time where settled zebra mussels could grow and reproduce. Self-recruiting populations could further perpetuate downstream zebra mussel populations by providing a source of veligers. The Upper Mississippi River does not have a large infested lake that serves as a source of zebra mussels, yet populations have persisted for many years (Stoeckel et al., 2004).

Spread of mussels in North America via natural connections has been studied almost exclusively in large rivers such as the Illinois River, Mississippi River, and the Hudson River (Bobeldyk et al., 2005). Bobeldyk et al. (2005) assessed lake-stream systems by examining infested inland lakes and reservoirs throughout the United States and their stream connections.

As of 2003, 295 lakes and reservoirs were reported to contain zebra mussels. There are 25 lakes less than 1 km downstream of an infested lake, and 23 of these were reported to have zebra mussels. However, of the 26 lakes more than 20 km downstream of an infested lake, only seven have been reported as invaded. These results are consistent with Kraft et al. (2002) who found that nearly all lakes in Belarus less than 15 km from an infested lake were also invaded.

In 2012, zebra mussels were found in Ray Roberts Lake on the Elm Fork of the Trinity River. This detection increased north Texas awareness of zebra mussel movements in riverine systems. Lakes most threatened by natural flows in north Texas include Lewisville Lake below Ray Roberts Lake, Lake Worth below Eagle Mountain Lake, and Lake Ray Hubbard below Lavon Lake. However, other lakes face some degree of threat because of the potential for upstream infestations. This threat may be somewhat mitigated by the distance from upstream reservoirs and/or the reduced level of boat traffic in smaller upstream reservoirs. In addition, there are lakes at risk from a combination of natural flows and transfers where water is now or will be pumped from the mainstem Trinity River and delivered through wetlands to tributary reservoirs for ultimate reuse in the metroplex. These lakes include Lavon Lake, Richland-Chambers Reservoir, Cedar Creek Reservoir, Lake Arlington, Benbrook Lake, Eagle Mountain Lake, and Lake Worth.

Hydraulic conditions can also impact a stream's ability to sustain a viable zebra mussel population. Survival of zebra mussels in intermittent streams may be impacted when extended periods of zero flow conditions are encountered. Low dissolved oxygen levels and lack of a constant food supply affect mussel sustainability. In 2009, zebra mussels were detected in Sister Grove Creek, a tributary to Lavon Lake. Since NTMWD pumping ceased in 2009 the creek has experienced periods of zero flow conditions and extreme summer temperatures. These conditions coupled with the potassium chloride treatment conducted by TPWD on Sister Grove Creek in 2010 may have led to the demise of the zebra mussel population in Sister Grove Creek. USGS samples multiple sites along Sister Grove Creek to monitor reproductive activity of surviving zebra mussels. From 2010 through 2012, there has been no evidence of reproduction or settlement in Sister Grove Creek. These data suggest that zebra mussels in Sister Grove Creek have not been able to establish a reproducing population. TPWD also monitors Sister Grove Creek and while they documented adult zebra mussels in 2009, 2010, and 2011 none were detected in 2012. In addition, Horvath et al. (1996) suggests that continued exposure to turbulence in streams may reduce the number of viable larvae that are transported downstream.

The Trinity River extends from north Texas southeastward to Trinity Bay on the Gulf of Mexico and also serves as a source of water for Houston. Most major lakes on the Trinity River and its tributaries are either in north Texas or near the Houston area. There are approximately 100 river miles between the southernmost lake in north Texas (Richland-Chambers Reservoir) and the next lake (Lake Livingston) in the Houston area. The Trinity River differs from other major river systems, such as the Mississippi, in that it lacks barge traffic and recreational boating is limited. The depth and water quality of the river are both highly variable as it receives both storm runoff and treated effluent from the Dallas/Fort Worth area. In addition, high total suspended solid (TSS) values suggest that turbidity may impact establishment of a zebra mussel population in the river. Due to these physical conditions, it is not clear whether the Trinity River will sustain a zebra mussel population and infest Lake Livingston. Further research on this topic is needed.

4 Risk Assessment

4.1 APPROACH

Detrimental ecological and economic impacts of zebra mussels can be extensive. Therefore, there is considerable interest in understanding the risk and vulnerability of surface water sources in the state. To establish a viable population, zebra mussels introduced to uninfested waters must be able to survive, grow, and reproduce. One straightforward method of assessing the risk of infestation of a given water source is to compare its physical and chemical water quality parameters with those required to sustain a viable zebra mussel population (Kozlowski et al., 2002; Wu et al., 2010; Hincks and Mackie, 1997).

Although boat traffic, interbasin transfers, and natural connections influence the overall risk of a water source, they were not considered in the risk assessments in this document. These risk assessments are based on the dominant factor of water quality, i.e. the ability of a water source to support and sustain zebra mussels. If relevant water quality parameters remain outside the ranges required for zebra mussel survival, controlling the vector of transport is redundant. This section summarizes the relevant water quality parameters for water sources selected by project sponsors and identifies the extent to which these sources are capable of sustaining zebra mussel populations.

4.1.1 Method

Much research has been performed on the survivability of zebra mussels based on water quality parameters (Cohen and Weinstein, 1998; Kozlowski et al., 2002). Differences have been reported, however, on levels of risk associated with certain ranges of water quality values. Therefore, it could be misleading to base a risk assessment on only one scientific study. Mackie and Claudi (2010) compiled an extensive list of known biological, chemical and physical parameters, and their tolerance ranges for zebra mussels. The tolerance range they reported for each parameter was obtained by consolidating the findings of numerous researchers. Their list includes 15 water quality parameters; however, their research and others have concluded that calcium, alkalinity, total hardness and pH are the physical and chemical variables most likely to determine mollusk survival (Mackie and Claudi (2010); Hincks and Mackie (1997)). Furthermore, these parameters are among the most studied variables that have been correlated to zebra mussel distribution (Cohen and Weinstein, 1998) and data for these parameters were readily available for this study.

Water temperature and dissolved oxygen can also impact zebra mussel survival in regions that experience climatic conditions outside the tolerance range of zebra mussels. In Texas, summer air temperatures can exceed 100°F for extended periods of time, typically during July and August. Water temperature and dissolved oxygen data were included in risk assessment summaries; however, seasonal fluctuations and spatial variations make it difficult to assign an overall risk based solely on temperature or dissolved oxygen.

Water quality parameters addressed in developing this risk assessment method are:

- Calcium
- Hardness
- Alkalinity
- pH
- Water temperature
- Dissolved oxygen

The water quality parameters and ranges for zebra mussels used in the assessment are shown in Table 4-1.

Table 4-1 Identified Parameters Used to Predict Zebra Mussel Infestation

Parameter	No Potential for Adult Survival	Little Potential for Larval Development	Moderate Potential for Nuisance Infestations	High Potential for Massive Infestations
Calcium (mg Ca/L)	<8	8-15	15-30	30-80
pH	<7.0, >9.5	7.0-7.8, 9.0-9.5	7.8-8.2 or 8.8-9.0	8.2-8.8
Alkalinity, total (mg $CaCO_3$/L)	<30	30-55	55-100	100-280
Hardness, total (mg $CaCO_3$/L)	<30	30-55	55-100	100-280
Dissolved Oxygen (mg/L) (% saturation)	<3 (<25%)	3-7 (25-50%)	7-8 (50-75%)	≥8 (75%)
Temperature (°C)	<10, >32	26-32	10-20	20-26

***Data in Table 4-1 obtained from Mackie and Claudi (2010).**

The lower temperature range for "little potential for larval development" shown in Table 4-1 is 26°C. In Lake Texoma, researchers have observed larval development above 26°C and estimate the lower range in Texas is closer to 30°C. This variation may be a result of zebra mussels acclimating to higher water temperatures in the south where it is not uncommon for summer air temperatures to exceed 40°C for extended periods of time.

Parameters shown in Table 4-1 are divided into four major categories based on their potential to sustain a zebra mussel population: no potential, little potential, moderate potential or high potential. To simplify the risk assessment, these four categories were combined into three: low, moderate, and high. The "Little Potential for Larval Development" and the "No Potential for Adult Survival" categories were combined into one low risk category. A no-risk category was not used because of uncertainties associated with sampling, acclimation and future watershed conditions. It is important to note that risk categories reflect the ability of a water source to sustain a zebra mussel population. Therefore, a low potential does not necessarily indicate that zebra mussels could not survive, but indicates that there is little to no potential that a large, biofouling population could be established.

4.1.1.1 Interaction of Water Quality Parameters

When analyzing the risk of a water source, it is important to consider not only the measured range of each water quality parameter but also the interdependencies among some parameters. Calcium and pH as well as dissolved oxygen and water temperature are water quality parameters that should be considered together. For example, moderate levels of calcium along with moderate pH can result in high risk as demonstrated by massive infestation of San Justo Reservoir, California (Renata Claudi, personal communication, August 22, 2012). Also, water temperature can affect the length of time that zebra mussels can survive low dissolved oxygen levels. In cooler waters, mussels can remain closed for longer periods of time and survive lower dissolved oxygen levels. Furthermore, if the water temperature is out of the range of survival for zebra mussels, dissolved oxygen levels are of little importance.

4.1.2 Water Quality Parameters

The following sections describe the significance of the water quality parameters used in this assessment.

4.1.2.1 Calcium

Calcium is an important component in shell formation, and is critical for zebra mussel growth and reproduction. Zebra mussels require a higher level of calcium than most bivalves (Kozlowski et al., 2002). Calcium concentration is considered to be the key factor for assessing the potential for zebra mussel colonization in North America (Mackie and Claudi, 2010) and is the key water quality parameter for risk assessments in this document. Calcium is naturally present in water and is likely to have been introduced through interaction with various rocks such as limestone, marble, or gypsum.

Calcium concentrations between 12-15 mg/L are required for adult survival in North American lakes (Cohen, 2007). Research conducted by Hincks and Mackie (1997) found that veligers were unable to survive in calcium levels less than 20 mg/L. Zebra mussel sensitivity to low calcium levels is thought to be based on physiology as calcium is involved in muscular contractions, cellular cohesion, nervous functions, and the maintenance of acid-base balances (Hincks and Mackie, 1997). Survival of veligers is required to maintain a reproducing population. Therefore, the lower risk level has been defined based on veliger survival. Table 4-2 provides ranges of values for calcium used to determine the level of risk in surface water sources.

Table 4-2 Calcium Range of Values

Risk	Range of Values
Low	<15 mg/L
Moderate	15-30 mg/L
High	30-80 mg/L

4.1.2.2 pH

pH regulates calcium uptake in zebra mussels. Acidic waters can reduce growth and reproduction (Kozlowski et al., 2002). Hincks and Mackie (1997) state that when the pH is lower than 6.9-6.8, the loss of calcium to the external environment exceeds the gain, and thus, the calcium necessary for normal metabolic functions is lost to the environment, resulting in mortality. In the laboratory, a pH range of 7.4-9.4 has been shown to be necessary for veliger development, with an optimal value occurring at about 8.5 (Sprung, 1993). A pH of less than 7.0 is considered lethal to zebra mussel veligers and adults (Mackie and Claudi, 2010). Table 4-3 shows the pH ranges selected to indicate a low, moderate or high risk for infestation.

Table 4-3 pH Range of Values

Risk	Range of Values
Low	<7.8, >9.0
Moderate	7.8-8.2, 8.8-9.0
High	8.2-8.8

4.1.2.3 Total Hardness/ Total Alkalinity

Total hardness is a measure of divalent ions that include calcium, magnesium and/or iron. Hardness is typically measured by chemical titration, and reported in milligrams per liter (mg/L) of calcium carbonate. Calcium and magnesium are the most common divalent ions. In general for Texas, a high total hardness value would indicate a high calcium concentration in the water.

The total alkalinity is the sum of the concentrations of bicarbonate (HCO_3) and carbonate (CO_3) anions. Alkalinity values can be used to assess the ability of water to resist a drop in pH. Alkaline compounds in water remove the H+ ions and lower the acidity of the water. Without the acid-neutralizing compounds, any acid added to the water would result in an immediate change in pH. Table 4-4 shows the total hardness and total alkalinity values used in the zebra mussel risk assessment.

Table 4-4 Total Hardness/ Total Alkalinity Range of Values

Risk	Range of Values
Low	<55 mg $CaCO_3$/L
Moderate	55-100 mg $CaCO_3$/L
High	100-280 mg $CaCO_3$/L

4.1.2.4 Dissolved Oxygen

Sufficient dissolved oxygen (DO) levels are necessary for respiration. Zebra mussels are some of the least tolerant to low levels of oxygen among all freshwater bivalves (Wu et al., 2010). Mackie and Claudi (2010) note that respiration rates of freshwater bivalves appear to vary vastly from season to season, with oxygen consumption higher in the summer months, depending on body size, species, and temperature range. DO concentrations less 4 mg/L are lethal to zebra mussels at 18 °C (Cohen and Weinstein, 1998); however, zebra mussels are able to survive for short periods in water with low DO by closing their shells.

Dissolved oxygen levels will vary seasonally, with the lowest levels typically occurring in the summer. In addition, DO varies throughout the day as a result of community photosynthesis and respiration patterns. In general, these diel fluctuations are unlikely to impact zebra mussel survival significantly due to the relatively short duration of low DO fluctuations. When assessing DO levels, it is important to consider the depth, time of year, and location of samples. Without extensive monitoring, seasonal, vertical, and spatial variations in dissolved oxygen values make it difficult to assign an overall risk rating based solely on this parameter. Dissolved oxygen levels were summarized seasonally to identify water sources where zebra mussel establishment may be hindered by this parameter and justify the need for additional sampling. Table 4-5 shows survival potential with corresponding ranges of DO values.

Table 4-5 Dissolved Oxygen Range of Values

Survival Potential	Range of Values
Low	<7 mg/L
Moderate	7-8 mg/L
High	≥8 mg/L

4.1.2.5 Temperature

Zebra mussels most commonly occur in water temperatures between 12.5-21.5 °C (55-71°F) (Wu et al., 2010). Maximum temperature for zebra mussel survival has been estimated at 32°C. Temperatures outside of the tolerance range for zebra mussels affect the mussel's ability to filter and ingest food particles. Optimal temperature range for zebra mussel spawning in North America is estimated to be between 18-26 °C (Robert McMahon, personal communication, March 1, 2013). Zebra mussels can be killed by short-term exposure to 40°C (104°F) (Mackie and Claudi, 2010). Other studies have found varying temperature tolerances. It is difficult to predict the exact tolerance ranges in nature because they may vary based on exposure periods, frequency of temperature fluctuations, and acclimation (Mackie and Claudi, 2010).

Surface water temperature data (0-1 meter) for each water source were summarized for July and August to estimate survival potential. Water temperatures around lakes and rivers can vary spatially depending on depth or industrial impacts such as hydroelectric power plant discharge. Therefore, the data were reviewed to identify outliers and results were noted in the individual risk assessments.

Seasonal, vertical, and spatial variations in water temperature values make it difficult to assign overall risk rating based solely on this parameter without extensive monitoring. Surface water temperatures exceeding 32°C would prevent zebra mussel establishment. In addition to the seasonal water temperature summary, a statement regarding the average surface water temperature for July and August is provided in each risk assessment (Section 5). Table 4-6 shows the survival potential and corresponding temperature values. The maximum value of 32°C is based on previous research and does not account for potential zebra mussel acclimation that may develop as mussels survive in southern states.

Table 4-6 Temperature (°C) Range of Values

Survival Potential	Temperature Range
Prevent zebra mussel establishment	Temperatures > 32°C
Little impact on mussel survival	Temperatures 8<32 °C

4.1.3 Water Quality Data Sources

A majority of the water quality data for these assessments were obtained from the Texas Commission on Environmental Quality's (TCEQ) Surface Water Quality Monitoring Information System (SWQMIS) database. Some data were also obtained from the United States Geological Survey (USGS) database. The SWQMIS database provides water quality data at various locations within a given water source that was collected and analyzed by the TCEQ, or other local, state and federal agencies. The amount and time periods of historical data vary from source to source. When possible, the risk assessment utilized data from 2000-2012. A minimum sample size of 10 was used for each parameter.

Calcium data were limited for several of the water sources evaluated. In order to complete risk assessments for all of the water sources identified by project sponsors, calcium was estimated for some of the water sources using a method outlined in Mackie and Claudi (2010). This method used alkalinity to estimate calcium values, and was derived from evaluating over 2,500 samples of calcium (Mackie and Claudi, 2010). It states that the alkalinity (as mg $CaCO_3$/L) values can be multiplied by .40 to calculate the calcium. This follows the equation of

$$Ca + CO_3 = CaCO_3 \qquad (1)$$

where 100 parts of $CaCO_3$ is made up of approximately 40 parts calcium and approximately 60 parts CO_3 based on the atomic weight of the elements. The category of the calculated values was compared to total alkalinity and total hardness to ensure they fell within the same risk category for all sources.

4.1.4 Summary

Water quality data were summarized for each water source. The 10th percentile, 90th percentile, average, and median values were calculated for calcium, hardness, alkalinity, and pH based on available data from each source. The summarized data were then compared to the values shown in Table 4-1 to evaluate the overall risk of the water source to an infestation and also considered the interdependencies of parameters discussed in section 4.1.1.1. Calcium was used as the first indicator of risk based on its importance in shell formation. If calcium values were above the level of survival, then alkalinity, hardness and pH were considered. Table 4-7 shows a summary of the water quality data and risk for each water quality parameter. The color scheme shown below is used throughout the risk assessment.

Table 4-7 Summary of Water Quality Parameters for Risk Levels

Legend
- High Potential for infestation (red)
- Moderate Potential for infestation (yellow)
- Low Potential for infestation (green)

Water Parameter	Units	Risk		
		Low	Moderate	High
Calcium	mg Ca/L	<15	15-30	30-80
Alkalinity	mg $CaCO_3$/L	<55	55-100	100-280
Hardness	mg $CaCO_3$/L	<55	55-100	100-280
pH		<7.8, >9.0	7.8-8.2 or 8.8- 9.0	8.2-8.8

Average surface water temperature for July and August are provided for each water source in the risk analysis. In addition, the values of water temperature and dissolved oxygen were averaged by season as shown in Table 4-8. The data for temperature and dissolved oxygen were recorded at various depths ranging from the surface to 30 meters below the water surface. To further categorize the data and potentially determine the vertical limit of zebra mussel survival, the temperature and dissolved oxygen values were divided into depth categories which include: 0-1, >1-6, >6-12, and >12-18 meters. Some sample locations were measured deeper than 18 meters below the water surface so the range was continued in 6 meter increments.

Table 4-8 Seasonal Summary

Season	Month
Spring	March-May
Summer	June-Aug
Fall	Sept-Nov
Winter	Dec-Feb

4.1.5 Water Sources

The water sources considered in the risk assessment included lakes, rivers and wetlands. Only water sources selected by the participating sponsors were considered. Table 4-9 shows a list of the lakes that were considered in the assessment. The river analysis was confined to segments of rivers that were of interest to the sponsors. These segments typically encompass current or potential future intake points along the Trinity River, Sabine River, and Neches River. Finally, the wetland assessment included two constructed wetlands located in the Trinity River basin.

Table 4-9 List of Lakes Included in Risk Assessment

Lakes/Reservoirs
B.A. Steinhagen Lake
Bardwell Lake
Benbrook Lake
Cedar Creek Reservoir
Eagle Mountain Lake
Grapevine Lake
Jim Chapman Lake (Cooper)
Joe Pool Lake
Lake Arlington
Lake Bonham
Lake Bridgeport
Lake Conroe
Lake Fork Reservoir
Lake Houston
Lake Livingston
Lake O' The Pines
Lake Palestine
Lake Ray Hubbard
Lake Tawakoni
Lavon Lake
Lewisville Lake
Ray Roberts Lake
Richland-Chambers Reservoir
Sam Rayburn Reservoir
Toledo Bend Reservoir
Wright Patman Lake

4.2 RESULTS

Each water source (lake, river segment, or wetland) was assigned an overall level of risk based on the water quality parameters previously discussed. Three levels of risk were used as shown in Table 4-8. A moderate or high risk designation indicates that the water source is susceptible to zebra mussel infestation. Regular monitoring of these sources is recommended. Low risk indicates little or no potential that a population could be established and maintained. Occasional monitoring of these sources is still recommended.

5 Lakes

This section includes risk assessments from 26 water sources in north and east Texas. A summary of the history[2], water quality and overall risk is provided for each lake. A map of each lake showing the sampling locations can be found in Appendix A. Risk assessment summaries by lake are included in Figures 5-1 through 5-26.

[2] The history for each water source written below was obtained from the Texas Parks and Wildlife Department, U. S. Army Corps of Engineers, Tarrant Regional Water District, Texas Water Development Board, Sabine River Authority, and Bureau of Reclamation websites.

Figure 5-1

Lake Risk Assessment Summary: B.A. Steinhagen Lake

Overall Risk Rating: Low
–Calcium below 12 mg/L required to sustain zebra mussels
–Additional sampling recommended for calcium to confirm estimated values
–Average July and August surface water temperature (30 °C) has little impact.

Location: Lake is on the Neches River, approximately twelve miles southwest of Jasper, Texas.

River Basin: Neches River Basin

TCEQ Segment ID: 0603

Conservation Pool Area: 13,700 acres

Conservation Pool Storage: 77,600 ac-ft

Completion: 1951

Uses: Water supply, flow regulation, hydroelectric power generation

Number of Sampling Locations: 2

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	4.4	7.3	6.8	10.4	98
Alkalinity, Total	mg/L CaCo3	11.0	18.3	17.0	26.0	98
Hardness, Total	mg/L CaCo3	12.0	18.2	16.5	26.0	52
pH		6.6	7.1	7.1	7.6	489

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.5 (21)	9.1 (21)
	>1-6	17.2 (50)	8.6 (50)
	>6-12	16.1 (46)	7.7 (46)
Summer	0-1	30.4 (23)	6.5 (21)
	>1-6	28.6 (55)	4.8 (50)
	>6-12	27.6 (52)	3.2 (47)
Fall	0-1	25.7 (21)	8.5 (21)
	>1-6	24.6 (45)	6.4 (45)
	>6-12	24.3 (50)	4.7 (50)
Winter	0-1	11.7 (18)	10.3 (18)
	>1-6	11 (32)	10.1 (32)
	>6-12	10.2 (25)	9.9 (25)

Figure 5-2

Lake Risk Assessment Summary: Bardwell Lake

Overall Risk Rating: High
– Moderate to high levels for calcium, alkalinity, hardness, and pH
– Average July and August surface water temperature (30 °C) has little impact

Location: Lake is on Waxahachie Creek, and located five miles south of Ennis, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0815

Conservation Pool Area: 3,570 acres

Conservation Pool Storage: 42,800 ac-ft

Completion: 1965

Uses: Flood control, recreation

Number of Sampling Locations: 4

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	34.1	43.2	44.7	54.5	54
Alkalinity, Total	mg/L CaCo3	83.3	103.5	105.9	135.4	32
Hardness, Total	mg/L CaCo3	97.7	120.0	122.4	150.0	48
pH		7.6	8.0	8.0	8.4	433

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.7 (33)	8.6 (33)
	>1-6	19.7 (57)	7.8 (57)
	>6-12	18.7 (33)	6.4 (33)
Summer	0-1	30.1 (33)	7.9 (33)
	>1-6	28.7 (87)	5.4 (87)
	>6-12	27.4 (44)	1.2 (44)
Fall	0-1	21.2 (12)	8.8 (12)
	>1-6	21.4 (37)	7.8 (37)
	>6-12	19.4 (9)	5.7 (9)
Winter (Jan-Feb)	0-1	9.1 (22)	11.5 (22)
	>1-6	8.9 (40)	11.2 (40)
	>6-12	9 (26)	10.8 (26)

Figure 5-3

Lake Risk Assessment Summary: Benbrook Lake

Overall Risk Rating: High
–Moderate to high levels of calcium, alkalinity, hardness, and pH
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (29.2 °C) has little impact

Location: Lake is on the Clear Fork of the Trinity River, approximately ten miles southwest of Fort Worth, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0830

Conservation Pool Area: 3,770 acres

Conservation Pool Storage: 72,500 ac-ft

Completion: early 1952

Uses: Water supply, flood control

Number of Sampling Locations: 7

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	35.6	43.2	44.3	56.0	297
Alkalinity, Total	mg/L CaCo3	88.9	108.0	110.8	139.9	297
Hardness, Total	mg/L CaCo3	110.8	125.0	123.0	133.6	4
pH		7.4	8.0	7.9	8.4	1861

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	15 (99)	9.9 (99)
	>1-6	14.3 (221)	9.5 (221)
	>6-12	13.4 (138)	8.9 (138)
	>12-18	13.1 (31)	8 (31)
Summer	0-1	28.1 (115)	8.4 (115)
	>1-6	27.5 (275)	6.7 (275)
	>6-12	26.1 (181)	3 (181)
	>12-18	24.3 (46)	1.5 (46)
Fall	0-1	25.2 (101)	7.4 (101)
	>1-6	25.4 (213)	6 (213)
	>6-12	25.6 (125)	3.7 (125)
	>12-18	25.9 (14)	2.7 (14)
Winter	0-1	9.9 (82)	10.9 (82)
	>1-6	9.8 (159)	10.4 (159)
	>6-12	10.2 (95)	10 (95)
	>12-18	10.8 (16)	9.2 (16)

Figure 5-4

Lake Risk Assessment Summary: Cedar Creek Reservoir

Overall Risk Rating: Moderate
– Moderate levels of calcium
– Moderate average and median values for alkalinity, hardness, and pH
– Average July and August surface water temperature (29.7 °C) has little impact

Location: Lake is on Cedar Creek, approximately fifteen miles west of Athens, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0818

Conservation Pool Area: 32,873 acres

Conservation Pool Storage: 644,785 ac-ft

Completion: 1965

Uses: Water supply, water conservation, recreation

Number of Sampling Locations: 27

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (total)	mg/L Ca	15.5	18.6	19.0	23.3	196
Alkalinity, Total	mg/L CaCo3	45.6	55.1	55.9	67.6	514
Hardness, Total	mg/L CaCo3	55.4	57.7	58.3	61.7	4
pH		7.3	7.8	7.9	8.8	4465

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.4 (280)	8.5 (280)
	>1-6	18.6 (543)	8.1 (543)
	>6-12	17.6 (343)	7.3 (343)
	>12-16	16.7 (27)	5.8 (27)
Summer	0-1	29.5 (375)	7.7 (375)
	>1-6	28.9 (622)	6 (622)
	>6-12	26.9 (403)	2.5 (403)
	>12-16	23.4 (50)	0.3 (50)
Fall	0-1	24.1 (205)	8 (203)
	>1-6	23.8 (409)	6.9 (404)
	>6-12	23.5 (276)	5.4 (268)
	>12-16	22.1 (11)	3.7 (11)
Winter	0-1	10.9 (202)	11.1 (190)
	>1-6	10.6 (408)	10.7 (385)
	>6-12	10.2 (284)	10.4 (265)
	>12-16	9.4 (27)	9.5 (26)

Figure 5-5

Lake Risk Assessment Summary: Eagle Mountain Lake

Overall Risk Rating: High
– High levels of Calcium
– High levels of alkalinity and hardness
– Moderate median and average pH
– Average July and August surface water temperature (29.6 °C) has little impact

Location: Lake is on the West Fork of the Trinity River, approximately fifteen miles northwest of Fort Worth, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0809

Conservation Pool Area: 9,104 acres

Conservation Pool Storage: 182,725 ac-ft

Completion: 1932

Uses: Water supply, recreation

Number of Sampling Locations: 10

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (total)	mg/L Ca	30.8	36.8	37.3	44.5	126
Alkalinity, Total	mg/L CaCo3	98.0	115.1	116.9	138.0	467
Hardness, Total	mg/L CaCo3	112.2	133.0	128.0	139.8	4
pH		7.5	8.0	8.0	8.4	3078

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.2 (198)	8.9 (198)
	>1-6	18.7 (415)	8.1 (415)
	>6-13	17.7 (199)	6.9 (199)
Summer	0-1	29.5 (202)	7.4 (202)
	>1-6	29.1 (414)	5.5 (414)
	>6-13	27.1 (192)	1.5 (192)
Fall	0-1	20.4 (190)	8.5 (190)
	>1-6	20.6 (359)	7.3 (359)
	>6-13	20.8 (166)	5.5 (166)
Winter	0-1	8.6 (202)	11.5 (202)
	>1-6	8.6 (381)	10.9 (381)
	>6-13	8.7 (161)	9.9 (161)

Figure 5-6

Lake Risk Assessment Summary: Grapevine Lake

Overall Risk Rating: High
– High levels of calcium
– High levels of alkalinity, hardness, and pH
– Average July and August surface water temperature (30 °C) has little impact

Location: Lake is on Denton Creek, a tributary of the Elm Fork of the Trinity River and located approximately 20 miles northwest of Dallas, Texas. It is surrounded by the cities of Grapevine, Flower Mound and Trophy Club.

River Basin: Trinity River Basin

TCEQ Segment ID: 0826

Conservation Pool Area: 7,280 acres

Conservation Pool Storage: 145,100 ac-ft

Constructed: 1952

Uses: Flood control, water supply, recreation

Number of Sampling Locations: 18

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	34.1	43.5	42.8	48.1	25
Alkalinity, Total	mg/L CaCo3	91.0	110.0	108.0	121.0	101
Hardness, Total	mg/L CaCo3	116.0	130.0	134.8	161.8	112
pH		7.7	8.2	8.2	8.7	952

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.8 (120)	10 (118)
	>1-6	21.5 (49)	9.7 (47)
	>6-12	16.2 (14)	9.1 (14)
	>12-18	17.5 (10)	7.9 (10)
Summer	0-1	29.4 (200)	8.8 (200)
	>1-6	28.7 (165)	6.9 (165)
	>6-12	27.4 (21)	2.1 (21)
	>12-18	24.8 (7)	0.4 (7)
Fall	0-1	24.1 (141)	8.3 (138)
	>1-6	24 (87)	7.5 (87)
	>6-12	19.7 (17)	7.3 (17)
Winter	0-1	9.9 (100)	10.9 (100)

Figure 5-7

Lake Risk Assessment Summary: Jim Chapman Lake (Cooper)

Overall Risk Rating: High
– Moderate risk levels for all calcium, alkalinity, hardness, and pH values
– Calcium and pH are both within range required to interact and sustain a viable population.
–High risk based on interdependencies
– Average July and August surface water temperature (29.4 °C) has little impact

Location: Lake is on the South Sulphur River, approximately 70 miles northeast of Dallas, Texas.
River Basin: Sulphur River Basin
TCEQ Segment ID: 0307
Conservation Pool Area: 19,305 acres
Conservation Pool Storage: 273,120 ac-ft
Completion: 1991
Uses: Water supply, recreation, flood control
Number of Sampling Locations: 6

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	21.6	24.2	25.0	29.6	42
Alkalinity, Total	mg/L CaCo3	65.6	76.0	77.6	90.2	77
Hardness, Total	mg/L CaCo3	62.6	80.4	75.5	87.0	37
pH		7.4	7.8	7.9	8.5	476

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.7 (41)	8.6 (41)
	>1-6	16.5 (58)	8.5 (58)
Summer	0-1	29 (40)	7.9 (40)
	>1-6	27.9 (59)	5.8 (59)
Fall	0-1	19.5 (39)	8.5 (40)
	>1-6	19.5 (45)	8.1 (47)
Winter	0-1	8.7 (40)	11.4 (40)
	>1-6	8.3 (51)	11.1 (51)

Figure 5-8

Lake Risk Assessment Summary: Joe Pool Lake

Overall Risk Rating: High
- High levels of calcium and hardness
- Moderate to high levels of alkalinity and pH
- Average July and August surface water temperature (29.8 °C) has little impact

Location: Lake is on Walnut Creek and Mountain Creek, approximately twenty miles southeast of Fort Worth, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0838

Conservation Pool Area: 7,470 acres

Conservation Pool Storage: 142,900 ac-ft

Completion: 1991

Uses: Water supply, recreation, flood control

Number of Sampling Locations: 9

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	40.6	55.5	55	63.3	133
Alkalinity, Total	mg/L CaCo3	98.1	105.5	104.0	110.6	28
Hardness, Total	mg/L CaCo3	150	168	173.7	200	125
pH		7.6	8.1	8.0	8.4	750

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.3 (74)	8.7 (74)
	>1-6	18.6 (58)	8.7 (58)
	>6-12	18.6 (70)	8.6 (70)
	>12-18	18.3 (28)	7.3 (28)
Summer	0-1	29.1 (81)	7.4 (79)
	>1-6	29 (60)	6.8 (60)
	>6-12	27.2 (90)	3.4 (90)
	>12-18	25.3 (31)	1.4 (32)
Fall	0-1	20.8 (27)	7.7 (5)
	>1-6	27.4 (5)	5.8 (5)
	>6-12	27.3 (6)	5.6 (6)
	>12-18	22.9 (7)	2.3 (7)
Winter	0-1	10.5 (72)	10.7 (71)
	>1-6	10.2 (43)	10.5 (43)
	>6-12	10.6 (73)	10.3 (73)
	>12-18	10.1 (28)	10.4 (28)

Figure 5-9

Lake Risk Assessment Summary: Lake Arlington

Overall Risk Rating: High
–Moderate to high levels for calcium, alkalinity, and hardness
– pH high enough to support a surviving population
– Average July and August surface water temperature (31 °C) has little impact
–Average water temperature near hydroelectric power plant discharge (northern end of the Lake) is 34°C which may prevent establishment; however, sample size is limited and requires additional sampling to determine spatial limit of zebra mussel establishment.

Location: Lake is on Village Creek, a tributary of the West Fork of the Trinity River and located seven miles west of Arlington, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0828

Conservation Pool Area: 1,926 acres

Conservation Pool Storage: 40,188 ac-ft

Completion: 1957

Uses: Hydroelectric power generation, recreation

Number of Sampling Locations: 10

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	30	35.7	35.2	38.4	64
Alkalinity, Total	mg/L CaCo3	80.9	98.0	101.0	123.4	244
Hardness, Total	mg/L CaCo3	97.3	110.0	105.7	110.0	22
pH		7.5	8.0	8.0	8.6	1387

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	22.2 (106)	8.6 (106)
	>1-6	22.2 (173)	7.6 (173)
	>6-14	20.2 (121)	6.3 (121)
Summer	0-1	31.5 (92)	7.9 (92)
	>1-6	30.4 (170)	5.7 (171)
	>6-14	28 (87)	1.9 (87)
Fall (Sept, Nov)	0-1	18.2 (72)	9.2 (72)
	>1-6	18.1 (152)	8.5 (152)
	>6-14	18.2 (55)	6.4 (55)
Winter	0-1	11.3 (97)	10.8 (97)
	>1-6	10.4 (172)	10.6 (172)
	>6-14	10.3 (89)	9.6 (89)

Figure 5-10

Lake Risk Assessment Summary: Lake Bonham

Overall Risk Rating: Moderate
– Low to moderate risk for calcium, alkalinity, hardness, pH
– Limited data limits confidence in low risk designation
– Average July and August surface water temperature (29.2 °C) has little impact

Location: Lake is on Timber Creek and located five miles northeast of Bonham, Texas.

River Basin: Red River Basin

TCEQ Segment ID: N/A

Conservation Pool Area: 1,012 acres

Conservation Pool Storage: 11,038 ac-ft

Completion: 1969

Uses: Flood control, recreation

Number of Sampling Locations: N/A

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	12.5	15.2	15.3	17.8	25
Alkalinity, Total	mg/L CaCo3	42.4	53.0	54.0	67.2	25
Hardness, Total	mg/L CaCo3	48.8	62.0	62.7	80.0	25
pH		6.9	7.2	7.2	7.6	25

Seasonal Temperature and DO Risk Summary

Water Quality Parameter	Average			
	Spring	Summer	Fall	Winter
Temperature (°C)	16	28	22	10

Figure 5-11

Lake Risk Assessment Summary: Lake Bridgeport

Overall Risk Rating: High
– High levels of calcium and alkalinity– Moderate to high pH
– Average July and August surface water temperature (29.3 °C) has little impact

Location: Lake is on the West Fork of the Trinity River and approximately 45 miles northwest of Fort Worth, Texas. Also, upstream of Eagle Mountain Lake.

River Basin: Trinity River Basin

TCEQ Segment ID: 0811

Conservation Pool Area: 11,954 acres

Conservation Pool Storage: 366,236 ac-ft

Completion: 1932

Uses: Flood control, residential and commercial sales, irrigation, recreation

Number of Sampling Locations: 12

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (total)	mg/L Ca	33.6	37.0	37.2	41.7	122
Alkalinity, Total	mg/L CaCo3	102.0	110.6	110.3	118.4	369
Hardness, Total	mg/L CaCo3	ND	ND	ND	ND	ND
pH		7.4	8.0	7.9	8.4	3193

ND = No Data

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.1 (144)	9.2 (144)
	>1-6	17.9 (320)	8.9 (320)
	>6-12	17.5 (284)	8.4 (284)
	>12-18	16.6 (109)	7.4 (109)
	>18-22	15.2 (19)	5.6 (19)
Summer	0-1	28.5 (160)	7.5 (160)
	>1-6	28.5 (306)	7 (307)
	>6-12	26.9 (244)	3.1 (244)
	>12-18	23.5 (97)	0.7 (97)
	>18-22	22.4 (17)	0.8 (17)
Fall	0-1	21.4 (130)	8.2 (130)
	>1-6	20.9 (319)	7.9 (319)
	>6-12	20.4 (271)	7.5 (271)
	>12-18	20.2 (99)	6.9 (99)
Winter	0-1	8.8 (120)	11.4 (108)
	>1-6	8.5 (268)	11.3 (245)
	>6-12	8.3 (227)	11.2 (214)
	>12-18	8.2 (79)	10.9 (78)
	>18-22	8.3 (19)	9.9 (19)

Figure 5-12

Lake Risk Assessment Summary: Lake Conroe

Overall Risk Rating: High
–Calcium alkalinity, hardness, and pH are in range to interact and sustain a viable population
–High risk based on interdependencies
– Average July and August surface water temperature (30.7 °C) has little impact
– Two sampling locations averaged 34 °C but data was limited to a few sampling events.

Location: Lake is on the West Fork of the San Jacinto River and located 8 miles northwest of Conroe, Texas.

River Basin: San Jacinto River Basin

TCEQ Segment ID: 1012

Conservation Pool Area: 21,572 acres

Conservation Pool Storage: 430,260 ac-ft

Completion: 1973

Uses: Water supply, recreation

Number of Sampling Locations: 21

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	19.3	23.3	23.2	26.3	166
Alkalinity, Total	mg/L CaCo3	56.0	67.0	67.7	82.0	680
Hardness, Total	mg/L CaCo3	63.0	76.0	77	94.0	1144
pH		7.3	7.9	8.0	8.7	5646

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.3 (495)	9.1 (486)
	>1-6	19.4 (488)	8.7 (488)
	>6-12	18.4 (435)	7.8 (434)
	>12-18	15.5 (85)	7.5 (85)
Summer	0-1	30 (521)	7.6 (513)
	>1-6	29.6 (604)	6.2 (610)
	>6-12	28.1 (526)	3.1 (529)
	>12-18	25.3 (130)	1 (130)
Fall	0-1	25.4 (364)	7.3 (357)
	>1-6	24.9 (415)	6.1 (422)
	>6-12	24.8 (304)	4.9 (304)
	>12-18	24.3 (31)	3.5 (27)
Winter	0-1	13 (415)	10.1 (411)
	>1-6	13 (539)	10.1 (541)
	>6-12	12.7 (386)	9.5 (388)
	>12-18	12.6 (42)	9.1 (42)

Figure 5-13

Lake Risk Assessment Summary: Lake Fork Reservoir

Overall Risk Rating: Low
– Low levels of calcium, alkalinity, hardness, and pH
– Calcium near the 12 mg/L limit required to sustain zebra mussels
– Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (29.8 °C) has little impact

Location: Lake is on Lake Fork Creek, a tributary of the Sabine River and located approximately 5 miles northwest of Quitman, Texas.

River Basin: Sabine River Basin

TCEQ Segment ID: 0515

Conservation Pool Area: 27,690 acres

Conservation Pool Storage: 675,800 ac-ft

Completion: 1980

Uses: Water supply, recreation

Number of Sampling Locations: 7

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	8.0	12.0	12.4	16.0	254
Alkalinity, Total	mg/L CaCo3	20.0	30.0	31.0	40.0	254
Hardness, Total	mg/L CaCo3	32.0	40.0	43.7	56.0	210
pH		6.7	7.3	7.3	8.1	2940

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.6 (216)	8.9 (216)
	>1-6	18.2 (280)	8.4 (281)
	>6-12	16.7 (265)	7 (265)
	>12-18	14.3 (76)	5.9 (76)
Summer	0-1	29.2 (227)	7.6 (227)
	>1-6	28.8 (279)	5.7 (284)
	>6-12	24.8 (218)	1.9 (222)
	>12-18	18 (40)	0.5 (41)
	>18-21	14.9 (12)	0.5 (12)
Fall	0-1	22.6 (182)	7.3 (181)
	>1-6	22.4 (217)	6.8 (217)
	>6-12	22.5 (217)	4.7 (217)
	>12-18	18.1 (58)	2.6 (58)
Winter	0-1	9.8 (184)	10.4 (184)
	>1-6	9.5 (219)	10.4 (219)
	>6-12	9.4 (191)	10.2 (191)
	>12-18	9.7 (50)	9.8 (50)

Figure 5-14

Lake Risk Assessment Summary: Lake Houston

Overall Risk Rating: Moderate
- Moderate risk levels of calcium, alkalinity, and hardness
- Values of pH at upper limit of low risk category
- Average July and August surface water temperature (30.3 °C) has little impact

Location: Lake is on the San Jacinto River, and approximately 18 miles northeast of Houston, Texas.

River Basin: San Jacinto River Basin

TCEQ Segment ID: 1002

Conservation Pool Area: 11,864 acres

Conservation Pool Storage: 146,000 acft

Completion: 1954

Uses: Municipal, industrial, recreational, mining, and irrigation purposes

Number of Sampling Locations: 21

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	11.9	15.4	15.7	20.6	91
Alkalinity, Total	mg/L CaCo3	32.0	59.0	59.3	86.0	524
Hardness, Total	mg/L CaCo3	44.0	58.0	59.1	77.0	759
pH		6.9	7.6	7.7	8.7	3347

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	21.8 (834)	7.8 (638)
	>1-6	21.4 (195)	8.1 (196)
	>6-13	17.8 (15)	7.7 (15)
Summer	0-1	29.8 (779)	6.9 (590)
	>1-6	29.3 (290)	5.4 (290)
	>6-13	27.7 (28)	2.9 (28)
Fall	0-1	23.2 (702)	7.6 (555)
	>1-6	24.9 (160)	5.8 (161)
	>6-13	29.1 (14)	4.1 (14)
Winter	0-1	13.2 (732)	9.4 (536)
	>1-6	13.6 (96)	9.4 (91)
	>6-13	13.3 (15)	9 (14)

Figure 5-15

Lake Risk Assessment Summary: Lake Livingston

Overall Risk Rating: High
– High risk levels of calcium
– Moderate to high levels of alkalinity, hardness, and pH
– Average July and August surface water temperature (30.9 °C) has little impact

Location: Lake is on the Trinity River and about 80 miles north of Houston, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0803

Conservation Pool Area: 83,277 acres

Conservation Pool Storage: 1,741,867 million ac-ft

Completion: 1969

Uses: Industrial, municipal, and agricultural needs

Number of Sampling Locations: 19

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	34.5	44.9	43.9	50.9	40
Alkalinity, Total	mg/L CaCo3	75.0	92.0	91.7	110.0	121
Hardness, Total	mg/L CaCo3	94.0	118.0	119.0	140.0	150
pH		7.6	8.1	8.1	8.8	1043

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	19.8 (273)	9.8 (270)
	>1-6	16.6 (82)	8.8 (82)
	>6-12	15.9 (117)	8.2 (117)
	>12-18	15.9 (107)	7.3 (109)
	>18-24	16.5 (51)	4.1 (55)
Summer	0-1	30.4 (444)	8.5 (418)
	>1-6	29.4 (292)	6 (289)
	>6-12	28.9 (432)	3.6 (430)
	>12-18	27.5 (298)	1.5 (296)
	>18-24	22.2 (94)	0.3 (94)
Fall	0-1	24.2 (254)	8.6 (236)
	>1-6	24 (121)	7 (118)
	>6-12	23.6 (130)	5.3 (126)
	>12-18	23.1 (93)	4.4 (91)
	>18-24	21.1 (49)	4.4 (49)
Winter	0-1	11.8 (345)	10.2 (343)
	>1-6	11.4 (228)	9.6 (222)
	>6-12	11.3 (356)	9.4 (348)
	>12-18	11.1 (289)	9.4 (283)
	>18-24	10.7 (79)	9.5 (76)

Figure 5-16

Lake Risk Assessment Summary: Lake O' the Pines

Overall Risk Rating: Low
– Low risk levels for all parameters
– Calcium values less than the 12 mg/L required for survival.
– Average July and August surface water temperature (31.7 °C) has little impact

Location: Lake is on Big Cypress Creek and about 25 miles northeast of Longview, Texas.

River Basin: Cypress Creek Basin

TCEQ Segment ID: 0403

Conservation Pool Area: 18,700 acres

Conservation Pool Storage: 251,100 acre-feet

Completion: 1958

Uses: Flood control, water supply, recreation

Number of Sampling Locations: 16

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	4.7	6.8	7.2	10.8	129
Alkalinity, Total	mg/L CaCo3	11.0	20.0	21.7	32.0	141
Hardness, Total	mg/L CaCo3	24.7	30.0	33.1	47.0	98
pH		6.4	7.0	7.0	7.8	2378

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	22.4 (173)	8.5 (174)
	>1-6	21.2 (307)	6.9 (310)
	>6-12	17.9 (124)	6.1 (124)
	>12-16.5	15.8 (19)	5.5 (19)
Summer	0-1	30.6 (263)	7.5 (263)
	>1-6	29.2 (455)	4.3 (454)
	>6-12	26 (125)	0.8 (119)
	>12-16.5	24.4 (15)	0.5 (13)
Fall	0-1	21.5 (128)	8.1 (128)
	>1-6	20.7 (220)	7.3 (220)
	>6-12	20.8 (42)	5.4 (42)
	>12-16.5	24.2 (6)	0.3 (6)
Winter	0-1	10.3 (152)	10.7 (152)
	>1-6	9.9 (256)	10.5 (256)
	>6-12	9.3 (91)	10.5 (91)
	>12-16.5	9.5 (13)	10.6 (13)

Figure 5-17

Lake Risk Assessment Summary: Lake Palestine

Overall Risk Rating: Low
- Majority of values for calcium, alkalinity, hardness, and pH fall under low risk
- Average July and August surface water temperature (29.8 °C) has little impact

Location: Lake is on the Neches River and approximately 15 miles southwest of Tyler, Texas.

River Basin: Neches River Basin

TCEQ Segment ID: 0605

Conservation Pool Area: 22,656 acres

Conservation Pool Storage: 373,202 ac-ft

Completion: 1962

Uses: Industrial, recreational, and municipal uses

Number of Sampling Locations: 13

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	2.4	14.0	19.1	18.9	14
Alkalinity, Total	mg/L CaCo3	21.5	32.0	34.2	50.5	226
Hardness, Total	mg/L CaCo3	23.4	37.0	37.0	50.6	2
pH		6.7	7.3	7.4	8.5	1670

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	20.2 (142)	8.5 (142)
	>1-6	19.5 (243)	8 (243)
	>6-13	17.8 (114)	6.7 (114)
Summer	0-1	29.9 (162)	7 (162)
	>1-6	29 (310)	4.9 (310)
	>6-13	26.1 (151)	1.6 (151)
Fall	0-1	22.7 (153)	7.8 (152)
	>1-6	22.2 (262)	5.9 (262)
	>6-13	21.3 (115)	4.7 (115)
Winter	0-1	10.5 (132)	10.2 (133)
	>1-6	10.2 (228)	10.1 (232)
	>6-13	9.9 (108)	9.9 (108)

Figure 5-18

Lake Risk Assessment Summary: Lake Ray Hubbard

Overall Risk Rating: High
– Moderate to high risk levels of calcium, alkalinity, and hardness
– Majority of moderate risk levels are near high risk level boundary
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (29.5 °C) has little impact

Location: Lake is on the East Fork of the Trinity River and about 15 miles east of Dallas, Texas.

River Basin: Trinity

TCEQ Segment ID: 0820

Conservation Pool Area: 20,963 acres

Conservation Pool Storage: 452,040 ac-ft

Completion: 1969

Uses: Water supply, recreation, hydroelectric power generation

Number of Sampling Locations: 6

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	30.0	36.4	37.5	46.4	152
Alkalinity, Total	mg/L CaCo3	75.1	91.0	93.8	115.9	152
Hardness, Total	mg/L CaCo3	95.0	123.0	125.2	158.4	129
pH		7.5	8.1	8.0	8.4	696

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.1 (146)	9.7 (149)
	>1-6	11.1 (18)	10.5 (18)
	>6-13	10.2 (11)	10.2 (11)
Summer	0-1	29 (129)	8 (129)
	>1-6	29.4 (40)	5.7 (40)
	>6-13	27.7 (34)	1.4 (34)
Fall	0-1	22.1 (122)	8.3 (118)
	>1-6	17 (24)	8.1 (24)
	>6-13	17.1 (15)	7.5 (15)
Winter	0-1	9.4 (118)	11.3 (119)
	>1-6	8.6 (21)	10.5 (21)
	>6-13	8.2 (15)	10.5 (15)

Figure 5-19

Lake Risk Assessment Summary: Lake Tawakoni

Overall Risk Rating: High
- Moderate levels of calcium, alkalinity, and hardness for most values
- Calcium, alkalinity, and pH when combined support a high risk.
- Additional sampling recommended for calcium to confirm estimated values.
- Average July and August surface water temperature (29.9°C) has little impact

Location: Lake is on the Sabine River, and approximately 50 miles east of Dallas, Texas.

River Basin: Sabine River Basin

TCEQ Segment ID: 0507

Conservation Pool Area: 37,879 acres

Conservation Pool Storage: 888,137 ac-ft

Completion: 1960

Uses: Municipal, industrial, and irrigation purposes

Number of Sampling Locations: 8

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	24.0	28.0	28.5	32.0	321
Alkalinity, Total	mg/L CaCo3	60.0	70.0	71.3	80.0	321
Hardness, Total	mg/L CaCo3	60.0	69.0	73.4	88.0	323
pH		7.4	8.0	8.0	8.8	2307

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.5 (220)	9.2 (220)
	>1-6	17.8 (231)	8.5 (231)
	>6-12	16.8 (126)	8.1 (126)
	>12-16.5	15.5 (47)	6.3 (47)
Summer	0-1	29.2 (209)	8.2 (209)
	>1-6	28.9 (217)	6 (222)
	>6-12	26.8 (114)	2.8 (116)
	>12-16.5	22.6 (42)	0.6 (43)
Fall	0-1	22.1 (208)	8 (208)
	>1-6	22.1 (207)	7.2 (207)
	>6-12	21.8 (98)	5.8 (98)
	>12-16.5	21.6 (35)	3.5 (35)
Winter	0-1	9.2 (212)	11 (212)
	>1-6	8.8 (206)	10.8 (206)
	>6-12	8.6 (96)	10.8 (96)
	>12-16.5	9.2 (31)	10.2 (31)

Location: Lake is on the East Fork of the Trinity River located 3 miles east of Wylie, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0821

Conservation Pool Area: 21,400 acres

Conservation Pool Storage: 380,000 ac-ft

Completion: 1953

Uses: Flood control, water supply, recreation, industrial

Number of Sampling Locations: 8

Figure 5-20
Lake Risk Assessment Summary: Lavon Lake

Overall Risk Rating: High
– High levels of calcium, alkalinity, and hardness
–Average July and August surface water temperature (29.5 °C) has little impact

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	39.7	47.5	47.2	51.4	64
Alkalinity, Total	mg/L CaCo3	87.9	109.5	112.1	138.2	152
Hardness, Total	mg/L CaCo3	130.0	163.0	155.5	185.0	11
pH		7.6	8.0	8.0	8.3	1096

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.6 (206)	9 (207)
	>1-6	17.8 (164)	8.5 (164)
	>6-12	17.3 (134)	8.4 (134)
	>12-18	16.9 (108)	8.3 (108)
	>18-24	16.5 (77)	8.1 (77)
	>24-30	16.6 (99)	7.9 (99)
Summer	0-1	28.6 (266)	7.8 (266)
	>1-6	28.5 (248)	6.9 (250)
	>6-12	28.1 (162)	6.8 (163)
	>12-18	28 (121)	6.5 (121)
	>18-24	27.6 (80)	5.8 (80)
	>24-30	27.1 (101)	4.5 (101)
Fall	0-1	21.9 (244)	9 (257)
	>1-6	21.7 (221)	8.2 (250)
	>6-12	20.9 (142)	8 (153)
	>12-18	21.3 (116)	7.5 (128)
	>18-24	21 (75)	7.2 (82)
	>24-30	21.3 (81)	6.5 (90)
Winter	0-1	9.5 (197)	11.6 (197)
	>1-6	8.8 (170)	10.9 (170)
	>6-12	8.7 (135)	10.7 (135)
	>12-18	8.7 (111)	10.6 (111)
	>18-24	8.6 (78)	10.6 (78)
	>24-30	8.6 (76)	10.3 (76)

Figure 5-21

Lake Risk Assessment Summary: Lewisville Lake

Overall Risk Rating: High

- High risk levels of calcium, alkalinity, and hardness
- Additional sampling recommended for calcium to confirm estimated values
- Average July and August surface water temperature (28.6 °C) has little impact

Location: Lake is on the Elm Fork of the Trinity River, near the City of Lewisville in Denton County, Texas.

River Basin: Trinity River Basin

TCEQ Segment ID: 0823

Conservation Pool Area: 29,592 acres

Conservation Pool Storage: 640,986 ac-ft

Completion: 1954

Uses: Flood control, water conservation, recreation

Number of Sampling Locations: 11

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	35.0	41.0	40.7	46.0	96
Alkalinity, Total	mg/L CaCo3	87.5	102.5	101.7	115.0	96
Hardness, Total	mg/L CaCo3	103.0	120.0	125.7	163.0	96
pH		7.4	8.1	8.0	8.5	552

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.5 (120)	9.3 (120)
Summer	0-1	27.9 (217)	6 (217)
	>1-6	28.8 (40)	5.9 (40)
	>6-12	26.4 (30)	1 (30)
	>12-18	22.8 (16)	0.3 (16)
Fall	0-1	22.4 (95)	8 (92)
Winter	0-1	9.8 (120)	11 (120)

Figure 5-22

Lake Risk Assessment Summary: Ray Roberts Lake

Overall Risk Rating: High
– High risk levels of calcium
–Moderate to high levels of alkalinity, hardness, and pH
–Additional sampling recommended for calcium to confirm estimated values
–Average July and August surface water temperature (29.3 °C) has little impact

Location: Lake is on the Elm Fork of the Trinity River and about 10 miles north of Denton, Texas.

River Basin: Trinity

TCEQ Segment ID: 0840

Conservation Pool Area: 29,350 acres

Conservation Pool Storage: 749,200 acre-feet

Completion: 1987

Uses: Water supply, recreation

Number of Sampling Locations: 13

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	26.0	40.0	38.5	45.6	160
Alkalinity, Total	mg/L CaCo3	65.0	100.0	95.6	114.0	160
Hardness, Total	mg/L CaCo3	88.0	111.0	119.0	160.7	144
pH		7.5	8.0	8.0	8.5	950

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.2 (178)	9.3 (176)
	>1-6	21.4 (20)	7.8 (20)
Summer	0-1	28.9 (207)	6.7 (207)
	>1-6	29.7 (71)	5.8 (69)
	>6-12	28 (35)	2.5 (34)
	>12-18	22.4 (18)	0.3 (18)
Fall	0-1	22.5 (168)	7.5 (166)
	>1-6	22.3 (27)	7.3 (27)
	>6-12	20.1 (17)	7.7 (17)
Winter	0-1	9.3 (162)	11.1 (161)
	>1-6	5.9 (10)	10.6 (10)

Figure 5-23

Lake Risk Assessment Summary: Richland-Chambers Reservoir

Overall Risk Rating: High
– Calcium, alkalinity, hardness, and pH in upper ranges of moderate risk
– 90th percentile of all parameter values at high risk levels
–Average July and August surface water temperature (29.5 °C) has little impact

Location: Lake is on Richland and Chambers creeks and about 8 miles east of Corsicana, Texas.

River Basin: Trinity

TCEQ Segment ID: 0836

Conservation Pool Area: 43,384 acres

Conservation Pool Storage: 1,112,763ac-ft

Completion: 1987

Uses: Water supply, recreation

Number of Sampling Locations: 15

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (total)	mg/L Ca	29.2	36.6	36.3	42.9	192
Alkalinity, Total	mg/L CaCo3	82.2	95.9	96.5	109.9	396
Hardness, Total	mg/L CaCo3	85.1	95.9	97.3	110.7	4
pH		7.5	8.1	8.1	8.6	3278

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	15.9 (130)	9.7 (130)
	>1-6	15.5 (306)	9.3 (306)
	>6-12	15.2 (299)	8 (299)
	>12-17	13.4 (63)	7.7 (63)
Summer	0-1	28.7 (217)	8 (219)
	>1-6	28 (348)	7.1 (348)
	>6-12	25.4 (346)	2.6 (346)
	>12-17	21.1 (75)	0.5 (75)
Fall	0-1	26.5 (195)	7.6 (193)
	>1-6	25.5 (307)	6.3 (302)
	>6-12	24.6 (256)	4.3 (250)
	>12-17	22.2 (39)	1.5 (39)
Winter	0-1	11.3 (114)	10.7 (114)
	>1-6	11.3 (270)	10.3 (270)
	>6-12	11.3 (262)	10 (262)
	>12-17	12.4 (49)	9.5 (49)

Figure 5-24

Lake Risk Assessment Summary: Sam Rayburn Reservoir

Overall Risk Rating: Low
- Calcium is below the 12 mg/L needed to support zebra mussels
- Average July and August surface water temperature (30.5 °C) has little impact

Location: Lake is on the Angelina River and about 10 miles northwest of Jasper, Texas.

River Basin: Neches

TCEQ Segment ID: 0610

Conservation Pool Area: 114,500 acres

Conservation Pool Storage: 1,446,500 ac-ft

Completion: 1965

Uses: Flood control, water supply, recreation, hydroelectric power generation

Number of Sampling Locations: 15

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	5.5	6.9	6.9	8.7	112
Alkalinity, Total	mg/L CaCo3	14.7	22.0	23.1	32.0	208
Hardness, Total	mg/L CaCo3	28.0	33.0	32.3	34.0	27
pH		6.7	7.3	7.3	7.9	2715

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	18.2 (252)	9.1 (252)
	>1-6	14.9 (221)	8.7 (221)
	>6-12	14.1 (175)	8.7 (175)
	>12-18	13.3 (118)	8.3 (118)
	>18-26	13.2 (15)	7.7 (15)
Summer	0-1	29.8 (234)	7.5 (214)
	>1-6	28.1 (220)	5.3 (205)
	>6-12	25.9 (158)	3.2 (140)
	>12-18	21.1 (103)	0.9 (90)
	>18-26	19.1 (11)	1 (11)
Fall	0-1	24.3 (221)	7.6 (217)
	>1-6	24.5 (201)	6.3 (200)
	>6-12	25.2 (140)	5.4 (140)
	>12-18	22.4 (73)	2.9 (73)
Winter	0-1	11.8 (126)	9.9 (126)
	>1-6	11.2 (212)	9.8 (212)
	>6-12	12.2 (152)	9.6 (152)
	>12-18	12.1 (80)	9.3 (80)
	>18-26	9 (10)	10.8 (10)

Figure 5-25
Lake Risk Assessment Summary: Toledo Bend Reservoir

Overall Risk Rating: Low
–Calcium, alkalinity, hardness and pH are within the low risk and would not support a viable population.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (30.9 °C) has little impact

Location: Lake is on the Sabine River on the Texas and Louisiana border and about 80 miles northeast of Beaumont, Texas.

River Basin: Sabine

TCEQ Segment ID: 0504

Conservation Pool Area: 181,600 acres

Conservation Pool Storage: 4,477,000 ac-ft

Completion: mid-1960's

Uses: Water supply, recreation, hydroelectric power generation

Number of Sampling Locations: 14

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium*	mg/L Ca	7.8	12.0	11.1	16.0	545
Alkalinity, Total	mg/L CaCo3	19.4	30.0	27.8	40.0	545
Hardness, Total	mg/L CaCo3	28.0	40.0	40.6	56.0	558
pH		6.5	7.2	7.2	7.9	4473

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	20.3 (346)	8.3 (346)
	>1-6	19.3 (526)	7.2 (527)
	>6-12	17.7 (191)	6.3 (191)
	>12-18	15.7 (96)	5.7 (96)
	>18-24	13.9 (52)	4.4 (52)
	>24-29	12.5 (18)	4.2 (18)
Summer	0-1	30.3 (290)	6.8 (295)
	>1-6	29.1 (478)	4.5 (486)
	>6-12	26.5 (169)	2.1 (174)
	>12-18	20 (74)	0.6 (77)
	>18-24	16.7 (43)	0.4 (44)
	>24-29	15.1 (20)	0.4 (20)
Fall	0-1	23.8 (311)	7.6 (312)
	>1-6	23.5 (489)	6.4 (489)
	>6-12	23.2 (168)	4.5 (168)
	>12-18	20.1 (88)	3.7 (88)
	>18-24	18.4 (46)	2.7 (46)
	>24-29	16.1 (19)	0.9 (19)
Winter	0-1	11.4 (333)	9.8 (330)
	>1-6	11 (440)	9.7 (433)
	>6-12	11 (159)	9.6 (156)
	>12-18	10.9 (81)	9.6 (79)
	>18-24	11 (45)	9.4 (44)

Figure 5-26

Lake Risk Assessment Summary: Wright Patman Lake

Overall Risk Rating: Moderate
- Calcium levels in upper ranges of low risk category
- Moderate levels for a majority of alkalinity and hardness values
- Low to high risk levels for pH
- Average July and August surface water temperature (30.5 °C) has little impact

Location: Lake is on the Sulphur River and about 11 miles southwest of Texarkana, Texas.

River Basin: Sulphur River Basin

TCEQ Segment ID: 0302

Conservation Pool Area: 20,300 acres

Conservation Pool Storage: 90,000 ac-ft

Completion: 1956

Uses: Flood control, municipal water supply

Number of Sampling Locations: 13

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	18.3	26.5	26.4	33.8	80
Alkalinity, Total	mg/L CaCo3	47.0	69.0	69.2	91.7	222
Hardness, Total	mg/L CaCo3	61.3	82.0	85.1	100.0	72
pH		6.9	7.7	7.8	8.7	2293

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	23.4 (212)	8.2 (212)
	>1-6	22.2 (309)	6.2 (309)
	>6-10	22.7 (23)	2 (23)
Summer	0-1	30 (344)	6.5 (345)
	>1-6	28.9 (514)	3.7 (517)
	>6-10	26.1 (21)	1.8 (21)
Fall	0-1	19.4 (175)	8.8 (176)
	>1-6	19.2 (207)	6.7 (210)
	>6-10	16.1 (14)	6.1 (14)
Winter	0-1	9.8 (203)	10.9 (203)
	>1-6	9.1 (254)	10.3 (254)
	>6-10	8.5 (26)	10.2 (26)

5.1 LAKE/RESERVOIR RISK ASSESSMENT SUMMARY

Table 5-1 shows a summary of lakes and their corresponding risks. Figure 5-27 shows these risks on a map. Of the lakes assessed, ones located in the Trinity River Basin are within the high risk category with the exception of Cedar Creek which is moderate risk. Lakes to the east of the Trinity River Basin tend to be low to moderate risk with the exception of Jim Chapman and Tawakoni which are both high risk. In the San Jacinto River Basin, Lake Conroe is high risk and Lake Houston is moderate risk.

Table 5-1- Reservoir/ Lake Risk Assessment Summary

Water Source	Risk
B.A. Steinhagen Lake	Low
Bardwell Lake	High
Benbrook Lake	High
Cedar Creek Reservoir	Moderate
Eagle Mountain Lake	High
Grapevine Lake	High
Jim Chapman Lake (Cooper)	High
Joe Pool Lake	High
Lake Arlington	High
Lake Bonham	Moderate
Lake Bridgeport	High
Lake Conroe	High
Lake Fork Reservoir	Low
Lake Houston	Moderate
Lake Livingston	High
Lake O' The Pines	Low
Lake Palestine	Low
Lake Ray Hubbard	High
Lake Tawakoni	High
Lavon Lake	High
Lewisville Lake	High
Ray Roberts Lake	High
Richland-Chambers Reservoir	High
Sam Rayburn Reservoir	Low
Toledo Bend Reservoir	Low
Wright Patman Lake	Moderate

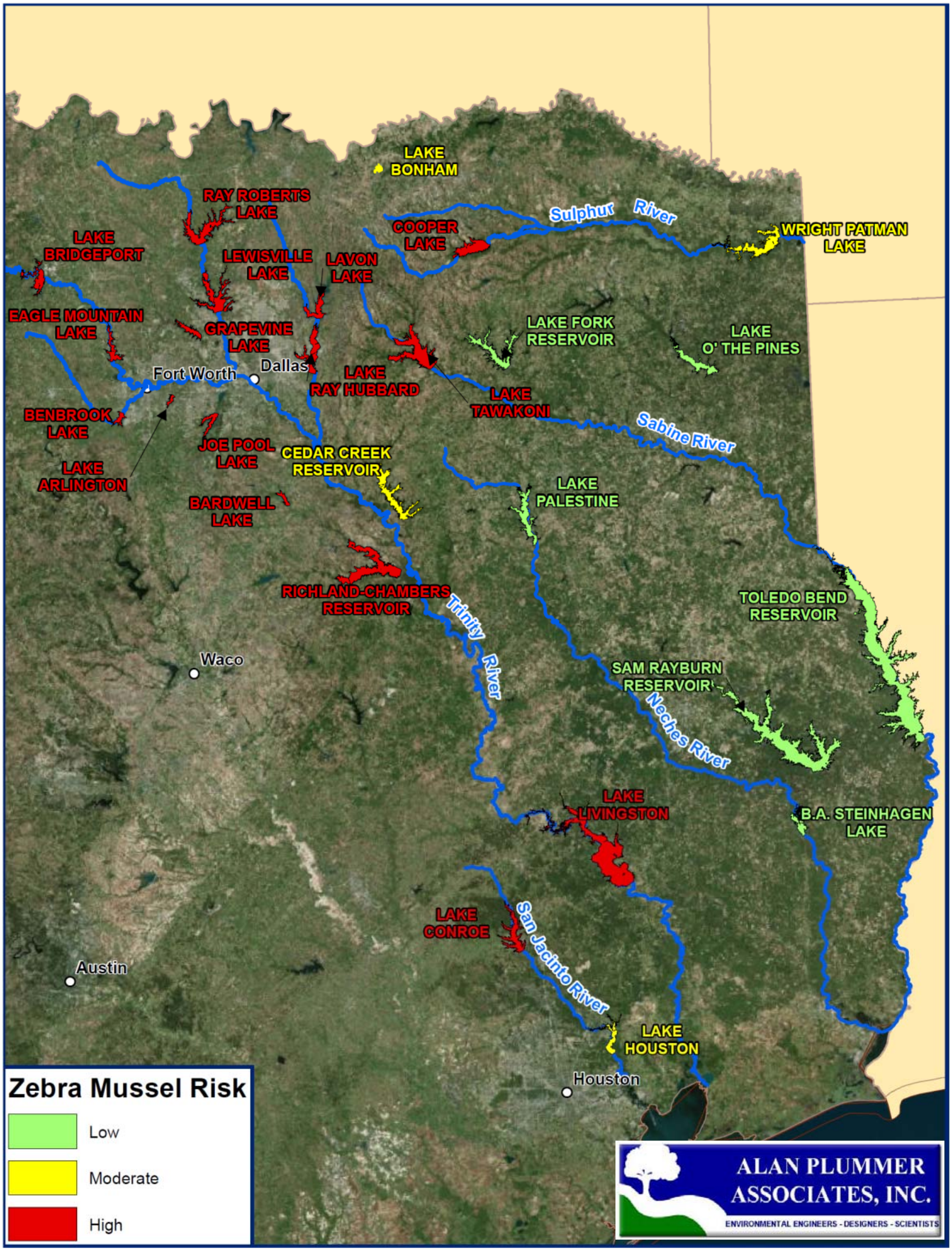

Figure 5-27- Summary Map of Risk Assessment Results

6 Rivers

Another mode of zebra mussel transport is the natural connection of water sources by rivers, creeks or streams. Stream connectivity contributes to downstream dispersal of zebra mussels (Johnson et al., 2006). Therefore, there is concern over the ability of zebra mussels to invade rivers connected to infested water sources, to sustain problematic populations, and subsequently to infest downstream water. Some of the concern is directed at the effects mussels will have on intake structures as well as the ability to transport mussels from rivers to adjacent water sources. The first step in assessing the risk to river segments is to determine whether reproducing and viable zebra mussel populations could be sustained.

River systems differ from lakes in that they require a constant influx of zebra mussels to sustain viable populations. As addressed in Section 3.3, researchers have determined that lakes as far as 15 km downstream from infested water sources have high probability of being inhabited by zebra mussels (Kraft et al., 2002)). Rivers are continuously moving with varying depths, velocities, cross-sections, and temperatures. Alexander et al. (1994) states that it is important to consider that the environmental conditions of lakes and rivers are sufficiently different and suggests that greater thermal mixing and higher sediment loads of rivers are two abiotic differences that should be considered when determining the sustainability of zebra mussels.

In addition to the water quality parameters used in the lake assessments, turbidity and total suspended solids (TSS) may also need to be considered in river assessments. Turbidity levels in a river can depend on the river bed soil type and the quality of inflows from tributaries. Turbidity can increase during storm events or from suspension of river bed sediment during natural flows. Mackie and Claudi (2010) suggest upper limits for zebra mussel survival of 96 mg/L (TSS) or 80 Nephelometric Turbidity Units (NTU), if the turbidity is caused mainly from sediment suspension. However, the upper limit of turbidity is not well documented and requires additional research before any decisive conclusions can be made.

When considering turbidity and TSS as limiting factors, it is important to understand what types of particles (i.e. organic or inorganic) make up the turbidity in the water. Sediment in the water column can affect zebra mussels in many ways. Alexander, et al. (1994) provides a few potential mechanisms on how high turbidity affects zebra mussels. They state that high concentrations of suspended materials can depress growth rates by overloading the intestines and gills with inorganic solids, interfering with respiration and feeding by fouling water currents passing over gills, or physically impeding gas exchange across cell membranes.

Alexander, et al. (1994) studied the acute effects of turbidity and temperature on zebra mussels. They tested the effect of turbidity on respiration rates of zebra mussels, and found a 40-70% decrease in the oxygen consumption rates when turbidity values were 80-160 NTU. They concluded the most stressful condition for adult zebra mussels was when both temperature and turbidity are high. Chronic effects of turbidity may result in an adaptation of mussels to cope with higher sediment loads. Alexander, et al. (1994) suggests that zebra mussels may depend more on anaerobic respiration to satisfy energy demands during times of higher turbidity, or become more efficient in filtering out indigestible inorganic particles from the gills. However, it is unclear how long they would be able to sustain anaerobic respiration, as some river systems may have highly turbid water a majority of the year.

The significance of turbidity limiting zebra mussel expansion is not well documented. However, some researchers, including those cited above, suggest that turbidity could impact zebra mussel survival. The river risk assessments did not consider turbidity as one of the parameters due to the lack of data available and the unknown composition of the TSS within the river segments. As noted earlier, further research regarding the potential sustainability of populations in rivers would be very beneficial and should consider the impacts of turbidity and TSS.

This assessment considered six segments of the Trinity River extending from North Texas to near Houston, two segments of the Sabine River, and one segment on the Neches River. The segments were assessed separately and water sampling locations were reviewed on the SWQMIS database to determine what locations were available.

6.1 TRINITY RIVER

The Trinity River rises from four branches: East Fork, Elm Fork, West Fork and the Clear Fork. The river flows over 420 miles from the confluence of the Elm Fork and West Fork to the coast, making it the longest river having its entire course within Texas. Six segments were evaluated for the Trinity River, extending from Lewisville Lake south to the Houston area. The risk assessments are shown in Figures 6-1 through 6-6. The segment lengths varied, and were mainly based on the number of sampling points. The composition of the inorganic and organic particles that contribute to the turbidity of the Trinity River was not available for this assessment; therefore, turbidity and total suspended solids were not considered in the assessment. Minimal boat traffic in the Trinity River severely constrains another potential conduit for introduction.

Figure 6-1

River Risk Assessment Summary

Trinity River: Segment 1

Overall Risk Rating: High
– Data were limited to values after the year 2000.
– Low DO values during summer may inhibit zebra mussel survival. Additional sampling is recommended to confirm low DO values are sustained throughout the river segment for a period of time.
–Alkalinity, hardness, and calcium data indicate the segment is at high risk.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (27.4 °C) has little impact

Location: Begins directly below Lewisville Lake Dam and extends downstream to the confluence with Denton Creek.

Reach Name: Elm Fork

River Basin: Trinity River

Segment Length: 12.2 miles

TCEQ Segment ID: 0822

Number of Sampling Locations: 3

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (calculated)	mg/L Ca	37.1	44.0	43.6	49.2	35
Alkalinity, Total	mg/L CaCo3	92.8	110.0	109.0	122.9	35
Hardness, Total	mg/L CaCo3	120.4	139.0	147.7	177.6	35
pH		7.3	7.7	7.7	8.0	217

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.6	17.9 (64)	8.3 (65)
Summer	0-0.6	26.9 (55)	6.6 (49)
Fall	0-0.6	21.9 (54)	7.2 (53)
Winter	0-0.6	11 (55)	10.3 (53)

Figure 6-2

River Risk Assessment Summary

Trinity River: Segment 2

Overall Risk Rating: High
– Data were limited to values after the year 2000.
–Alkalinity, hardness, and calcium data indicate the segment is at high risk.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (29.9 °C) has little impact

Location: Begins near the intersection of the Northwest Highway (Spur 348) in Las Colinas, Texas and extends through Storey Lane near Fishing Hole Lake.

Reach Name: Elm Fork

River Basin: Trinity River

Segment Length: 6.3 miles

TCEQ Segment ID: 0822

Number of Sampling Locations: 5

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (calculated)	mg/L Ca	37.1	43.2	43.7	50.7	29
Alkalinity, Total	mg/L CaCo3	92.8	108.0	109.3	126.8	29
Hardness, Total	mg/L CaCo3	120.2	142.0	145.5	171.6	93
pH		7.5	7.9	7.9	8.4	189

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.3	19.2 (52)	8.6 (50)
Summer	0-0.3	29.5 (46)	7.8 (41)
Fall	0-0.3	22.1 (53)	7.3 (47)
Winter	0-0.3	11.1 (52)	10.1 (48)

Figure 6-3

River Risk Assessment Summary

Trinity River: Segment 3

Overall Risk Rating: High
– Data since 1990 were included to obtain a large enough sample size for this study.
– Only one sample of Total Hardness (TH) was available in the data set. Additional sampling is recommended to confirm the TH values.
– Alkalinity, and calcium data indicate the segment is at high risk.
– Average July and August surface water temperature (29.3 °C) has little impact

Location: Begins just upstream of the intersection of the river with Interstate 20 and extends through Highway 175.

Reach Name: East Fork

River Basin: Trinity River

Segment Length: 10.0 miles

TCEQ Segment ID: 0819

Number of Sampling Locations: 5

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	38.8	47.0	49.7	66.0	109
Alkalinity, Total	mg/L CaCo3	92.1	115.0	116.6	138.0	73
Hardness, Total	mg/L CaCo3	68.0	68.0	68.0	68.0	1
pH		7.4	7.7	7.7	8.0	188

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.38	19.1 (44)	7.8 (44)
Summer	0-0.38	28.1 (69)	5.8 (68)
Fall	0-0.38	21 (37)	6.7 (36)
Winter	0-0.38	11.1 (38)	9.5 (38)

Figure 6-4

River Risk Assessment Summary

Trinity River: Segment 4

Overall Risk Rating: High
– Data from 2000-2011 were evaluated in this study.
– Alkalinity values were limited in the data set, but are considered valid because they fall within the same risk range as calcium and total hardness.
– Calcium, alkalinity, and total hardness data indicate the segment is at high risk.
– Average July and August surface water temperature (29.4 °C) has little impact

Location: Extends both upstream and downstream of the intersection of the river with Highway 31, south of the Village of Rosser, Texas.

Reach Name: Main Stem of Trinity River

River Basin: Trinity River

Segment Length: 9.1 miles

TCEQ Segment ID: 0805

Number of Sampling Locations: 1

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	46.7	53.6	55.9	70.9	62
Alkalinity, Total	mg/L CaCo3	109.1	121.5	121.6	132.8	8
Hardness, Total	mg/L CaCo3	148.0	180.0	189.1	220.8	140
pH		7.6	7.8	7.8	8.1	186

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.3	19.3 (45)	8.7 (44)
Summer	0-0.3	29.1 (56)	7.3 (56)
Fall	0-0.3	23.2 (45)	8 (43)
Winter	0-0.3	12.6 (41)	10.5 (41)

Figure 6-5

River Risk Assessment Summary

Trinity River: Segment 5

Overall Risk Rating: High
– Data from 2000 to 2011 were used in this study.
– Calcium values were limited to 7 samples, but 20 samples were available for the other 3 parameters.
– Calcium, alkalinity, and total hardness data indicate high risk for this segment.
– pH is within the moderate to high risk range and could sustain a viable population.
– Average July and August surface water temperature (30.1 °C) has little impact

Location: Begins just upstream of Highway 85 and extends downstream to the south before the intersection with Highway 287.

Reach Name: Main Stem of Trinity River

River Basin: Trinity River

Segment Length: 53.8 miles

TCEQ Segment ID: 0804 and 0805

Number of Sampling Locations: 3

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	31.4	67.3	56.2	73.7	7
Alkalinity, Total	mg/L CaCo3	113.1	128.5	129.2	149.5	22
Hardness, Total	mg/L CaCo3	153.2	192.0	198.5	239.2	87
pH		7.5	7.9	7.9	8.2	114

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-2	21.1 (28)	8.3 (27)
Summer	0-2	30 (38)	7.3 (29)
Fall	0-2	22.8 (29)	8.1 (28)
Winter	0-2	12.6 (29)	10.5 (28)

Figure 6-6

River Risk Assessment Summary

Trinity River: Segment 6

Overall Risk Rating: High
– Over 100 samples were available for alkalinity and pH.
– Measured calcium values were limited to data from 1990 to 1999.
–Calcium and hardness fall within the high risk for the median, average and 90th percentile. Alkalinity falls in the upper end of the moderate risk category.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (30.6 °C) has little impact

Location: Begins at the Lake Livingston Dam and extends south to Highway 146 near Dayton, Texas.

Reach Name: Main Stem of Trinity River

River Basin: Trinity River

Segment Length: 76 miles

TCEQ Segment ID: 0819

Number of Sampling Locations: 5

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (calculated)	mg/L Ca	29.6	37.2	37.6	44.4	141
Alkalinity, Total	mg/L CaCo3	74.0	93.0	94.1	111.0	141
Hardness, Total	mg/L CaCo3	91.7	113.0	110.7	132.0	68
pH		7.6	8.1	8.1	8.6	484

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-1	20 (76)	9.5 (71)
	>1-6	20.1 (45)	9.5 (45)
	>6-10	18.2 (16)	10.2 (16)
Summer	0-1	29.5 (73)	8.2 (69)
	>1-6	28.4 (20)	7.8 (20)
Fall	0-1	24.6 (86)	8.6 (83)
	>1-6	25.1 (46)	7.7 (46)
	>6-10	25.1 (16)	8.8 (16)
Winter	0-1	13.4 (60)	10.6 (59)
	>1-6	13.4 (36)	10.1 (36)
	>6-10	13.4 (13)	9.6 (13)

6.2 SABINE RIVER

The Sabine River originates with three main branches: Cowleech Fork, Caddo Fork, and South Fork. These three branches join at Lake Tawakoni to form the Sabine River. The river extends 40 miles downstream of the lake where a fourth branch, Lake Fork Creek, connects to the river. The river continues to the southeast, through Toledo Bend Reservoir, and to the south until it empties into Sabine Lake and the Gulf of Mexico. Two segments of the Sabine River were considered in the risk assessment. The first segment is the section of river downstream of Lake Tawakoni to the confluence of Lake Fork Creek. The second segment is the section of river downstream of the Lake Fork Creek confluence with the Sabine River to the city of Gladewater. The risk assessments for the Sabine River are shown in Figures 6-7 and 6-8.

Figure 6-7

River Risk Assessment Summary

Sabine River: Segment 1

Overall Risk Rating: Moderate
– One sampling location (in the middle of this segment) was available and has over 50 samples taken since 2000.
– pH is within the low risk category for all summary values. Data from one sampling point may not be representative of the entire river reach.
– Overall moderate rating is consistent with the evaluation of Lake Tawakoni.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (27.9 °C) has little impact

Location: Begins at the Lake Tawakoni Dam and extends south to the confluence of the Sabine River and Lake Fork Creek.

River Basin: Sabine River

Segment Length: 67 miles

TCEQ Segment ID: 0506

Number of Sampling Locations: 1

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (calculated)	mg/L Ca	13.7	25.2	24.8	34.0	51
Alkalinity, Total	mg/L CaCo3	34.3	63.0	61.9	85.0	51
Hardness, Total	mg/L CaCo3	60.0	84.0	87.1	119.6	52
pH		7.0	7.3	7.3	7.6	103

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.3	17.6 (27)	7.4 (27)
Summer	0-0.3	27.3 (22)	5.2 (22)
Fall	0-0.3	20.1 (27)	6.5 (27)
Winter	0-0.3	8.9 (27)	10 (27)

Figure 6-8

River Risk Assessment Summary

Sabine River: Segment 2

Overall Risk Rating: Low
– Only 2 sampling locations were available due to the proximity of TCEQ regulated outfalls.
– Calcium, alkalinity, and hardness values are lower risk than in the upstream section of this river. This is likely due to the influence of Lake Fork Creek.
– Overall low rating is consistent with the evaluation of Lake Fork Reservoir.
–Additional sampling recommended for calcium to confirm estimated values
– Average July and August surface water temperature (29.6 °C) has little impact

Location: Begins at the confluence of the Sabine River and Lake Fork Creek and extends downstream until reaching the intersection with Highway 271 in the City of Gladewater, Texas.

River Basin: Sabine River

Segment Length: 46 miles

TCEQ Segment ID: 0506

Number of Sampling Locations: 2

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (calculated)	mg/L Ca	8.0	12.0	13.6	20.0	132
Alkalinity, Total	mg/L CaCo3	20.0	30.0	34.0	50.0	132
Hardness, Total	mg/L CaCo3	40.0	56.0	59.0	80.0	152
pH		6.7	7.1	7.1	7.5	273

*Calcium values were estimated using method described in Section 4.1.3

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.3	19.3 (74)	7.7 (72)
Summer	0-0.3	28.9 (62)	6.8 (60)
Fall	0-0.3	20.7 (68)	7.8 (66)
Winter	0-0.3	8.8 (70)	10.7 (70)

6.3 NECHES RIVER

The Neches River begins in Van Zandt County and flows over 400 miles to its mouth on Sabine Lake. The Neches River flows through two major lakes, Lake Palestine and B.A. Steinhagen Lake. The segment considered in this assessment is between these two lakes, extending from the Lake Palestine dam downstream to Texas Highway 21. The risk for Lake Palestine is low as indicated previously in Section 5 of the document. The water quality data for the Neches River is similar to Lake Palestine. The risk assessment is shown in Figure 6-9.

Figure 6-9

River Risk Assessment Summary

Neches River

Overall Risk Rating: Low
– Calcium and alkalinity fall within the low risk range for this river segment.
– Total hardness falls within the low risk
– Overall low rating is consistent with the evaluation of Lake Palestine.
– Average July and August surface water temperature (28.4 °C) has little impact

Location: Begins at the Lake Palestine dam and extends downstream to State Highway 21 just east of the Town of Alto, Texas.

River Basin: Neches River

Segment Length: 82 miles

TCEQ Segment ID: 0604

Number of Sampling Locations: 4

Water Chemistry Risk Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	8.1	10.5	10.4	13.9	66
Alkalinity, Total	mg/L CaCo3	20.5	28.0	28.2	36.5	106
Hardness, Total	mg/L CaCo3	37.0	44.0	45.5	56.0	44
pH		6.7	7.0	7.0	7.4	160

Seasonal Temperature and DO Risk Summary

Season	Water Depth (meters)	Temperature, °C (No. of Samples)	Dissolved Oxygen, mg/L (No. of Samples)
Spring	0-0.3	18.8 (52)	8 (50)
Summer	0-0.3	28.2 (54)	6.3 (53)
Fall	0-0.3	21.4 (46)	7.4 (46)
Winter	0-0.3	10.7 (44)	10.3 (44)

6.4 RIVER ASSESSMENT SUMMARY

All of the river segments that were assessed for the Trinity River were within the high risk category. A map of the Trinity River segments is shown in Figure 6-10 and Sabine and Neches River segments is shown in Figure 6-11. The results of the river assessment are consistent with the lake sources located within the Trinity River watershed. Further research should be conducted to assess the turbidity of the Trinity River and determine the ability of this water quality parameter to impact a zebra mussel infestation. The river assessments for the Sabine and Neches rivers were consistent with the upstream water source risk assessments. Maps of all river segments and sampling locations are provided in Appendix B.

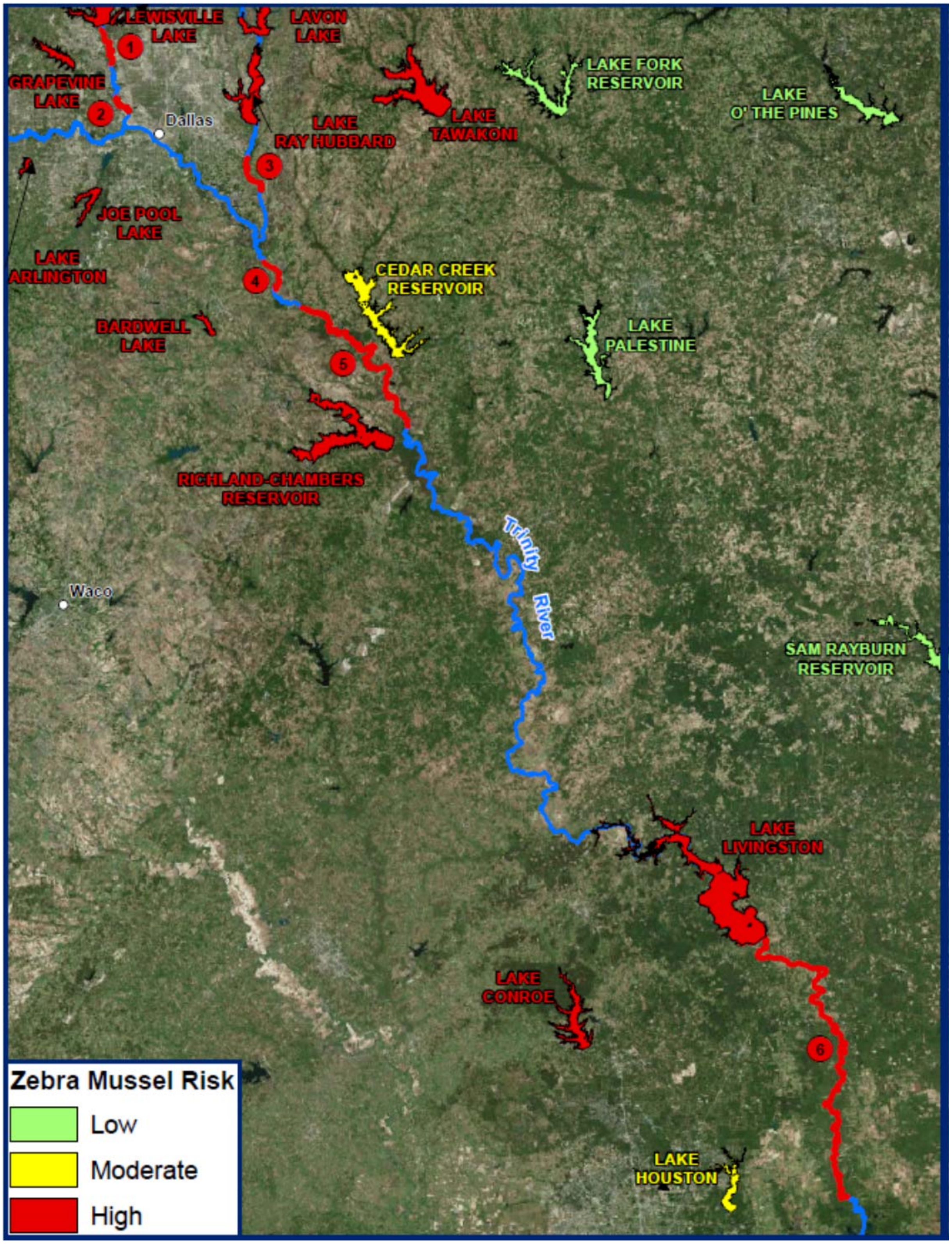

Figure 6-10- Trinity River Assessment Summary

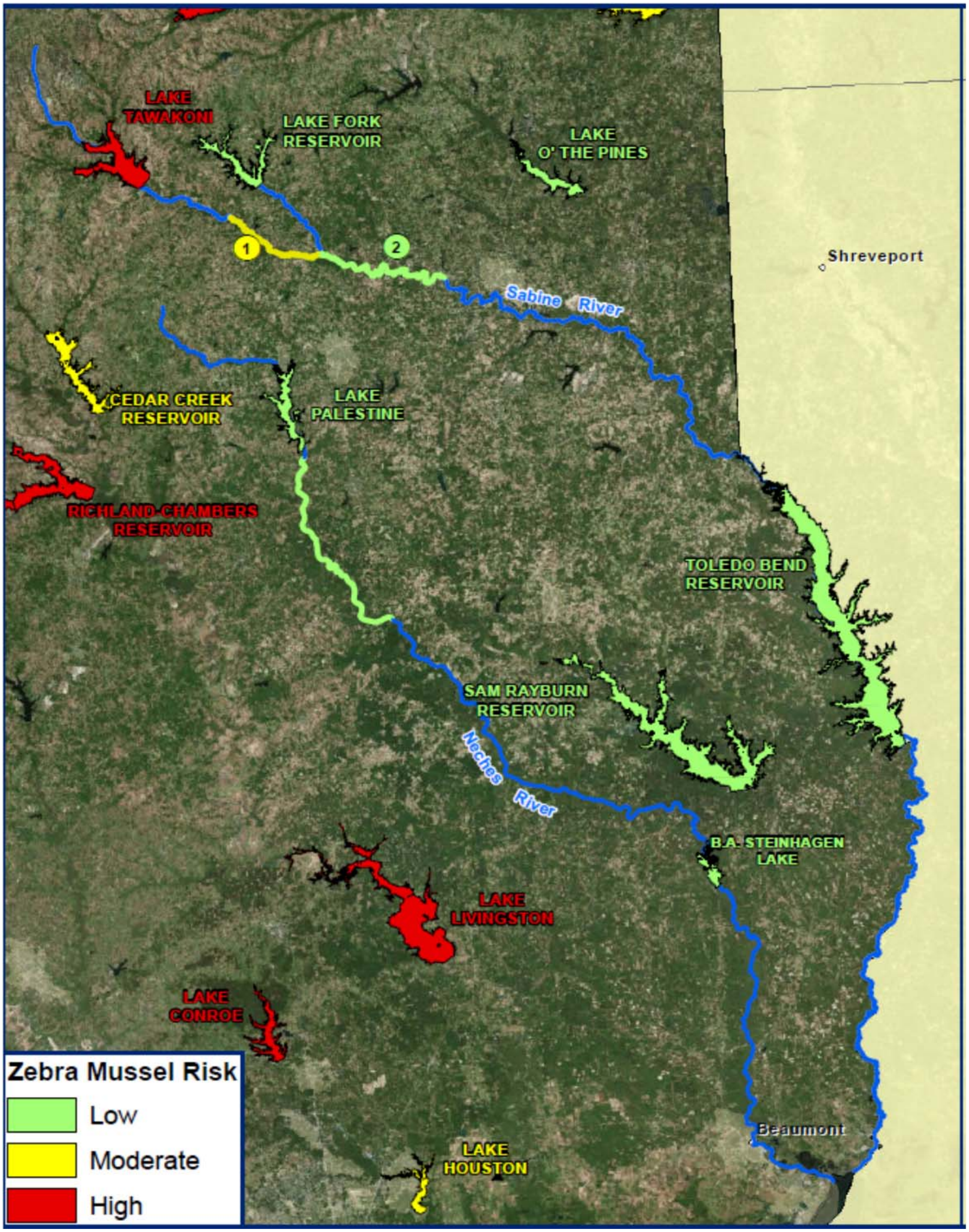

Figure 6-11- Sabine and Neches River Assessment Summary

7 Future Sources

The need for additional water as the population of Texas increases is documented in various studies. One of the proposed solutions is to construct new water supply lakes in the state. There is concern that some potential new lake sites may be susceptible to zebra mussel infestations. To assess this risk, five future lake sites were evaluated using river and creek water quality data collected within the boundary of each proposed lake. However, since some water quality parameters will change subsequent to construction; overall risks were not assigned for these future water sources. These lakes were selected by the participating sponsors and are either recommended or alternative strategies in the latest state water plan. The data provided are summaries of water quality within the boundaries of the lakes and are intended to provide some initial context of current water chemistry conditions.

7.1 GEORGE PARKHOUSE (NORTH)

George Parkhouse (North) is proposed to be located on the North Sulphur River approximately 85 miles northeast of Dallas. Appendix C shows the sample locations for George Parkhouse (North). Water quality data were obtained from the North Sulphur River and adjacent creeks within the proposed boundary of the future lake. Table 7-1 shows the water quality summary for the future George Parkhouse Lake (North).

Table 7-1- George Parkhouse Lake (North) Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	49.2	73.5	76.4	99.8	52
Alkalinity, Total	mg/L CaCo3	81.0	130.0	132.4	182.4	75
Hardness, Total	mg/L CaCo3	100.2	117.0	117.0	133.8	2
pH		7.4	7.9	7.9	8.2	172

7.2 GEORGE PARKHOUSE (SOUTH)

George Parkhouse (South) is proposed to be located downstream of Jim Chapman Lake on the South Sulphur River. Appendix C shows the sample locations for George Parkhouse (South). Water quality data were obtained from the South Sulphur River and adjacent creeks within the proposed boundary of the future lake. Hardness values were not available for sampling points within the lake. Table 7-2 shows the water quality summary for the future George Parkhouse Lake (South).

Table 7-2- George Parkhouse Lake (South) Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	2.2	26.1	23.5	35.0	12
Alkalinity, Total	mg/L CaCo3	68.0	86.0	85.3	101.7	44
Hardness, Total	mg/L CaCo3					
pH		7.3	7.6	7.6	8.0	57

7.3 LAKE COLUMBIA

Lake Columbia is proposed to be located fifteen miles southeast of Tyler on the Angelina River. Appendix C shows the sampling locations. Water quality data were obtained from creeks within the proposed boundary of the future lake. Table 7-3 shows the water quality summary for the river and creeks within the future Lake Columbia boundary. Note that calcium, alkalinity and hardness values were limited to fewer than ten samples.

Table 7-3- Lake Columbia Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	14.2	15.0	15.1	16.1	3
Alkalinity, Total	mg/L CaCo3	18.8	36.0	39.6	65.7	8
Hardness, Total	mg/L CaCo3	47.0	57.4	55.5	62.0	6
pH		6.6	7.1	7.1	7.7	88

7.4 MARVIN NICHOLS RESERVOIR

Marvin Nichols Reservoir is proposed to be located downstream of the confluence of the north and south Sulphur River approximately fifteen miles north of Mt. Pleasant. Appendix C shows the sampling locations that were considered in the summary. Table 7-4 shows the water quality summary. Water quality data were obtained from the Sulphur River and adjacent creeks within the proposed boundary of the future lake.

Table 7-4- Marvin Nichols Reservoir Summary

Water Quality Parameter	Unit	10th Percentile	Median	Average	90th Percentile	Sample Size
Calcium (dissolved)	mg/L Ca	25.5	46.9	44.8	63.6	13
Alkalinity, Total	mg/L CaCo3	85.6	127.0	125.9	163.8	39
Hardness, Total	mg/L CaCo3	107.6	170.0	150.6	184.0	7
pH		7.3	7.7	7.7	8.1	71

7.5 LOWER BOIS D'ARC CREEK RESERVOIR

Lower Bois d'Arc Creek reservoir is proposed to be downstream of Lake Bonham approximately 10 miles southeast of Ivanhoe on Bois d'Arc Creek. The data used in the risk assessment included four points along Bois d'Arc Creek within the limits of the proposed lake boundaries. The data used in the assessment were from 2005-2012. Appendix C shows the sampling locations that were considered in the summary. Table 7-5 shows the water quality summary.

Table 7-5- Lower Bois d'Arc Creek Reservoir Summary

Water Quality Parameter	Unit	10^{th} Percentile	Median	Average	90^{th} Percentile	Sample Size
Calcium (calculated)	mg/L Ca	53.5	70.4	75.0	105.4	39
Alkalinity, Total	mg/L $CaCo_3$	124.9	182.5	184.3	270.0	52
Hardness, Total	mg/L $CaCo_3$	148.4	184.0	186.0	227.2	15
pH		7.5	7.9	7.9	8.2	58

8 Wetlands

Another potential vector for zebra mussel invasion is transport through wetlands connected to infested waters or subject to inundation during high-flow events in adjacent rivers. Limited research examining downstream dispersal of zebra mussels has mainly considered movement in rivers and streams, but generally disregarded connected wetlands (Bodamer and Bossenbroek, 2008). Wetlands could serve as another conduit of infestation or as a natural filter preventing the further movement of mussels. Bodamer and Bossenbroek (2008) completed an assessment of four natural wetlands in Michigan that were connected to an infested lake. Zebra mussel populations throughout the wetlands were studied with routine sampling taking place from May to August 2006. During sampling, veligers were rarely found more than 1 kilometer downstream from where vegetation began. One of the four sample sites experienced a low dissolved oxygen concentration of 0.63 mg/L and a pH above the tolerance range. Results of the study indicate that vegetation densities were positively related to rate of veliger density decline for each site, but there was no relationship between water velocity and rate of veliger decline.

Bodamer and Bossenbroek (2008) suggest that zebra mussels may be restricted in wetlands because of large fluctuations in abiotic factors resulting in unsuitable conditions for zebra mussel survival. In addition, aquatic macrophytes can restrict veliger dispersal through reduced water velocity and particle retention (Miller and Hayes, 1997). Furthermore, the process of filter feeding by zebra mussels may also reduce the number of veligers (Miller and Hays, 1997).

The research cited above focused on natural wetlands. It is unclear whether similar results would be observed in constructed wetlands. Although constructed wetlands, built in the flood plain, consist of similar soil types and plant species, there may be some disparity in the hydrologic features of the two types of wetlands. In constructed wetlands designed for treatment, flow rates and water velocities are generally higher than experienced in natural wetlands. Although Bodamer and Bossenbroek (2008) suggest that vegetation density impacts veliger dispersal rather than water velocity, further research is needed before parallel conclusions can be drawn between natural and constructed wetlands.

Two constructed wetlands in the Trinity River Basin were assessed. The two constructed wetland systems summarized below use water pumped out of the East Fork and the Trinity River, which are not currently infested but may be at high risk as previously indicated in the river assessment. The wetlands assessments provide summaries of the water quality parameters in the wetlands which could indicate whether conditions would be suitable for zebra mussel survival or transport.

8.1 EAST FORK WETLAND

East Fork Wetland is located in north Texas along the East Fork of the Trinity River in Kaufman County. The 1,840 acre wetland is operated by North Texas Municipal Water District (NTMWD). The constructed wetland is used to remove excess nutrients and sediment from raw East Fork water before pumping it into Lavon Lake. Water is pumped out of the East Fork to a splitter box where it is distributed among several sedimentation basins. From there it flows through different wetland trains for treatment before collecting at the conveyance pump station to be pumped to Lavon Lake. Table 8-1 shows a summary of the water quality data for the East Fork Wetland, collected from 2009-2012. Data for calcium, alkalinity and hardness were unavailable. Table 8-2 shows the TSS values for the sampling locations in the East Fork Wetland. No data were available for TSS in the river at this location. The water quality data were collected at specific structures in the wetland and may not reflect the water quality within the wetland cells. From the limited data available, summertime temperature and dissolved oxygen appear to be the more significant parameters impacting the survivability of zebra mussels. Continued data collection may provide more conclusive results in the future.

Table 8-1: Seasonal Summary of Water Quality Data for East Fork Wetland (Stations listed are in order from upstream to downstream)

Season	Water Quality Parameter	Units	Splitter Box	W-111	Levee Crossing	Conveyance PS Intake
Spring	Temperature	°C	20.2 (22)	N/A	19.5 (23)	20.1 (24)
	Dissolved Oxygen	mg/L	7.8 (22)	N/A	7 (23)	7.8 (24)
	pH		7.5 (22)	N/A	7.9 (23)	7.9 (24)
Summer	Temperature	°C	29.6 (30)	29.3 (2)	29.3 (27)	30.9 (29)
	Dissolved Oxygen	mg/L	6.9 (30)	8 (2)	4.3 (27)	6.7 (28)
	pH		7.5 (30)	7.4 (2)	7.8 (27)	8.1 (29)
Fall	Temperature	°C	21.5 (29)	24.5 (1)	19.9 (26)	20.7 (29)
	Dissolved Oxygen	mg/L	7.1 (29)	6.5 (1)	6.5 (25)	7.4 (29)
	pH		7.8 (29)	7.5 (1)	8.1 (26)	8.1 (29)
Winter	Temperature	°C	10.7 (15)	N/A	9 (12)	9.1 (16)
	Dissolved Oxygen	mg/L	10.1 (23)	9.8 (3)	10.2 (20)	10.7 (23)
	pH		7.9 (23)	7.9 (3)	8.3 (20)	8.1 (23)

Table 8-2: Summary of TSS for East Fork Wetland

Water Quality Parameter	Units	Splitter Box	W-111	Levee Crossing	Conveyance PS Intake
TSS	mg/L	71.8 (106)	40 (6)	74.1 (98)	47.2 (108)

8.2 RICHLAND-CHAMBERS WETLAND

Richland-Chambers Wetland is located in Navarro County near Richland-Chambers Reservoir. The wetland, operated by Tarrant Regional Water District, is being constructed on Texas Parks and Wildlife Department (TPWD) property in two phases. The second phase is currently under construction, and when complete, the entire wetland will include a total of 21 wetland cells with over 1,700 wetted acres. This wetland is subject to overbank flooding from the Trinity River with potential to bring zebra mussels directly into the wetland.

Table 8-3 shows seasonal summaries for temperature, DO and pH at the pump station. Table 8-4 shows alkalinity, hardness and TSS. TSS was also included in the assessment since TSS data are available for this location in the Trinity River. TSS greater than 96 mg/L may limit the ability of zebra mussels to survive, although as mentioned earlier, it is important to understand the makeup of the TSS in term of organic and inorganic material. As with the East Fork Wetland, summertime temperature and dissolved oxygen may be limiting parameters for zebra mussel survival but additional sampling and data are needed for more conclusive determinations.

Table 8-3: Seasonal Summary of Water Quality Data for Richland-Chambers Wetland

Season	Water Quality Parameter	Units	Pump Station (No. of samples)
Spring	Temperature	°C	22.4 (47)
	Dissolved Oxygen	mg/L	8.1 (47)
	pH		8.2 (47)
Summer	Temperature	°C	30.4 (67)
	Dissolved Oxygen	mg/L	6.9 (67)
	pH		8.1 (67)
Fall	Temperature	°C	21.9 (62)
	Dissolved Oxygen	mg/L	8.4 (61)
	pH		8 (61)
Winter	Temperature	°C	12.3 (71)
	Dissolved Oxygen	mg/L	11 (69)
	pH		8.1 (70)

Table 8-4: Summary of Water Quality Data for Richland-Chambers Wetland

Water Quality Parameter	Unit	Trinity River (No. of samples)
Alkalinity, Total	mg/L CaCo3	99.6 (200)
Hardness, Total	mg/L CaCo3	169.7 (202)
TSS	mg/L	211.7 (202)

9 Facilities at Risk

Zebra mussels not only impact municipal infrastructure, including pipelines and pump stations, but they also create problems for the public by attaching to boat docks and recreational watercraft. It is important to understand how mussels affect infrastructure so control measures can be implemented to protect threatened facilities. The facilities discussed in this section are relevant to the project sponsors, although other types of facilities not addressed may also be at risk. Some of the facilities not discussed below include fire protection systems, strainers, and heat exchangers.

Zebra mussels will attach to almost any material of construction including concrete, carbon steel, and stainless steel (Mackie and Claudi, 2010). Copper, copper alloys, and tin are toxic to mussels (Mackie and Claudi, 2010). Unfortunately, zebra mussels can attach to copper pipes and survive in areas where a protective layer of biofilm has formed. Zebra mussels prefer a hard substrate for attachment although they will attach to plants. Some studies have found that areas where zebra mussel shells accumulated on soft substrates eventually created a hard substrate suitable for settlement. This section will review the types of infrastructure used by project sponsors, and identify areas that are susceptible to problems caused by zebra mussels.

9.1 PUMPS

9.1.1 Trash Racks/ Intake Screens

Trash racks are intended to remove large debris from the flow path in order to protect pump intake screens from damage. Spacing of trash rack bars is greater than intake screen openings since trash racks are designed to only remove large debris and handle impact from large objects. Trash racks and intake screens are susceptible to zebra mussel attachment. The level of infestation may vary spatially over large intake screens due to variations in water velocity across the screen. Some trash racks include automated scrapers that remove debris and prevent a reduction in flow. Depending on the trash rack finger spacing, scrapers also can be used to remove zebra mussels.

Submerged pump intake screens are primarily at risk for zebra mussel attachment since they typically are continually inundated, and contain small grid spacing that can easily be fouled by zebra mussels. Zebra mussels will settle and attach to the intake screens using the byssal threads. Attachment may occur directly to the structure or to other zebra mussels. An infestation can reduce the flow area of the screens, reduce hydraulic capacity, cause pump cavitation, and increase pumping costs. The level of infestation on intake screens depends on many factors including depth, intake velocity and design. In addition, pumps that are not operating continuously are more susceptible to mussel attachment. Intake screens are ideal places for zebra mussel attachment, as flow-through provides a constant supply of nutrients. Figure 9-1 shows an intake screen with zebra mussel attachment.

Figure 9-1- Zebra Mussels Attached to an Intake Screen

Design and layout of intake screens vary depending on application and location. Most submerged cylindrical intake screens are designed to minimize the approach velocity so aquatic life is not affected. Some intakes are designed with air backwashing systems which are normally used for removing debris. These systems use short bursts of air under high pressure to remove debris from the intake screens. The short bursts are capable of removing mussels from the intake screens; however, effectiveness will vary depending on design and location of the airburst system in relation to the intake screen. It is unlikely that backwash systems could remove all of the mussels without additional control measures.

9.1.2 Wet wells

Wet wells are used in pump stations to collect water in a centralized location prior to pumping. Depth and design of wet wells vary, but deep, low-velocity wet wells connected to an infested water source can result in a high risk of zebra mussel infestation. Zebra mussels can attach to the walls of wet wells in areas where they encounter low velocities. Dead shells can be transported into a wet well by water flows and accumulate on the bottom. If shell accumulation is allowed to perpetuate, it can impact performance of the pumps, as large masses of shells may break away, and be subsequently sucked into the pumps. Deep wet wells may not be easily accessible, and removing a large volume of mussels can be costly.

9.1.3 Columns

Pump columns that are periodically idle can create suitable areas for attachment. This is particularly true for vertical turbine pumps, where pump columns remain inundated. There would be limited exchange of nutrients and veligers would have to swim up the pump impellers to inhabit the pump columns. However, some veligers and adults may be captured in the pump column when pumping is ceased and attach to the interior of the pump. When the pumps are restarted, the mussel shells could be captured and crushed, causing damage to components of the pump. During operation, the velocity within the pump column would most likely prevent any attachment of mussels. Idle submersible pumps are also susceptible to zebra mussel attachment.

9.1.4 <u>Cooling water</u>

Water, oil, or grease is typically used to lubricate the line shafting and bowl assembly bearing of vertical turbine pumps. In addition, water is also used to protect the seals and packing rings from damage during operation. Clean or process water is injected under pressure into the tension nut, and forced through the line shaft bearings. If the water used to cool the pump components contains zebra mussel veligers, there is a possibility that mussels may be able to inhabit certain areas. The mussels may be able to attach and grow impacting the internal bearings, seals and packing rings. If the pumps remain idle for some time, and adult mussels inhabit these areas, the shells could damage seals and packing rings when the pumps are restarted.

9.2 PIPELINES

Zebra mussels that attach to the inside of pipelines increase the frictional resistance, and subsequently increase pumping cost. Furthermore, as described before, zebra mussels attached to pipe walls can increase pitting and corrosion rates. Small diameter piping with low flow rates can induce settlement in areas that are inaccessible. Figure 9-2 shows zebra mussel attachment on a large diameter pipeline.

(Source: Mitch Harrison (NTMWD))

Figure 9-2- Zebra Mussels Inside of a Pipeline

Pipelines also contain various types of valves to either control flow, or protect the pipeline during draining and filling. Typical pipeline valves include gate, butterfly, and knife gate valves. Butterfly valves are designed to remain in the flow path of the fluid, and are susceptible to zebra mussel attachment at low velocities, depending on their orientation to the flow path. Gate and knife gate valves are less susceptible to mussel attachment since they are out of the flow path during the fully open position. However, the seals and seats of all valves are suitable for attachment, as are any other small crevices. Pipeline flow brings a continuous supply of nutrients to the mussels.

Air/vacuum valves are designed to allow air into and out of pipelines during draining and filling. They are typically located at high points along the pipeline profile on the crown of the pipe. Clogging air release and air vacuum valves with zebra mussels, and impacting their function, could impact the long term integrity of the pipeline. Zebra mussels on the valve seats could prevent proper sealing and result in leakage.

Long-term pipeline shutdown can increase the density of mussels in the pipeline as veligers settle. Shutdown also exposes intake screens and valve seats to zero flow conditions where mussels can attach or settle. The amount of biofouling will depend on the length of time of the shutdown and the amount of zebra mussels contained in the water. To sustain a viable population within a stagnant pipeline, zebra mussels require food and a minimum dissolved oxygen concentration. If the pipeline remains stagnant for a sustained period of time the zebra mussels trapped inside the pipeline will consume the available food and reduce the dissolved oxygen in the water resulting in eventual mortality. The length of time this takes depends on many factors including the density of zebra mussels, temperature, and water quality.

9.3 WATER TREATMENT PLANTS

With limited storage capacities, water treatment plants (WTP) must operate continuously to ensure constant supplies of treated water. Mussels can impact operations by clogging critical piping, disrupting the treatment process, and potentially causing unacceptable interruption in water service.

Water treatment processes includes many levels of treatment that are lethal to zebra mussels and deter infestation within the plant. Typically, the first few treatment processes in the WTP include some form of flocculation and chemical injection. Flocculation will trap any veligers in the floc blanket, and adult mussels will settle in the basin, removing them from the flow path. In addition, chemical addition to the water following flocculation will provide an additional level of treatment.

One significant problem area can be in the raw water sample ports prior to the treatment process. Many water treatment plant operators report zebra mussel accumulation in the sample ports. However, many plants are designed so the sample ports can be easily removed for cleaning. The frequency of cleaning depends on level of infestation and the distance of the water treatment plant from the infested water source. If a chemical or other form of control is added in an upstream pipeline, the WTP may receive high volumes of mussel shells, depending on the level of accumulation within the pipeline.

9.4 BALANCING RESERVOIRS

Balancing reservoirs are typically constructed to accommodate fluctuations in demand. Balancing reservoirs can consist of elevated reservoirs or ground storage reservoirs. They can be constructed of a variety of materials including steel, concrete, and native soil. The size and layout will vary from system to system. In warmer climates as in Texas, zebra mussels that are born in the spring spawning event will likely reach maturity and be able to reproduce in the fall. Therefore if mussels are transported to a balancing reservoir in the spring and have adequate retention time, it may be possible to create a breeding population in the balancing reservoir that can infest downstream facilities. In addition, veligers can settle and attach to the walls of a balancing reservoir. In an open balancing reservoir similar to a small pond, zebra mussels may attach along the edge within the first few feet of water. The water volume stored in a balancing reservoir can vary significantly over time. Changes in water surface levels may expose mussels to air and subsequent desiccation. This could create an accumulation of shells that would need to be removed.

9.5 CANALS

Canals provide a cost effective method to transport water from point to point where change in topography is favorable. Some canals may be unlined earth structures and others may be concrete or clay lined. At lower velocities, zebra mussels can settle in a canal, potentially reduce hydraulic capacity, and attach to structures further downstream. Zebra mussels can attach to gates and seals that may be used to control flow or adjust water surface elevation, resulting in improper sealing. Canals with turnouts that are equipped with measuring devices to determine the volume of flow are at risk as mussels can cause inaccurate measurements. Furthermore, canals can also provide another conduit for infestation when they connect an infested water source with an uninfested water source.

9.6 GATES

Types of gates include slide gates, downward opening gates, sluice gates, and flap gates. Some gates may remain in the fully open or closed position while others are used to set water surface elevations. Gates provide a flat surface oriented perpendicular to the flow path of water. This surface creates suitable substrate and conditions for zebra mussel attachment. In addition, zebra mussels can attach to the frames of gates that remain open for long periods of time. This can result in improper sealing of the gate when it is closed. Zebra mussels can plug drain holes in horizontal structural beams adding significant amounts of water that must be lifted when the gate is raised (Mackie and Claudi, 2010). If the gates are heavily fouled, automatically operated gates could fail if they are not designed for the additional weight of zebra mussels (Mackie and Claudi, 2010). Zebra mussels can accumulate at the base of downward opening weir gates since the areas behind the gates are subject to low velocities and continuous supplies of food.

9.7 INSTRUMENTATION AND GAUGES

Instrumentation is important for monitoring and controlling equipment. Instruments typically contain small ports that are in the flow path. These ports may not be easily accessible, and can become fouled with zebra mussels. Staff gauges and electronic pressure transmitters are also susceptible to fouling by zebra mussels.

9.8 HYDROELECTRIC POWER PLANTS

Hydroelectric power plants are located on the downstream side of dams, and use head from water to produce electricity. Pressure within the pipeline and turbine will depend on the reservoir depth and penstock location. Figure 9-3 shows a typical layout of a hydroelectric dam.

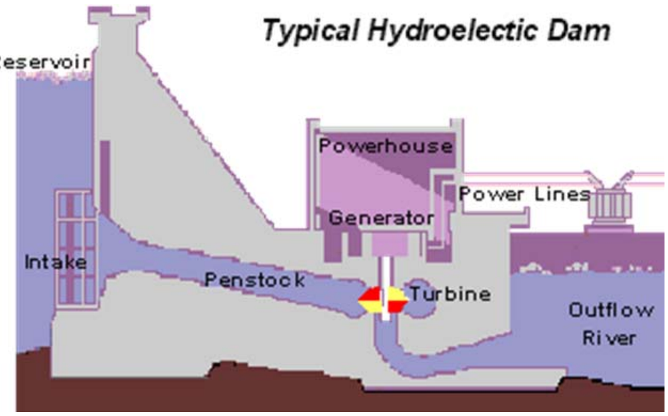

Figure 9-3: Typical Hydroelectric Dam
(Source: USGS)

9.8.1 Turbines

Turbines in hydroelectric power plants produce mechanical energy that is converted to electricity by a generator. Water flows over the turbine blades through wicket gates that spin the shaft in the generator (Figure 9-4). Wicket gates are used to adjust the flow rate through the turbine and can shut off flow for maintenance. Reservoir level and electricity demand determine operation of the hydroelectric power plant. Periods may occur where the turbine is inactive and susceptible to zebra mussel attachment.

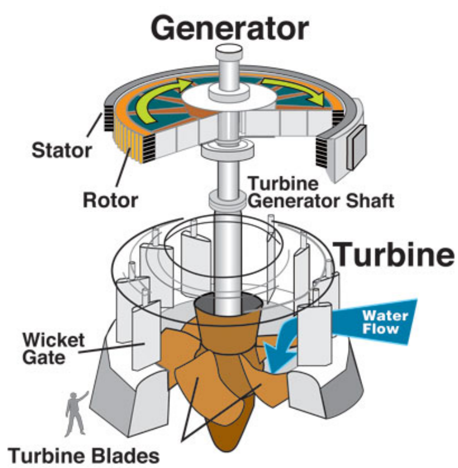

Figure 9-4: Generator Layout
(Source: USGS)

Zebra mussel attachment could impact the turbines in many ways. The most susceptible areas are cooling water ports, generator bearings and generator rotor coolers. During times when the wicket gates are closed, zebra mussels may attach to the outside of the gates, possibly interfering with their ability to open and make precise adjustments to control the flow of water over the turbines. Zebra mussels are unlikely to attach to wicket gates and turbine blades during normal operation due to high water velocity and turbulence.

9.8.2 Penstocks

Penstocks, shown in Figure 9-3, hydraulically connect turbines to the water source and are designed to minimize head loss. During normal operation, penstocks are usually exposed to high pressures and velocities. Most of the risk of mussel attachment is during periods of shutdown. Attachment of mussels could affect the hydraulics, create turbulence within the penstock, and plug dewatering ports.

9.8.3 Gate Tower

Gate towers control the flow of water into penstocks. Gate towers are usually constructed of concrete, with gates at varying heights that can be opened and closed as the water surface the lake fluctuates. Gates are typically stainless steel sluice gates that can remain closed for long periods of time. Zebra mussels can attach to the gates. They can also attach to the inside and outside of concrete structures, which may not be easily accessible for cleaning. Shells may also accumulate in the bottom of the structure. Gate towers also include fixed screens beyond the gates that can get fouled when gates are in the open position.

9.9 MAINTENANCE/ RESEARCH/ RECREATIONAL VESSELS

Any water vessels stored or operated within infested waters are susceptible to effects of zebra mussels. If left untreated, zebra mussels are capable of fouling boat hulls, and causing boat motors to overheat. Level of attachment will depend on many factors including length of time a vessel was stored in infested water, and size of the zebra mussel population. Movement of infested boats from infested to non-infested lakes is a major conduit of infestation.

Juvenile and adult mussels have the ability to attach to different types of substrates including fiberglass, aluminum, wood, and steel. Zebra mussel attachment to boat hulls can decrease fuel efficiency of the motor by increasing drag of the vessel. In addition, byssal threads can damage the finish on a boat. Veligers can be drawn into the boat motor, settle in the engine cooling system, and grow into adults, subsequently blocking intake screens, internal passages, hoses and strainers. Figure 9-5 shows zebra mussels attached to the keel of a boat.

Figure 9-5: Zebra Mussels Attached to the Bottom of a Boat.
(Source: USFWS)

9.10 DOCKS/MARINAS/ACCESS POINTS

Boat docks are susceptible to zebra mussel attachment when submerged in infested water. Zebra mussels will attach to boat docks, possibly reducing the life of the material, and causing a nuisance of shell accumulation. However, sustained low lake levels can expose zebra mussels to the air causing desiccation. Mussel shells may remain attached to the structures even after death. Floating docks and navigational buoys can sink with high densities of zebra mussel attachment. As lake levels drop, zebra mussels on the shoreline can also be exposed. Large accumulation of mussels can be similar to a pile of glass on the shoreline and can create a hazard to swimmers and reduce aesthetic and recreational value of beaches.

Marinas typically contain boat docks, ramps, and large numbers of boats. Marinas provide a threat of infestation due to their potential to house multiple boats in a confined area. Moored boats that have remained in infested water sources also pose a major risk of infestation when they are moved to uninfested waters.

10 Control Methods

There are many control methods and strategies available for dealing with zebra mussels, and no single method or strategy is appropriate for all situations due to physical, environmental, and regulatory factors. Appropriate strategies are dependent on the situation and are often comprised of several methods. The following sections review relevant methods, strategies, and their applications.

10.1 CONTROL METHODS

This section provides summaries of chemical and non-chemical control methods available for zebra mussels. Each summary includes a description of the method, available research, and advantages and disadvantages.

10.1.1 Chemical

Chemical control should be considered for systems where periodic manual cleaning is not effective or in systems where no zebra mussel attachment can be tolerated. Chemicals that are effective for controlling attachment of zebra mussels are widely used for many purposes. However, some of the chemicals can form harmful by-products, or have negative effects on facilities or other aquatic organisms, eliminating them as feasible control options. In addition, adult mussels can detect some treatment chemicals, and close as a defense mechanism for up to two weeks. If chemical treatment is desired, cost, dosage rate, environmental effects, permitting requirements, and desired treatment outcome should all be considered when selecting the appropriate chemical.

10.1.1.1 Chlorine

Chlorine is one of the most effective and popular methods of macro-fouling control. It can be added as chlorine gas, liquid sodium hypochlorite, or solid calcium hypochlorite. A number of raw water parameters influence the effectiveness of chlorine, including organic and inorganic compound concentrations, temperature, and pH. Similar to other oxidants, chlorine reacts rapidly with many other inorganic and organic compounds, making them essentially compete for the oxidant. Therefore, iron, manganese, and organic compounds in the water and in biofilm can interfere with the primary purpose of maintaining a residual concentration in the pipeline to prevent settlement and kill zebra mussels. Some waters may require a higher concentration of chlorine to maintain the required residual to control zebra mussel settlement.

Sodium hypochlorite is commonly used as an alternative to chlorine gas because it does not pose a storage hazard. Sodium hypochlorite is available in different strength solutions. The most common concentrations are 16 percent solution and 12.5 percent solution. The strength of solution degrades over time, and the rate of degradation increases as the initial concentration increases. The initial degradation rate of 16 percent solution is about twice that of 12.5 percent solution.

On-site production of low strength (0.8 percent) sodium hypochlorite is gaining in popularity, but the generators require a significantly larger capital investment than chemical storage and feed facilities required for delivery of 12.5 percent solution. Design and procurement time for hypochlorite generators would also be substantially larger than for bulk delivery of hypochlorite, meaning that bulk delivery could be implemented more quickly than generation facilities.

Chlorine has been used for many years in the treatment of potable water. However, one of the major concerns is formation of disinfection by products (DBP) which include trihalomethanes (THMs) and haloacetic acids (HAAs). THMs are regulated by the Environmental Protection Agency (EPA). The level of THM formation will depend on amount of chlorine that is added, organic material, and number of injection points that are required to maintain chlorine residual in the water. For water systems that already have THM levels near the EPA defined limit, chlorine may not be an option.

Many factors influence the effectiveness of chlorine, and the dose of chlorine required to be lethal to zebra mussels will vary. Veligers are more susceptible to chlorine than adults. In addition to the pH, inorganic and organic nitrogen content and water temperatures will impact the mortality rate of zebra mussels (Mackie and Claudi, 2010). High water temperature increases the metabolic rates of zebra mussels and increases uptake of the chemical (Mackie and Claudi, 2010; Rajagopal et al., 2002). A chlorine concentration of 0.4 mg/L total residual oxidants (TRO) took more than three weeks at low water temperatures to result in 100% mortality, while only two weeks were required at 15°C (Jenner, 1978, Mackie and Claudi, 2010). Rajagopal et al. (2002) studied the mortality patterns on different size groups of zebra mussels. They observed 100% mortality of a 10 millimeter size group exposed to 0.25 mg/L chlorine residual for 1,080 hours, while a 3.0 mg/L concentration took 252 hours to achieve 100% mortality. They concluded that all size groups (between 5 and 20 mm shell length) reached 100% mortality at identical exposure times when exposed to concentrations between 1 and 3 mg/L. It is important to remember that when adult zebra mussels detect the oxidants, they can close and survive for up to two weeks, depending on water temperature and maturity. De-chlorination may be required if water is discharged into a natural water source. As a general rule, a continuous residual of 0.3-0.5 mg/L should be maintained in pipelines to prevent settlement (Renata Claudi, personal communication, October 11, 2011).

There are many advantages and limitations to chlorine as a control option. Advantages are: chlorine residual in the water can prolong disinfection after initial treatment; chlorine works in most raw water systems; it is a very effective treatment method; chlorination systems are simple to construct and maintain; and most water utilities are familiar with their operation. Limitations include: chlorine residual, even at low concentrations, is toxic to aquatic life and could require de-chlorination; chlorine combines with various organic compounds to form THMs; cost of treatment varies with water quality rather than with the degree of zebra mussel fouling; and there are safety problems with transport and storage of liquefied chlorine.

10.1.1.2 Chlorine Dioxide

Chlorine Dioxide is used in water treatment plants for disinfection; oxidation of iron, manganese, and sulfides; taste and odor control; and minimization of nitrification. Chlorine dioxide is a yellow-green gas that is formed by a reaction between chlorine gas and sodium chlorite. There are several proprietary system arrangements that can be utilized for on-site chlorine dioxide generation. The most common systems that do not rely on the use of pressurized chlorine gas are as follows:

- Three-chemical system utilizing sodium hypochlorite, hydrochloric acid, and sodium chlorite
- Two-chemical system utilizing Purate® and sulfuric acid. Purate® is a proprietary combination of hydrogen peroxide and sodium chlorate.

Relevant research on chlorine dioxide concentration and effectiveness has yielded mixed results (Mackie and Claudi, 2010). Some research has indicated that chlorine is more effective than chlorine dioxide while other research has found the opposite. One study found that 0.125 mg/L of chlorine dioxide was sufficient to prevent settlement and another determined that a 0.2 mg/L residual of chlorine dioxide for eight days would lead to adult zebra mussel mortality (Mackie and Claudi, 2010). When chlorine dioxide is used as a disinfectant, it can form chlorite and chlorate disinfection by-products. De-chlorination by the addition of ferrous salts may be required to remove the chlorite and chlorate ions. As a general rule, a continuous residual of 0.3-0.5 mg/L should be maintained in pipelines to prevent settlement (Renata Claudi, personal communication, October 11, 2011).

There are many advantages and limitations to the use of chlorine dioxide for zebra mussel control. Some advantages are: chlorine dioxide forms lower levels of disinfection by-products than chlorine; it does not react with organic material to form THM/HAA byproducts: it can be generated on-site; and it is an effective biocide. Limitations include: formation of undesirable disinfection by-products, such as chlorite and chlorate ions; chemical storage hazards (especially if chlorine gas is used); health and safety concerns; and higher cost due to three chemical processes needed to generate the chemical.

10.1.1.3 Chloramines

Chloramines are most commonly formed when ammonia is combined with chlorine in water. When chlorine or sodium hypochlorite is added to lake water that contains ammonium, chloramines are formed as well. Higher levels of ammonium result in higher levels of chloramines. Chloramines are typically used in the treatment of potable water as a secondary treatment that provides a disinfectant residual in distribution pipelines. Chloramines are weaker but more stable disinfectants than chlorine. Since chloramines are not as reactive with organic matter as chlorine, they produce lower concentrations of disinfectant byproducts in a system. Chloramines could provide an advantage over chlorine if THMs are a concern.

Mackie and Claudi (2010) state that chloramine concentrations above 1.5 mg/L resulted in 90% veliger mortality in both static and flow-through tests. Research on chloramines is not as extensive as chlorine and other oxidants; therefore, concentrations for control are less well understood. However, as a general rule, a continuous residual of 0.3 to 0.5 mg/L should control zebra mussel settlement (Renata Claudi, personal communication, October 11, 2011). The advantages of chloramines include reduced production of disinfection byproducts and greater chemical stability compared to chlorine.

10.1.1.4 Potassium Permanganate

Potassium permanganate is commonly used in water treatment to control taste and odor, remove color, and remove iron and manganese. Some research suggests that it can be used to control adult zebra mussels, although it is less effective than chlorine (Mackie and Claudi, 2010). Potassium permanganate provides an advantage over other chemicals in that it does not form DBPs. High concentrations of potassium permanganate tend to turn the water pink which is an undesired consequence of the chemical. Although it costs more than chlorine, it can be less expensive than proprietary molluscicides. There is only one NSF approved chemical manufacturer of potassium permanganate. Since potassium permanganate is an oxidant, a continuous residual of 0.3-0.5 mg/L should be maintained to control zebra mussel settlement (Renata Claudi, personal communication, October 11, 2011). Potassium permanganate is supplied in powder form. A concentrated solution (typically 1-4%) is generated onsite and can be labor-intensive. Sodium permanganate has been gaining acceptance as a viable alternative and is commonly available in solutions of 20% and 40% (by weight), eliminating on-site solution preparation. Its use as a treatment method for zebra mussel control has not been well documented. Sodium permanganate has similar oxidizing potential as potassium permanganate; therefore, a continuous residual of 0.3-0.5 mg/L should be maintained to control zebra mussel settlement.

One advantage of potassium permanganate is the lack of disinfection by-product formation. The disadvantages are that large doses turn the water pink, it requires long contact time, and it has had limited use by municipal water suppliers for mussel control.

10.1.1.5 Bromine

Several forms of bromine can be utilized as antifouling agents. Examples include activated bromine, sodium bromide, and bromine chloride. There are also proprietary mixtures of bromine and chlorine or bromine and other chemicals. Bromine has been shown to be a more effective oxidizing agent when pH levels are greater than 8.0 (Mackie and Claudi, 2010). Research has shown that bromine has a higher toxicity to non-target species than chlorine, in some cases by a factor of 2 (Mackie and Claudi, 2010). Bromine research for zebra mussel control is limited compared to that of chlorine. Limited research, toxicity to non-target species, and limited use for zebra mussel control are all disadvantages of this chemical control method.

10.1.1.6 Hydrogen Peroxide

Hydrogen peroxide is a powerful oxidant that is an effective disinfectant and is commonly used in water to remove dissolved impurities such as iron and hydrogen sulfide. Hydrogen peroxide breaks down into hydrogen and oxygen, with no harmful environmental by-products. Research has shown that a relatively high dose of hydrogen peroxide is required to induce mortality in adult zebra mussels and veligers (Mackie and Claudi, 2010). Benschoten et al. (1993) studied the response of zebra mussel veligers to three chemical oxidants (chlorine, ozone, and hydrogen peroxide). During his study, he found that a concentration of 0.1-1.0 mg/L chlorine or ozone or 3-9 mg/L hydrogen peroxide resulted in at least 89% removal of veligers. He concluded that hydrogen peroxide was observed to be effective but only at high doses relative to doses of ozone and chlorine required for similar effectiveness. Since hydrogen peroxide is more expensive than chlorine and requires a higher concentration to obtain similar results, the cost of treatment for zebra mussels may not be practical.

10.1.1.7 Ozone

Ozone has been used in water treatment processes to remove viruses and bacteria. One of the benefits of ozone is that it can be produced on site; however, there are high initial capital costs and there can be difficulties maintaining the equipment. The ozone molecule dissipates quickly in water and ensures that there is little or no residual at the outlet and therefore no adverse environmental impact. However, this could be a disadvantage if control of downstream mussel settlement and growth is a consideration or in systems requiring greater than 20 minutes retention time (Mackie and Claudi, 2010). Maintaining sufficient residual levels required to kill adult zebra mussels in large systems could be very expensive and require multiple injection points. Research indicates that a minimum of 5 hours of contact time is required at 0.5 mg/L for 100% mortality of veligers and post-veligers (Mackie and Claudi, 2010). Adults require a longer contact time of 7-12 days at 0.5 mg/L, and time of death depends on concentration and ambient temperature (Mackie and Claudi, 2010). A continuous residual of 0.3 to 0.5 mg/L will control zebra mussel settlement (Renata Claudi, personal communication, October 11, 2011).

Ozone is environmentally friendly, effective at preventing settlement of veligers at low concentrations, and effective at killing adult mussels. However, there are many disadvantages that would limit ozone as a viable option. They include high capital cost, high operating cost, increased maintenance compared to other control methods, and off-gassing from excess ozone production.

10.1.1.8 Flocculation

Flocculation is a common WTP process for the removal of suspended particles in the water. A chemical such as alum is added, and charged sediment particles bind with the flocculent to form larger particles. The particles then travel to a sedimentation basin where they subsequently settle to form a sludge blanket. Direct contact with the flocculent is generally not sufficient to kill veliger larvae (Mackie and Claudi, 2010). The process appears to be a physical one, as veligers are bound in the flocculent and accumulate in the sedimentation blanket, preventing downstream transport.

10.1.1.9 pH Adjustment

Zebra mussels have a range of pH in which they can survive and reproduce. A pH range between 7.4 and 9.4 is required for successful development of zebra mussel veligers, with optimal conditions at 8.5 (Sprung, 1987 and Mackie and Claudi, 2010). Increasing or decreasing the pH out of the required range is one method that can be used to control zebra mussels. A sustained pH less than 6.9 or above 9.6 should be adequate to control zebra mussel settlement. A disadvantage of raising the pH is that calcium may begin to precipitate as pH increases, depending on calcium levels and alkalinity. In addition, a higher pH may also reduce the effectiveness of some disinfectants used in water treatment. Lowering the pH can impact the infrastructure through corrosion and pitting. This depends on the water quality and the initial pH required to ensure that pH remains below 6.9.

Sulfuric acid is one chemical that could be used to decrease pH in the water, and sodium hydroxide could be used to increase the pH. Testing would be required to establish the amount of chemical required to lower or raise the pH. In water sources with high alkalinity, a low pH adjustment will be harder to sustain as the buffering capacity of the water would resist the change in pH. The length of the pipeline, flow rate, and impact of the lower pH on the pipeline material should all be considered.

10.1.1.10 Proprietary Molluscicides

Unlike chemical treatment, proprietary molluscicides in water are typically not detected by zebra mussels, and will not cause them to close. Many proprietary molluscicides work by coating the zebra mussels' gills or by being absorbed into vital organs, ultimately resulting in death. The length of time required will depend on dosing rate, water temperature, and selected product. Proprietary molluscicides are typically most effective in warm waters. There are many proprietary molluscicides on the market; however, NSF approved proprietary molluscicides are limited to Bulab 6002® and VeliGON®. Bulab 6002®is produced by Buckman Laboratories, Inc. and is approved at up to 0.5 ppm for mollusk treatment in potable water systems. A concentration of 2.0 ppm of Bulab 6002, would be required for 250-313 hours for 100% mortality (Sprecher and Getsinger, 2000). VeliGON®, manufactured by Calgon Corportation, is a flocculent molluscicide that requires a filter to remove the flocculent and mussel remnants (Sprecher and Getsinger, 2000).

One disadvantage of molluscicides is that some of them have to be deactivated (e.g. with bentonite clay) before being released into the aquatic environment. Some chemicals used to kill zebra mussels are also lethal to other aquatic organisms. Another disadvantage is that some molluscicides will adhere strongly to negatively charged surfaces including sediment, clay particles, and organic matter. Therefore, in highly turbid water, additional chemical or injection points could be needed. Molluscicides can also cost more than other chemical treatment options. When released in the environment, proprietary molluscicides can remain active until they are consumed or bound to sediment. The advantages of molluscicides are that they are not detected by zebra mussels which results in swift kill, and they do not create disinfection byproducts. A detailed discussion of available nonoxidizing proprietary molluscicides is provided in the United States Army Corps of Engineers Zebra Mussel Chemical Control Guide (Sprecher and Getsinger, 2000).

Pseudomonas fluorescens is a naturally occurring soil bacterium that protects plant roots from disease. A strain of the bacteria has been found to be lethal to zebra and quagga mussels. Zequanox® is a proprietary product manufactured by Marrone Bio Innovations, and is composed of dead cells of *Pseudomonas fluorescens*. The manufacturer states that Zequanox® has been proven to only be lethal to zebra and quagga mussels without harming the aquatic environment. Zequanox® is produced in a powder form. A solution is created onsite and injected into the pipeline or treatment area. Zebra mussels do not detect the bacteria, and consume the organisms, resulting in death. The manufacturer states that mortality typically results within the first few days of treatment and continues for several weeks. However, it is important to note that the product only remains viable in the water column for 24-48 hours. The product does not have NSF approval, although it is expected within the next 5 years. The product is currently produced in several locations, and production is limited to small quantities.

10.1.1.11 Potassium Chloride

Potassium chloride has historically been used in fertilizer and in the medical industry; however, the chemical is toxic to zebra mussels. Potassium chloride is relatively inexpensive and innocuous to other forms of aquatic life. Potassium changes gill physiology of mussels, preventing valve closure and reducing filtration rates (Mackie and Claudi, 2010). The impact of potassium chloride on valve closure suggests that this treatment could be followed by an oxidant, requiring less chemical and promoting faster mortality. Mackie and Claudi (2010) state that reported dosage rates required to achieve 100% mortality vary significantly. One study reported 100% mortality in adults with 20 mg/L for 52 days, while another found that 600 mg/L for 48 hours would result in total mortality.

Potassium chloride is a popular and successful treatment in confined systems such as lakes and ponds. It has been used by various state and governmental agencies to treat portions of or entire lakes that were determined to have zebra mussels. The Virginia Department of Game and Inland Fisheries (VDGIF) used potassium chloride to eradicate the invasive species on Millbrook Quarry Lake. The department injected 174,000 gallons of potassium chloride over a 3-week period in 2006 to the 12 acre, 93 foot deep lake. The target concentration was 100 mg/L which is far below the level that would invoke environmental or human health concerns, but more than twice the minimum concentration cited in some studies to kill adult mussels. Multiple test methods were utilized to determine whether the process was successful. The tests indicated that after 31 days of exposure, 100% of the test mussels died (VDGIF, 2011). There were no known environmental effects from the treatment.

Texas Parks and Wildlife Department also used potassium chloride to treat a 32 mile stretch of Sister Grove Creek in 2010. Their target concentration was 175 mg/L and the creek was dosed continuously for 48 hours. This was the first time anyone tried to treat a lotic system for zebra mussels. The results were mixed in that zebra mussel mortality was documented 10-15 days following treatment but it was not a 100% kill.

10.1.1.12 Copper Sulfate

Copper sulfate is typically used for algae control; however, this compound is also toxic to zebra mussels. Copper sulfate can also kill aquatic plants, animal plankton, plant plankton, fish, and aquatic insects. Toxicity of this chemical to fish varies among species. Copper sulfate is highly water soluble and can be applied as a solid or liquid concentrate. Copper is strongly bioaccumulated, and since it is a naturally-occurring substance, can persist indefinitely.

In Nebraska, copper sulfate was applied to Offutt Base Lake with positive results; however, application of the chemical did result in a fish kill. A target concentration of 1.0 ppm of copper was desired for the lake. In 2004 and 2005, the Minnesota Department of Natural Resources applied chelated copper to a 26-acre bay of Lake Ossawinnamakee in an attempt to restrict further movement of zebra mussels into adjacent water bodies. Veligers were killed in the bay waters. Settled and attached mussels in the outlet stream were also killed (Minnesota DNR, 2011). The chemical appears to be effective in closed lake systems; however, it can be lethal to fish and vegetation. Copper sulfate is less expensive than potassium chloride. However, environmental impacts of the copper-based product should be considered prior to use.

10.1.1.13 Copper Ion Generation

Copper-ion generation has historically been used in the shipping industry to protect cooling systems from macro-fouling; however, ionic copper can be used to control veliger settlement. Generation equipment electrolytically produces copper ions by the use of two copper plates with an electrical charge that releases copper ions into the water. Research indicates that a continuous dose of 10 ppb of copper ion would limit veliger settlement (Mackie, and Claudi, 2010). Macrotech®, a copper ion manufacturer, states that the ionic copper prevents biofilm formation and inhibits veliger settlement. However, adult mussels detect the ionic copper and close, reducing the effect on adult mussels. Copper ion generation does have advantages and disadvantages. The toxicity of copper in freshwater systems is highly dependent on the alkalinity of the water which suggests that the amount of copper required for zebra mussel control would vary for different water sources. The advantages are that copper ion generation can inhibit veliger settlement, limited maintenance is required, and treatment will prevent biofilm formation. The disadvantages include that adult mussels will close when they detect the ionic copper, the anodes have to be replaced yearly which creates additional cost and there are limited known municipal installations. There may also be stringent permit requirements.

10.1.2 Non- Chemical Controls

Options discussed in this section control zebra mussels without the addition of chemicals. This eliminates some of the environmental and water quality concerns of chemicals. Some non-chemical methods, however, require system shutdown which may not be feasible for some applications.

10.1.2.1 Manual Cleaning

10.1.2.1.1 Manual Scraping/ Power Washing

Depending on the level of infestation and the desired intent of treatment, manual scraping or power washing may be a cost effective and efficient solution to zebra mussels. Zebra mussels attached to intake screens and easily accessible structures can be removed with high pressure washing or scraping. In addition, large diameter pipelines (>48") can be manually cleaned. Small diameter pipelines and hard to access locations may be less conducive to manual cleaning and require alternative methods. If the frequency of manual cleaning becomes too exhaustive, preventative treatment methods (i.e., chemicals) should be considered to reduce zebra mussel attachment and growth.

Advantages of manual cleaning include no chemical storage or injection equipment, effective removal, and limited environmental impact. The disadvantage is that the process is labor intensive for large areas of infestation and would require that normal pumping operations cease during cleaning. As with other treatment methods, the cost of removal and disposal of mussels should be considered.

10.1.2.1.2 Pigging

Pigging is a commonly used process in the water and wastewater industry to clean pipelines and restore hydraulic capacity. The same process can remove zebra mussels from pipe walls without the use of chemicals. The process is relatively simple but requires construction of launching and retrieval stations. A pig is typically a foam cylinder fitted with a global positioning system (GPS) transmitter. The GPS transmitter enables the contractor to locate the pig if it becomes stuck in the pipeline. The pig is introduced into the pipeline through a launching station and water pressure created by the pumps pushes the pig to the retrieval station. The pig will remove zebra mussels and other debris as it travels down the pipeline. Most debris will remain in front of the pig. Typically, different size pigs are introduced to ensure thorough cleaning, and minimize the probability of a pig being stuck in the pipeline. Pigging may not be a cost effective option if the pipeline contains multiple butterfly valves that would preclude passage and require multiple launching and retrieval stations. The potential discharge of a large amount of debris should be considered when selecting a site for the retrieval station. The volume discharged at the retrieval station may have to be contained and treated.

This control option has many advantages over other control technologies. Pigging does not require additional buildings, equipment, or storage of chemicals that may be needed with other methods. In addition, it is environmentally friendly in that it does not introduce chemicals into the water that could have a negative effect on aquatic life. However, there are some disadvantages that include taking the pipeline out of normal operation for a period of time, the possibility of getting the pig stuck, and additional cost if the pipe is damaged or if pre- or post-cleaning is required.

10.1.2.2 Velocity Control

Velocity management in pipeline is a control option that may not require additional equipment or personnel. Research indicates that settlement is reduced when a minimum velocity of 4.9 ft/s is maintained in the pipeline (Mackie and Claudi, 2010). However, this may not be a viable option for systems that operate over a large range of flow or systems with larger pipes designed for maximum or future flow conditions. Mussels may settle in crevices or other areas shielded from flow. The advantage of this control strategy is that no additional equipment or treatment methods would have to be implemented. To ensure that zebra mussels do not settle in the pipeline, a minimum continuous velocity of 6.5 ft/s is recommended.

10.1.2.3 Filtration

Filters can be used to remove zebra mussels and veligers, along with suspended solids and pathogens, depending on the filter size. Other significant variables to be considered in design are flow rate and backwash frequency. Filtration can employ media systems such as sand or activated carbon or mechanical filters with automated backwash. Various filtration methods are described below. In general, filters do not provide 100% removal and may need to be used in tandem with additional control methods.

10.1.2.3.1 Gravity Media Filtration

Gravity filtration using slow sand or dual media has not widely been used for control of zebra mussels. Adult mussels can cause channeling in the sand media, allowing the passage of larger particles through the filter bed. Gravity filtration is a vital part of the water treatment process for many treatment plants in the Great Lakes region where zebra mussel infestation has been a problem for many years, but the filtration step is predominantly preceded by coagulation, flocculation, sedimentation, and some form of disinfection. Therefore, filters at these facilities are not subject to the same conditions as would be expected at raw water installations.

Sand infiltration systems have been used with some success at raw water intakes. Intakes that are positioned in special filtration beds have been used at a few installations for zebra mussel filtering. These infiltration galleries typically require geological formations that can both filter and transmit the water. Reservoirs addressed in this document do not typically contain these formations; therefore, sand infiltration would require very expensive construction of filter beds.

10.1.2.3.2 Mechanical Filtration

Two types of automatic backwash filters typically used for zebra mussels are screen filters and disc filters. Screen filters can remove particles down to ten microns. Water flows thorough the filter from the inside out. As water passes through the filter, a cake is formed on the mesh. After a differential pressure threshold is reached, a rotating suction scanner spirals around the screen removing the filter cake without interrupting the flow of water. After the cake has been removed, full filtration flow is restored. Units can be sized for flow rates in excess of 30,000 gpm; however, decreasing the micron filter size to the level required to remove zebra mussel veligers will reduce the capacity of the filter substantially.

Disc filters are another type of mechanical filtration that provides a higher surface area for contact with zebra mussels than screen filters. The filter consists of multiple compressed plastic discs through which water flows from the outside to the inside. Water passes between the compressed discs where solids are trapped and continues to a pipe located in the center of the discs. After the differential pressure reaches a preset threshold, a switch activates the backwash cycle releasing pressure on the discs. Flow to disc filters will be shut off during the backwash cycle. Therefore, it is recommended to manifold multiple disc filters to allow backwash of one while the others continue the filtration process.

Design requirements for mechanical filtration include operating pressure and additional head loss created by the filters. Minimum and maximum operating pressure for mechanical filtration is typically between 35-150 pounds per square inch (psi) but may vary by manufacturer. The additional head loss through the clean filter and the clogged filter prior to backwash would have to be provided by the existing pumps or a booster pump. Head loss will vary depending on micron size and backwash filter setting. The head loss for a clean 100 micron filter, for example, is approximately 2-3 psi and a backwash is typically set to initiate at a pressure differential of 7 psi across the filter.

10.1.2.3.3 Bag or Cartridge Filtration

Bag and cartridge filtration is commonly used in many applications to remove small particles (>5 microns) at relatively low flows. The aquaculture industry uses these types of filters to remove all zebra mussels to prevent infestation of their systems or to prevent infestation of other sources during a fish release. Bag and cartridge filters could be trailer or truck mounted to provide a mobile filtration unit. They do not require backwash which is an added benefit in remote areas where clean backwash water is not available. The bag filters and cartridges are replaced when the differential pressure reaches a preset threshold.

A typical bag filter system is shown in Figure 10-1 and Figure 10-2. Maximum capacities of bag filters are typically around 2000 gpm, depending on the manufacturer. Bag filters are typically provided with nominal or absolute ratings for particle removal. The removal efficiencies of nominal and absolute rated bags vary among manufacturers. Nominal bags typically remove 50-85% of the particles larger than the filtration size while absolute bags have >99% removal. The absolute filters improve removal efficiency by increasing the thickness of the filter. This reduces the flow capacity of the absolute filters, in some cases up to a third, compared to nominal filters of equivalent particle size.

Figure 10-1- Bag Filter Unit

Figure 10-2- Housing of a Bag filter Unit

Cartridge filters use long cylindrical filters that contain larger surface areas than bag filters. They are effective at removing small particles with >99% removal efficiency. These units can be positioned horizontally or vertically, although horizontal orientation is recommended since it is easier to access and replace the filters (Figure 10-3). Single cartridge filter housings are designed to handle flow rates up to 4,000 gpm depending on the manufacturer. Replacement cartridges are almost 10 times the cost of bag filters but typically last longer (Figure 10-4).

Cartridge and bag filtration systems have limited use for zebra mussel control. Pipelines typically are designed for higher flow rates than these types of filters allow. Since bag and cartridge filters require periodic replacement, they are not a cost effective control method for most pipelines. However, when small volumes of water require treatment, filtration is an ideal solution. For instance, filtration is an option for treatment of water released from blow off valves used to drain a pipeline for maintenance. They can be mounted on a trailer and fitted with a pump to become mobile filtration units that can be transported to various blow off valves along the pipeline alignment. The units are connected to the pipeline where zebra mussels are removed from the water with the filtration units prior to discharging it in to the environment.

Cartridge and bag filters have some advantages and disadvantages. The disadvantages of bag filters are that seals around the filter bags can leak and high-flow units (>500 gpm) are large and bulky. However, bag filters are typically less costly than cartridge filters. Cartridge filters use a smaller footprint than a bag filter of equivalent flow, but as noted above are more expensive than bag filters.

Figure 10-3- Inlet and Outlet Piping

Figure 10-4- Cartridge Filter

10.1.2.4 Thermal Treatment

Thermal treatment, either acute or chronic, is a viable strategy for control of adult and larval zebra mussels. This process does not require the use of chemicals and is very effective. Acute thermal treatment is beneficial when sustained temperatures are not feasible or cost effective. However, determining the temperature that will kill mussels instantaneously or almost instantaneously can depend on many factors. Acclimation temperature (current temperature of water), rate at which the water is heated, and mussel size are a few factors that determine the instantaneous temperature that will kill zebra mussels. Furthermore, thick accumulations of mussels may require a higher temperature to ensure that interior mussels are killed. McMahon and Ussery (1995a) studied the thermal tolerance of zebra mussels relative to rate of temperature increase and acclimation temperature. They found that in general, the lower the acclimation temperature, the lower the instantaneous lethal temperature required for 100% mortality. For an acclimation temperature of 5°C, a rate of increase of 1°C per 15 minutes resulted in an instantaneous lethal temperature of 35.1 °C. An acclimation temperature of 30°C with the same rate of increase resulted in an instantaneous lethal temperature of 40.6°C. The thermal tolerance of seals and other temperature sensitive components are important considerations in thermal treatment. To ensure instant lethality without considering acclimation, a temperature approaching 60 °C is recommended. One advantage of thermal treatment is that the heated water will cool and can be discharged without any negative effect on aquatic life or water quality. The disadvantage of thermal treatment is the high cost of heating large volumes of water to temperatures as high as 50-60 °C.

10.1.2.5 Antifoul and Foul Release Coatings

Coatings can be used to prevent growth of macrofouling organisms on intake infrastructure. Thermal-spray coatings contain zinc, copper and brass which repel mussels by the slow dissolution of metal ions in the water. These coatings are applied by spraying molten droplets of the metal on the surface to be treated. Leaching of metal ions into the water may prevent use of these coatings in potable water systems.

The overall trend is toward the use of environmentally friendly coatings that form physical barriers to attachment. These coatings are subject to abrasion, however, and should be limited to areas that are not susceptible to damage by debris. Currently, the most promising coatings are nontoxic, silicone–based paints that prevent or greatly decrease the strength of attachment (Mackie and Claudi, 2010). Skaja (2012) concluded that silicone foul release coatings work very well and that many coatings work in static water but fail in flowing water. Surface preparation requirements, cost, longevity, and effect on the environment are all factors that should be considered when choosing a coating or determining whether a coating is a feasible method of control. One advantage of coatings is the limited maintenance required. Some disadvantages are the high cost of installation, susceptibility to abrasion, limited warranty (5-10 years), and the toxicity of some coatings to the aquatic environment.

10.1.2.6 Desiccation

Desiccation is the process of exposing the mussels to air which dries tissue resulting in death. It is a cost-effective solution as it does not require chemicals or additional infrastructure. However, for this treatment method, some systems (i.e. pipelines and balancing reservoirs) may require prolonged shutdowns that may not be practical. The time required for desiccation to be lethal will vary with temperature and humidity. Ussery and McMahon (1995b) found that zebra mussels were able to survive longer than 10 days in temperatures less than 15°C and high relative humidity. They also found that 100% mortality was observed in 125 hours at 15°C and 33% humidity. When desiccation is used, it is important to expose all zebra mussels to air and increase the time of exposure in cool temperatures and high humidity conditions. In general, zebra mussels should be exposed for a minimum of 14 days to ensure complete mortality.

10.1.2.7 Ultraviolet Light

Ultraviolet radiation (UV) is used in drinking water disinfection, wastewater disinfection, water reuse and ground water remediation. UV is lethal to zebra mussel veligers by affecting genetic material and preventing the organisms from reproducing or functioning. Irradiated veligers appear to be alive but do not settle. Factors that affect UV effectiveness include turbidity, alkalinity, hardness, and flow rate. Turbidity can impact the ability of UV to penetrate the water.

Whitby (2011) found that a dose of 110 mJ/cm^2 is required to control the settlement of veliger zebra mussels. UV is a viable option for veliger control in small to medium water systems but may be cost prohibitive at high flow rates. One advantage of UV is that it does not introduce chemicals into the water. However, UV does have some disadvantages that include higher dose rate compared to the intensity required for conventional disinfection (excluding viruses); it is an ineffective control method for adults; and effectiveness is dependent upon water quality.

10.1.2.8 Acoustics

The use of acoustics has been explored as a zebra mussel control method. However, the research performed in this area often produces controversial or inconclusive results, and more research is needed. Potential applications for acoustic energy control of zebra mussels include cavitation, sound treatment, and vibration. With further development, acoustic energy may prove to be a practical mitigation strategy against mussel attachment. However, there is some concern about potential destructive impacts of vibration on structures.

10.1.2.9 Electrical Current

Electrical current can be used in flowing water systems to shock or disable incoming veligers, or it can be used to create an electrical field on or just above a substrate to prevent settlement of zebra mussels (Mackie and Claudi, 2010). Pulse rate, amplitude, duration, and amplitude shape are all important factors affecting the success of electric fields. High-voltage fields applied continuously to fresh water can kill veliger mussels but would be cost-prohibitive in high-volume or high velocity systems. Other research indicates that low-voltage electric fields could control the settlement of zebra mussels with potentially acceptable costs (Smythe and Dardeau, 1999). Short-term exposure to low-voltage electric fields could stun veligers, causing them to close and not allowing them to attach. However, this impulse would only last for a short time and the mussels could open further down the pipeline. Mackie and Claudi (2010) concluded that the voltages necessary, the required length of exposure, and the amount of power needed, make this control method impractical for most industrial applications.

10.2 CONTROL STRATEGIES

One strategy for control of zebra mussels is to provide an absolute barrier, or 100 percent mortality. Barriers can be provided through various filters, chemical and other treatments, or combinations thereof. A review of literature indicates that the required dosages and times required to ensure 100 percent mortality vary among researchers. In addition, there are factors such as temperature and acclimation that will impact the effectiveness of treatment. Short pipelines with high flow rates may not provide the contact time needed for many barrier treatment options. Consideration of barrier strategies is a consequence of interbasin transfer challenges faced by many water providers, especially where state lines are crossed and the Lacey Act prohibits any zebra mussel transport. Though absolute barriers may be appropriate or even required in certain specific situations (such as to comply with the Lacey Act or to prevent fouling of critical and sensitive cooling systems) they may not always be cost effective. The relatively high cost to provide a barrier must be considered in light of the requirement, the costs of alternative maintenance strategies, the risks of establishing new zebra mussel populations, and the multiple vectors generally available for zebra mussel infestation. Each potential barrier consideration has its own unique set of circumstances and there is no universal formula for determining feasibility. Research and experience should continue to compile data on methods, costs, and effectiveness so informed analyses of alternatives can be made to support future determinations of the most appropriate control strategies. One control strategy that could provide a barrier would be a combination of filtration and chemical injection. A filter could be installed at the infested water source pump station. The filter would remove all adult and juvenile mussels and backwash them into the infested water source. A larger media or screen size would reduce the required frequency of backwashing, but still ensure that adults and juveniles were removed. The pipeline then could be injected with a chemical to obtain 100% mortality of fertile eggs and veligers passing through the filter. Chemical treatment in the pipeline would still require adequate contact time to ensure mortality which would depend on the chemical used and dosing. In addition, the chemical dose would have to be low enough or neutralized to allow discharge into the environment.

All remaining options in this section address treatment methods that could control zebra mussel impacts on infrastructure, but not necessarily provide a barrier or 100 percent mortality. The chemical dosing required would be less than for a barrier as the ultimate goal is to minimize or prevent attachment of zebra mussels rather than provide an absolute barrier. In addition, non-barrier strategies increase the number of methods available, including manual cleaning and velocity control.

Chemical control is often a preferred option as it is convenient and effective (Mackie and Claudi, 2010). Treatment methods for chemical control can be separated into preemptive and reactive control methods. The discussion below pertains mostly to chemical control strategies although they could also apply to some non-chemical control options. A reactive strategy does not imply that it is not deliberately planned; rather it means that treatment is implemented when some level of fouling is reached. The selection of an appropriate strategy will depend on the level of infestation and cost.

10.2.1 Preemptive

Preemptive control methods would be used to prevent settlement or attachment of zebra mussels. Preemptive treatments can be intermittent or continuous.

10.2.1.1 Intermittent

Intermittent treatment uses a chemical dose at frequent intervals (typically 12-24 hours) to prevent infestations before they begin. Veligers and newly settled post-veligers are more susceptible to treatment than adults; therefore, the concentration of chemical and duration of application should be less than if adults were targeted (Mackie and Claudi, 2010). This method will target the mussels that are introduced; however, if adult mussels already exist, higher chemical concentrations would be required.

Intermittent treatment may be suitable for small raw water systems as the cost of intermittent treatment may be more acceptable than continuous treatment. For large diameter pipelines with high flow rates this treatment option may be cost prohibitive depending on the chemical used for treatment and the dosing requirements. This type of treatment can be implemented effectively during the breeding season when veligers are present.

10.2.1.2 Continuous

Continuous chemical treatment is a proactive strategy designed to prevent any level of zebra mussel attachment within the treated area. This treatment option includes continuous chemical injection and is one of the most frequently used methods of control. However, for systems with high flow rates and long pipelines, continuous treatment may be cost prohibitive. Multiple injection points for the chemical may be required to maintain a residual in a long pipeline, and a high flow rate increases the amount of chemical required. The concentration of chemical required can be lower than intermittent treatment as long as continuous treatment and the required residual are maintained (Mackie and Claudi, 2010). The dose would depend on the chemical selected. If continuous treatment is used, the mussels in the pipeline would be smaller and more susceptible to the chemical effects. Many utilities already use continuous treatment to control biofilm growth in pipelines.

10.2.2 Reactive

Reactive control strategies are typically used in raw water systems that are able to endure some level of zebra mussel attachment and growth. In general, the chemical concentration required will be higher than for proactive treatment strategies since the mussels are developed and have been allowed to accumulate on the structures.

10.2.2.1 End-of-Season Treatment

End-of-season treatment is a reactive control strategy that is usually performed after the breeding season in the fall. During chemical treatment with an oxidant at a low residual (0.3-0.5 mg/L), many zebra mussels will detect the chemical and eventually release from the pipeline to find better living conditions. During chemical treatment with an oxidant at a high dose, zebra mussels attached to the pipeline will close and die within a few weeks. Chemical treatment using a higher dose is beneficial for extensive pipelines where a majority of the infestation is near the injection point and maintaining a residual for a prolonged period of time is difficult or not cost effective. The required dosage and length of application will vary depending upon treatment method and water temperature. This treatment method is a viable option if the pipeline can tolerate one breeding season of mussel growth. Some extensive, large diameter pipelines may require multiple chemical injection points to sustain the residual needed to be lethal to mussels if the entire pipe is infested. For these systems, this treatment option may provide a cost advantage over continuous treatment. Any system that utilizes end-of-season treatment as a control method must be able to handle large pulses of mussels at the outlet. Additional maintenance and cleaning may be required to deal with the large accumulation of mussel shells.

Manual cleaning can also be performed as an end-of-season control strategy. Yearly cleaning of raw water systems can be implemented to control the growth of mussels and can be combined with chemical control methods, if needed.

10.2.2.2 Periodic

Periodic treatment is similar to end-of-season treatment except that the treatment is performed more frequently. Frequency of treatment will depend on the rate that mussels accumulate and the utility's tolerance for this accumulation. Periodic treatment can be used to limit the growth of adult mussels in the pipeline and will reduce the number of shells that are transported to the outlet of the pipeline following each treatment event. However, chemical costs will be higher as compared to end-of-season treatment since the number of treatment events will be greater.

10.3 TREATMENT CONSIDERATIONS

Before selecting a treatment method or strategy it is important to conduct a detailed assessment of the treatment goals and potential constraints. Issues such as cost, permitting, and water quality impacts should all be considered. The following provides an overview of issues that should be considered before selecting treatment strategies and methods.

10.3.1 Treatment Strategy

Prior to selecting specific treatment method, the overall strategy of the control program should be established and the goals of the treatment strategy defined. Questions that should be asked in developing the strategy include:

- Is the goal to prevent the transport of any mussels/veligers, or to control the level of infestation?
- If some level of infestation is tolerable, how much accumulation is acceptable?
- Are there redundant elements of the system that will allow for portions of the system to be shut down for periodic cleaning?
- Is the cost of continuous treatment feasible?
- Is the receiving body able to handle a pulse of shells after treatment?

10.3.2 Treatment Method

When selecting treatment methods consider the following:

- What is the impact of the treatment method on aquatic life?
- Does the raw water quality limit the use of some methods (formation of disinfection byproducts)
- How would the raw water quality i.e., (pH, chlorine demand, temperature, and turbidity) affect treatment?
- What impact does the treatment method have on the infrastructure (i.e., corrosion)?
- Are there any discharge permitting requirements?
- Are there any state or federal regulations on the use of the treatment method?
- How many injection points would be required to maintain the recommended residual?
- Is pump shutdown an option?
- What is the acceptable cost of treatment?
- What is the treated flow rate and does it limit the available options (i.e., filtration)?
- Is there enough contact time available for treatment?
- What is the range of flow in the pipeline (i.e., velocity control)
- How would inactive periods impact zebra mussel growth and treatment (i.e., short- and long- term shutdown)?
- Does this method control all possible sources?

11 Treatment Options

Zebra mussel control options for the infrastructure facilities described in Section 9 are provided in Table 11-1. Specific constraints of control options should still be considered to select the best method. These constraints include cost, water quality, permitting requirements, impact to aquatic life, and other environmental impacts.

Table 11-1- Control Options

Infrastructure		Options(s)	Comment(s)
Pumps	Intake Screens	Manual cleaning, coatings (silicone), proprietary metal alloy intake screen (Z-alloy®), and chemical injection	• State and federal permitting requirements as well as emergency shut-off provisions are critical factors in the design of chemical injection systems at intakes.
	Trash Racks	Manual cleaning and automatic cleaning systems	• Automatic cleaning systems must be designed to ensure that rake arms travel close enough to the rails to remove mussels.
	Wet Wells	Manual cleaning and chemical injection	• In design it is advisable to avoid using deep wet wells and minimize the amount of area that will be exposed to low velocity water.
	Pump Columns	Manual cleaning, thermal treatment and chemical control	• Vertical turbine pump columns that are operated frequently do not typically need treatment as continuous operation will reduce or prevent zebra mussel attachment • For manual cleaning, the pump column can be removed and the inside cleaned by power washing or manual scraping. This method can be time intensive and requires removal of the pump motor and shaft. • Chemical treatment can be used to control attachment and growth in pump columns. However, any chemical that is used could be discharged directly into the water source and may require some form of permit. • Thermal treatment would require monitoring to assure the desired temperature and duration.
	Cooling Water	Mechanical filtration (screen or disk), Ultraviolet radiation and chemicals	• The major threat occurs when pumps are not in operation, allowing attachment and growth of mussels. • If pump cooling water is discharged into the environment, the use of chemicals is not recommended. • UV radiation is only effective against veligers.
Pipelines		Velocity control, manual cleaning, pigging, desiccation, chemical injection and mechanical filtration (screen or disk), Zequanox®	• Mechanical filtration is recommended for flow rates <10 mgd. Higher flow rates may be cost prohibitive. • Pipeline exposure to outside air for a minimum of 14 days is recommended to ensure effective desiccation. The length of time depends on ambient temperature and humidity in the pipeline (see 10.1.2.6 above). • Continuous velocities above 6.5 ft/s are recommended to prevent attachment.
Water Treatment Plants		Chemical injection near intake and flocculation	• If periodic or end-of-season treatment is used, provisions should be made to accommodate the mass of shells that may be released from upstream piping during treatment.
Balancing Reservoirs		Desiccation, manual cleaning, design changes and chemical control	• Balancing reservoirs should include two separate cells so one may be drained and desiccated while the other remains in operation. • Basins should be designed to provide access for mechanical machinery to remove accumulated shells. • Protruding structures into the basin should also be minimized or eliminated as they may impact the ability to mechanically remove shells. • If the balancing reservoir is not covered, chemical degradation and wildlife impacts (i.e. birds, waterfowl, etc.) should be considered.
Canals		Desiccation, manual cleaning and chemical treatment	• In concrete channels, a small front end loader, such as a bobcat, can be used to remove any mussels that have settled on the bottom • The soft floor of naturally lined canals may limit the ability of mechanical removal of shells unless the entire canal is allowed to completely dry first. • Impacts to wildlife and permitting issues should be considered when using chemical treatment.
Gates		Manual cleaning/Coatings/ construct of copper-based alloys	
Instrumentation/Gauges		Change to non-contact instrumentation, manual cleaning and chemical treatment	• Chemical treatment or desiccation used to protect a pipeline can also help control biofouling of instruments and gauges in the pipeline.
Hydroelectric Power Plants	Turbines	Desiccation and chemical treatment	• The high velocities associated with normal continuous operation of turbines will prevent attachment of mussels • Cooling water can use the same treatment methods described for pumps. • Desiccation through dewatering is recommended for prolonged periods of shutdown.
	Penstocks	Desiccation and chemical treatment	• Penstocks that are in continuous operation have limited zebra mussel attachment problems since the velocity and turbulence prevent attachment. • Chemical treatment is also an option, although impact on the downstream water source and associated permitting issues need to be considered.
	Gate Towers	Manual Cleaning	• The viability of chemical treatment is typically limited since the towers are usually installed in the water source and discharge of the chemicals to the water source may not be allowed.
Maintenance, Research, and Recreational Vessels		Manual cleaning, desiccation, and thermal treatment	• Boats should be removed from infested water when not in use to prevent attachment of mussels • High pressure washers (>3,000 psi) with 180°F water can be used to remove attached mussels.
Docks/Marinas/Access Points		Manual cleaning and coatings	• Shell accumulation can be a significant nuisance and safety hazard at boat ramps and along shorelines.

12 Cost

The purpose of this section is to provide cost information for most of the zebra mussel control methods discussed in Section 10. Some control methods not mentioned in Table 11-1 were included in this section because they may be used for applications not discussed in this document or develop into viable options in the future. There are limitations to the use of this information because costs vary widely with flow rate, water quality, and design requirements, such as downstream use, degree of treatment, and site conditions.

Because of the wide array of factors that impact costs, a detailed cost estimate for every possible scenario is not practical for this document. Instead, the information presented in this section should be used as a tool for developing planning level opinions of probable cost. Selecting a control method should not be based solely on cost. Other factors that should be considered include disinfection by-product formation, water quality, impacts on the environment (i.e., de-chlorination), impacts on infrastructure, regulatory approval, and risk management. This section is organized by methods used to control zebra mussels rather than by infrastructure features. This allows similar treatment methods to be grouped together for comparison.

12.1 CHEMICAL TREATMENT

Chemical control includes oxidants, molluscicides, pH control chemicals, and other chemical agents. Many of the chemical costs provided in this section are given on a unit cost per day per million gallons per day (MGD). The unit cost can be multiplied by the flow rate (in MGD) and duration of treatment time (in days) to determine total cost. Yearly costs were not provided since the duration of treatment will vary for different control strategies. Costs shown in this section only consider one injection point. For long pipelines, multiple injection points may be required to maintain the recommended residual.

12.1.1 <u>Oxidants</u>

Oxidants are treatments for intakes, pipelines, wet wells, balancing reservoirs and canals. Costs for chlorine, chloramines, chlorine dioxide, and potassium permanganate are included in this section. The cost of these chemicals is highly dependent on the form in which they are purchased and/or applied. For example, chlorine can be purchased as a gas in various quantities (e.g. 150-pound containers, 1-ton cylinders, and 80-ton rail car) or as sodium hypochlorite or calcium hypochlorite liquid in various strengths (e.g. 10%, 12.5%, or 16%). Chlorine gas and liquid sodium hypochlorite (0.8% strength) can also be generated on site. Permanganate is typically supplied in a powdered form (potassium permanganate), but a liquid alternative is available (sodium permanganate). Both of these products are manufactured by a single U.S. supplier approved for drinking water applications (NSF 60/61). This illustrates the complexity of estimating costs for oxidants since the chemicals used to form the oxidants will vary. Costs in this section are generally conservative by selecting the higher priced chemical combinations.

The two common chlorine sources are chlorine gas and sodium hypochlorite. Chlorine gas tends to be less expensive than sodium hypochlorite. On the other hand, chlorine gas is a hazardous gas and a respiratory irritant. Storing it on-site requires a risk management plan and may increase the amount of safety and security that is required. Exposure to the gas can cause choking, coughing, watery eyes, and lung irritation. The hazardous risk of chlorine gas causes many municipal utilities to use alternative chemicals. For this cost analysis, chlorine gas was avoided and sodium hypochlorite was used as the chlorine source.

Mixing chlorine and ammonia forms chloramines and the ratio at which the chemicals are combined determines the type of chloramines formed. Sodium hypochlorite (10%) was used as the chlorine source and liquid ammonium sulfate (LAS) (10%) was used as the ammonia source. LAS is typically more expensive than other forms of ammonia. Therefore, the use of LAS in the cost shown below is conservative. For this assessment a 3:1 ratio of sodium hypochlorite and liquid ammonium sulfate was used.

Section 10 of this document describes the production of chlorine dioxide as a two or three chemical process. A two chemical process uses chlorine gas as the chlorine source. To avoid the use of chlorine gas, a three chemical process was considered in the cost estimate. The three chemicals are hydrochloric acid, sodium hypochlorite and sodium chlorite.

For this assessment 0.5 mg/L, 1.0 mg/L, and 1.5 mg/L doses were assumed with the understanding that the dosing requirements will vary depending on initial water quality. These doses were selected to achieve residuals of 0.3 mg/L-0.5 mg/L – the recommended residual for control of mussel settlement. Table 12-1 shows an infrastructure cost comparison for the oxidants. Infrastructure costs include tanks, containment area, and injection equipment only. No site development was included in these costs. The infrastructure costs include multipliers for electrical and instrumentation, contingency, contractor overhead and profit, and engineering and permitting. The tank and containment costs were based on 15 days of storage at the corresponding flow and dose.

Table 12-1- Chemical Infrastructure Cost Comparison

Chemicals	Infrastructure Cost[1,2]	
	10 MGD (0.5-1.5 mg/L)[4]	100 MGD (0.5-1.5 mg/L)[4]
Sodium Hypochlorite	\$120,000-\$140,000	\$220,000-\$350,000
Potassium Permanganate	\$290,000-\$320,000	\$770,000-\$880,000
Chloramines	\$160,000-\$220,000	\$350,000-\$540,000
Chlorine Dioxide[3]	\$450,000-\$550,000	\$750,000-\$1,240,000

Notes:

1. Cost in 2012 dollars.
2. Cost includes the following multipliers: 25% electrical, 20% contingency, 20% overhead, and15% engineering.
3. Cost for three chemical process
4. Concentrations are feed concentrations, not residual concentrations

A chemical cost comparison is shown in Table 12-2. De-chlorination may be required depending on the chemical used and disposition of the treated water. De-chlorination costs were not included in Table 12-2. The costs are normalized to \$/MGD, so that total unit costs could be extrapolated based on the flow rate and desired treatment time. Sodium hypochlorite will degrade when it is stored and the degradation rate is highly dependent on outside temperature. To account for degradation, a 10% solution of sodium hypochlorite was used at a

12.5% solution cost. The chemical cost is lowest for sodium hypochlorite and most expensive for chlorine dioxide for the chemical processes used in this analysis. The cost per MGD will vary depending on volume of chemical used and relative location to a manufacturing site.

Table 12-2- Daily Chemical Cost Comparison

Chemicals	Chemical Cost[5]		
	$/day/MGD @ 0.5 mg/L[6]	$/day/MGD @ 1.0 mg/L[6]	$/day/MGD @ 1.5 mg/L[6]
Sodium Hypochlorite[1]	$5.20	$10.40	$15.60
Chloramine[2]	$9.00	$18.00	$27.00
Potassium Permanganate[3]	$14.60	$29.20	$43.80
Chlorine Dioxide[4]	$23.70	$47.30	$71.00

Notes:

1. Cost assumes 10% Sodium Hypochlorite solution at $1.20/gal.
2. Cost assumes 10% Sodium Hypochlorite ($1.20/gal) and 10% Liquid Ammonium Sulfate ($1.32/gal) at a 3:1 ratio, respectively.
3. Assumes unit cost of $3.50/lb of Potassium Permanganate.
4. Cost assumes 15% Hydrochloric Acid ($1.10/gal), 10% Sodium Hypochlorite ($1.20/gal), and 25% Sodium Chlorite ($8/gal).
5. Cost is in 2012 dollars.
6. Concentrations are feed concentrations, not residual concentrations

Bromine is an oxidant that is typically more effective at pH greater than 8.0 (Mackie and Claudi, 2012). The amount of research available for bromine is limited. For this reason it was not mentioned in Table 11-1. Bromine costs approximately $3.30-6.50/ lb depending on quantity.

12.1.2 Other Chemicals

Potassium chloride and copper sulfate have been used in northern states to eradicate zebra mussels from infested lakes (closed systems). The level of treatment varied from spot treatment to treatment of an entire water source. These chemicals can be applied as a solid or liquid typically spread over the water source. Potassium Chloride concentrations required to ensure mortality can be up to 100 mg/L. Millbrook Quarry Lake, discussed in Section 10, is a 12 acre lake with a maximum depth of 93 feet. Treatment of Millbrook Quarry Lake with 177,000 gallons of potassium chloride solution in 2006 cost approximately $365,000 (VDGIF, 2011). The current unit cost of potassium chloride is $0.35/lb.

Copper sulfate was used to treat the 115 acre Offutt Base Lake in Nebraska. Treatment consisted of 28,000 lbs of chemical to obtain a 1.0 ppm copper concentration throughout the lake. Treatment cost was not available; however, 2012 unit cost of 25% copper sulfate is $2.80/lb.

12.1.3 Proprietary Molluscicides

Proprietary molluscicides provide a competitive advantage over conventional chemical oxidants in that they are not detected by zebra mussels and do not result in disinfection by-products. However, environmental impacts limit their use in water that is discharged into the environment. Table 12-3 shows the approximate cost of Bulab 6002® manufactured by Buckman Laboratories, Inc. which is currently NSF approved up to 0.5 mg/L. The unit cost is $2.91/ pound. The cost of treatment varies for other molluscicides and will increase further if deactivation is required. Molluscicides are generally delivered in solution and injected into the treatment area using chemical injection equipment. Therefore, infrastructure cost for Bulab 6002® is similar to chlorine.

Table 12-3- Bulab 6002 Cost

$/day/MGD 0.2 mg/L	$/day/MGD 0.5 mg/L
$5	$12

Zequanox® was mentioned in Section 11 to control zebra mussels in pipelines. Currently, Zequanox® is not widely produced and therefore cost is available from the manufacturer only on a case-by-case basis. Similar to potassium permanganate, Zequanox® is provided in powder form and must be made into a solution by adding water in the field prior to use. As technology for this chemical improves, NSF approval is obtained, and production increases, cost and application rates will be more readily obtained from the manufacturer.

12.1.4 pH Control

Reducing pH to at least 6.9 by the addition of an acid is a control option for pipelines. There are many factors that impact the cost of reducing pH including the initial pH and alkalinity of the raw water. Pilot testing would be required to determine the amount of acid needed to balance the initial pH and the length of time it can be maintained. If pH goes above the desired range within a few miles of the injection, additional injection points may be required or the initial pH may need to be lowered. Impacts to the infrastructure should be considered, as lowering the pH can increase the rate of corrosion. To estimate costs for this document, an initial pH of 8.0, target pH of 6.9 and alkalinity of 117 mg/L were assumed. For these assumptions, approximately 13 gallons of 96 percent sulfuric acid would be used per day per MGD. The storage and feed infrastructure would cost approximately $200,000 for a 10 MGD system and $410,000 for a 100 MGD system. The infrastructure cost includes multipliers for electrical and instrumentation (25%), contingencies (20%), contractor overhead and profit (20%), and engineering and permitting (15%). The 2012 unit cost of sulfuric acid is $0.27 per pound. Based on these assumptions lowering the pH would have a chemical cost of approximately $55 per day per MGD.

For raw water that has a naturally high pH, raising the pH to 9.6 may be a more practical form of control. The main concern with this approach is that precipitation of calcium may occur near a pH of 10.0, depending on water quality. Chemicals that are typically used to raise the pH of raw water are sodium hydroxide and calcium hydroxide. To estimate costs for this study, an initial pH of 8.0, target pH of 9.6 and alkalinity of 117 mg/L and the use of sodium hydroxide to adjust pH were assumed. For these assumptions, approximately 34 gallons of 50 percent sodium hydroxide would be used per day per MGD. The storage and feed infrastructure would cost approximately $240,000 for a 10 MGD system and $670,000 for a 100 MGD system. The infrastructure cost includes multipliers for electrical and instrumentation (25%), contingency (20%), contractor overhead and profit (20%), and engineering and permitting (15%). The 2012 unit cost of sodium hydroxide is $0.15 per pound. Based on these assumptions raising the pH would have a chemical cost of approximately $5.10 per day per MGD.

12.2 FILTRATION

Filtration can be used to control zebra mussel infestation in pipelines and pump cooling water. The level of treatment can be adjusted based on the filter size and could be combined with other treatments. The costs for gravity media filtration, mechanical filtration, bag filtration and cartridge filtration are provided in this section.

12.2.1 Gravity Media Filtration

Gravity media filtration has not been widely used for control of zebra mussels. It has been used with some success at raw water intakes that are positioned with special filtration beds. The challenge in developing a cost for media filtration is the amount of variation in design criteria. The criteria include filter loading rate, filter media selection, raw water quality, filter backwashing, and filter under-drains. Developing cost estimates for all media filters is not practical and would be based on a case by case basis.

A 20 MGD gravity filter with media composed of sand and anthracite would cost approximately $5.1 million. The cost includes piping, structure, media and under drain. The cost also includes multipliers for electrical and instrumentation (25%), contingency (20%), contractor overhead and profit (20%), and engineering and permitting (15%).

12.2.2 Mechanical Filtration

Disc and screen filters are options for pump cooling water and smaller raw water systems (<10 mgd). At higher flow rates, the number of mechanical filters increases, drastically elevating the cost and footprint of the infrastructure. The flow rate obtained with filtration will depend on the filter size and initial water quality. The main water quality parameter that greatly impacts the number of backwash events is concentration of total suspended solids (TSS). The frequency of backwashing may increase after a rain event as TSS typically increases. Table 12-4 shows infrastructure costs for mechanical filtration. These costs include piping, control valves, and a concrete pad as well as multipliers for electrical and instrumentation, contingency, contractor overhead and profit, and engineering and permitting. Disc and screen filter equipment costs are shown in Table 12-5. The number of filters will vary based on the design flow rate and site conditions. The costs shown in Table 12-4 and 12-5 include 4-9 screen filters and 3-16 disc filters. The size and quantity of the filters to obtain the desired flow rate can vary depending on site conditions and design. For some manufacturers, it may be less expensive to provide multiple smaller filters rather than one large filter since the smaller ones are produced frequently and they tend to be stocked. The costs shown in Table 12-4 do not include a backwash water disposal system. The flow rates and costs shown in Table 12-5 will vary depending on design conditions.

Table 12-4-Mechanical Filter Infrastructure Cost

Filter	Flow Rate (MGD)	Infrastructure Cost (millions)
Screen Filter	11.5	$1.7
	33.1	$4.6
Disc Filter	11.5	$1.9
	33.1	$4.8

Note:

1. Cost includes the following multipliers: 25% electrical, 20% contingency, 20% overhead, and15% engineering.

Table 12-5- Mechanical Filter Equipment Costs[1]

Filter	Flow Rate (MGD)	50 Micron	100 Micron
Screen filters	11.5	$540,000	$260,000
	33.1	$1,560,000	$700,000
Disc Filter	11.5	$520,000	$264,000
	33.1	$1,375,000	$690,000

Notes:

1. Equipment costs include filter equipment for the corresponding flow rate.
2. Valves, piping and other appurtenances are included in Table 11-4.

The use of filtration does require minimum and maximum operating pressures. Typically this varies from a minimum pressure of 35-75 pounds per square inch (psi) and a maximum pressure of 150 psi. There is also head loss created by the filters that has to be overcome with the use of existing or additional pumps. Therefore, energy cost should also be considered in the cost of filtration. The backwash cycle for a filter typically initiates when the pressure differential reaches 7 psi and there is 2-3 psi head loss over a clean filter. A daily energy cost for a 7 psi and 10 psi pressure differential is $5.43 and $7.76 per MGD, respectively. This cost calculation assumes $0.08 per kilowatt hour.

12.2.3 Bag and Cartridge Filtration

Bag and cartridge filters are options for remote areas where filtration of raw water discharge is required. These units can be mounted on a skid, truck, or trailer which is not included in the cost shown in Table 12-6. Bag and cartridge filter costs are shown in Table 12-6 which includes pricing for 316 stainless steel and carbon steel units. The unit cost of bag filters is higher due to the additional metal used in the housing. The filter replacement cost for standard 40 micron bag filters ranges from $5 for nominal rated bags to $50-$70 for absolute rated. There are other types of bag materials that could affect the cost of replacement bags. The cost to replace 40 micron cartridge filers is typically $300-$400; however, cartridge filters are capable of handling up to 350 gpm per unit while each absolute rated bag filter is capable of 50 gpm depending on filter size.

Table 12-6- Bag Filter and Cartridge Filter Cost

Filter	Material	Flow Rate (MGD)	Vessel Cost[1,2]	# of Filters in Housing
Bag Filter	316 Stainless Steel	.36	$36,000	5
		1.4	$105,000	20
	Carbon Steel	.36	$13,500	5
		1.4	$38,000	20
Cartridge Filter	316 Stainless Steel	.36	$3,700	1
		1.4	$11,000	3
	Carbon Steel	.36	$2,500	1
		1.4	$8,000	3

Note:
1. Vessel cost includes a housing sized to accommodate the corresponding number of filters shown in the table.
2. Cost includes the corresponding number of filters shown in the table.

12.3 ANTIFOUL COATINGS

Anti-foul coatings are recommended for intake screens and include silicone and metal based coatings. A recent shift has been toward the more environmentally friendly silicone coatings. Metal coatings tend to leach toxic compounds into the water which can negatively impact the aquatic environment. The cost of coatings will vary based on material cost and installation costs. Some can be coated onsite while others have to be applied offsite by manufacturers. In addition, the thickness of the coating will vary as well, which could impact the capacity of the screen. Jacquelyn® coating is a metal coating that is copper based. The estimated cost of Jacquelyn® coating for screens is $20-25 per square foot installed by the manufacturer. This cost does not include removing the screen or transport to and from the manufacturing facility in Ohio.

Material cost for silicone coating is approximately $3-$5 per square foot of screen. However, the application cost can be substantial. The coating process requires extensive preparation and trained personnel to ensure it adheres correctly. Screens can be removed and sent to the manufacturer for application or the coating can be applied on site. This coating cost provided does not include removal and reinstallation of the screen.

One manufacturer has produced a copper based intake screen. The Z-Alloy® material manufactured by Johnson Screens is a proprietary product composed mostly of copper. This screen eliminates the problems of chipping and reduced hydraulic capacity observed with some coatings; however, the cost of the Z-Alloy® screen can be substantial. A rule of thumb for Z-Alloy® screens is approximately 2.5 times the cost of a typical 304 stainless steel screen.

12.4 MECHANICAL CLEANING

The cost of mechanical cleaning will depend on many factors and providing costs for all types of infrastructure is not possible. However, a pipeline cleaning project completed in 2011 can be used to provide an idea of what could be expected. Manual cleaning on this project included removing sediment accumulation in the pipeline, scraping ten miles of six foot diameter pipeline and removing mussels from the pump header. The cost of manual cleaning was approximately

$350,000. Most of the mussel accumulation was confined to the first mile of pipeline and the pump header. The cost to clean the intake screen in place using underwater divers and 10,000 psi water was approximately $40,000 which included a $15,000 mobilization fee.

Pig launching and retrieval stations were added to this same pipeline. The project cost of $750,000 included excavation and construction; however, no additional land or easements were required. Pigs are usually purchased for one pass and not reused due to the damage sustained during the pigging process. For this project, two 72" pigs were purchased. The cost of the purchasing the pigs and pigging the 10 mile pipeline was between $75,000-$100,000. A 36" pig can range in cost from $800-$4,000 and a 60" pig can range in cost from $4,000-$13,000. The cost of pigging will depend on many factors such as the amount of mussels/debris in the pipeline, the number of pig passes required and the pipeline length and diameter.

12.5 ULTRAVIOLET LIGHT

Ultraviolet (UV) light is typically used to disinfect wastewater and treated water. The cost will depend on the transmissibility of the water being treated. Ultraviolet transmissibility (UVT) is the ability of the UV light to penetrate the water column. This is greatly impacted by turbidity, iron levels, and hardness of the water. For finished water, the transmissibility is typically around 95% and for wastewater it is 65%. Table 12-7 shows infrastructure cost for UV. This includes piping and valves. The infrastructure cost includes multipliers for electrical and instrumentation, contingency, contractor overhead and profit, and engineering and permitting. Table 12-8 shows only the UV equipment cost.

Table 12-7- Ultraviolet Light Infrastructure Cost

Flow Rate (MGD)	Cost
2	$150,000
2.8	$180,000
3.2	$195,000

1. Cost includes the following multipliers: 25% electrical, 20% contingency, 20% overhead, and15% engineering.

Table 12-8- Ultraviolet Light Equipment Cost

Flow Rate (MGD)	75% UVT	85% UVT
2	$275,000	$245,000
2.8	$385,000	$260,000
3.2	$470,000	$275,000

12.6 COPPER ION GENERATION

Cooper Ion Generation was not mentioned as a treatment method because of the lack of municipal installations. In the future, it may become a viable treatment method. The 2012 equipment cost of copper ion generation is shown in Table 12-9.

Table 12-9- Copper Ion Generation Equipment Cost

2.9 mgd	10.8-18 mgd	18-25.2 mgd	50.4 mgd
$25,000	$68,000	$88,000	$160,000

13 Monitoring and Detection Techniques

As zebra mussels continue to invade Texas waters, various agencies have responded with substantial detection and monitoring efforts. Early detection allows time for water providers to implement zebra mussel control programs and protect vital infrastructure. Monitoring of the established zebra mussel population in Lake Texoma has shown an explosion and subsequent moderate decline. As zebra mussels spread, further monitoring may allow scientists to predict patterns of density, longevity, and impacts in Texas waters.

Boat inspections can reduce the number of viable zebra mussels transported into non-infested waters. Data obtained from boater surveys can be used to understand boater behavior and predict risk to watersheds. This section reviews boat inspection programs conducted in various states.

13.1 ZEBRA MUSSEL MONITORING

Monitoring can provide early detection of zebra mussels as well as monitor an existing population. Water quality data can also provide valuable information for risk assessments. A comprehensive zebra mussel monitoring program includes plankton tow sampling, passive sampling, SCUBA diving, and water-quality monitoring (Churchill and Baldys, 2012).

In the event zebra mussels become established in a water source, it is important to continue sampling and increase the frequency. Additional data can provide valuable information regarding the timing of spawning events and level of infestation which can help guide the selection of treatment methods and strategies.

13.1.1 Plankton Tow Sampling

Plankton tows are commonly used to sample the water column for zebra mussel veligers. A plankton tow net with a long cone-like mesh and a collecting cup at the bottom, as shown in Figure 13-1. A mesh size of 63-64-µm is commonly used (Churchill and Baldys, 2012, California DFG, 2012). The volume of water sampled will depend on the diameter of the net, length of the tow, and speed of pull (as water can spill out and around the net if it is pulled too fast). Veligers are captured in the collection cup shown in Figure 13-2. Contents of the collecting cup are transferred to a sample bottle and taken to a lab for analysis. Plankton tow samples should be collected at locations near intakes, pipe outlets, tributary inflows from infested water sources, and boat ramps at least twice a year when breeding is most likely and veliger densities are expected to be highest. Samples should be analyzed using cross-polarized light microscopy (CPLM) and polymerase chain reaction (PCR) techniques for identification of zebra mussels. PCR detection requires the presence of species-specific DNA sequences. PCR amplifies target DNA and offers the potential of early detection using small sample sizes but is prone to false positives. There are many cases where PCR results were positive for a particular water body but no zebra mussels have ever been documented.

Figure 13-1- Plankton Tow Net
(Source: Christopher Churchill USGS)

Figure 13-2- Collecting Cup
(Source: Christopher Churchill USGS)

13.1.2 Passive Samplers

Artificial substrates are used to monitor the growth and colonization of zebra mussel juveniles and adults (Churchill and Baldys, 2012). They should be deployed where zebra mussel introduction is likely, i.e. boat docks, pump stations, and tributary inflows. Many commercial manufacturers produce artificial substrates; however, large scouring pads or concrete blocks can be used as low cost alternatives. Artificial substrates should remain submerged for at least three weeks before being inspected to allow sufficient time for algae growth to develop which promotes zebra mussel settlement (Churchill and Baldys, 2012). During periodic visits, the substrates can be removed and either visually inspected or examined under a microscope to detect the presence of recently-settled mussels. Densities and shell length should be recorded. Substrates should be located out of sight and away from areas where people tend to congregate to minimize the potential for human interference.

13.1.3 SCUBA Dives

A SCUBA dive inspection of boat docks and intakes should occur at least once a year to determine the presence and density of juvenile and adult zebra mussels. Boat docks and access ramps with high traffic volumes should have high priority. If a small number of mussels are found, they sometimes can be removed to prevent further infestation. Submerged intake screens and trash racks are common places for attachment and provide good indicators of whether a zebra mussel population has been established. Mussels may be difficult to detect by inexperienced scuba divers as they are often covered in algae and other periphyton, which makes them appear similar to other submerged surfaces.

13.1.4 Water Quality Data

Water quality data can be used to assess risks of zebra mussel infestation as discussed in Section 4. Water temperature, pH, dissolved oxygen, calcium, and other physicochemical water properties are critical for zebra mussel survival, growth, and reproduction should be collected (Churchill and Baldys, 2012). Salinity, turbidity and other limiting parameters should be included on a watershed specific basis. Vertical profiles of water temperature and dissolved oxygen can provide information needed to predict the vertical limit of zebra mussel survival and seasonal stresses. Sampling locations should be spatially distributed, especially near infrastructure, pipeline outfalls, and other specific areas of interest. Water quality monitoring should continue after zebra mussels are established to detect any changes.

13.1.5 Routine Inspections

Routine inspections of intake screens for zebra mussel growth should continue after an infestation has occurred. Pipelines should be added to routine inspections to assess density of mussel attachment and hydraulic loss. For pipelines, it is not always necessary to completely dewater for inspection. After pumping has ceased, any accessible high points in the pipeline can be inspected to determine if zebra mussels have become established. Pipe segments near the pump station should be inspected, especially if the pipeline is exposed to low velocities that are conducive to zebra mussel settlement. Gates, valves, and instrumentation should all be monitored for growth. If the level of infestation starts to impact the hydraulic capacity or function of equipment, removal of mussel accumulation may be desired.

13.1.6 Side-Stream Monitors

Side-stream monitors are used to monitor growth and settlement of zebra mussels in pipes without the need for dewatering or shutdown. During chemical treatment, side-stream monitors also can be used to evaluate the effectiveness of the treatment. These monitors are usually aquarium-like structures called bio-boxes that mimic flow in the pipeline. Bio-boxes are fairly simple with inflow and outflow pipes and a drain valve to remove accumulated sediment. A bio-box should be connected to the lower portion of a pipe to capture the highest number of zebra mussel larvae. These monitors should be placed in underground vaults or enclosed buildings to protect them from weather and heat.

13.1.7 Blue-Green Algae Monitoring

As noted earlier, there is some evidence that zebra mussels can contribute to increased levels of blue-green algae in lakes. If an infested lake is used for recreation and fishing, it is recommended that blue green algae levels be monitored.

13.2 CURRENT MONITORING IN TEXAS

Since the detection of zebra mussels in Lake Texoma, monitoring programs have begun in several lakes in north Texas. USGS began sampling Lake Texoma for NTMWD in April 2010 using passive samplers and plankton tow nets at a site near NTMWD's pump station. Two additional sites near the pump station were added in October 2011. Water temperature and water quality data are also collected. Samples were taken approximately eight times a year in 2010 and 2011 with site visits occurring in spring and fall. In 2011, winter sampling began weekly in October. Sampling during winter 2012 is scheduled to continue biweekly until spring of 2013. Sampling on Lake Texoma also includes yearly SCUBA dive inspections of the intake screen and surrounding structures. The level of zebra mussel accumulation on the intake screen has decreased from 2010-2012 which is consistent with the decline in veliger concentrations near the pump station. The extensive data set obtained from 2010-2012 on Lake Texoma has identified the spring and fall spawning events and temperatures.

NTMWD and USGS also implemented a monitoring program for Sister Grove Creek in 2010. USGS began sampling seven sites using passive samplers and plankton tow nets. From 2010 to 2012, the USGS had not detected veligers or settlement of mussels in Sister Grove Creek at the seven sites. USGS began sampling Lavon Lake in 2010, scheduling approximately eight visits and two SCUBA dive inspections per year with no detections thus far.

Before the detection of mussels in Ray Roberts Lake in 2012, the city of Dallas inspected Lake Tawakoni, Grapevine Lake, Lewisville Lake, Lake Ray Hubbard, Ray Roberts Lake, and Lake Fork twice a year using passive samplers and plankton tow nets. In 2012, Dallas began a monitoring program in Lake Palestine. After mussels were detected in Ray Roberts Lake, the frequency of sampling in a few of the lakes increased. These include Lewisville Lake, which is downstream of Ray Roberts Lake on the Elm Fork of the Trinity River. In October 2012, the USGS began sampling three points along the Elm Fork of the Trinity River below Ray Roberts Lake and above Lewisville Lake. The frequency and number of inspection locations in the Elm Fork have increased.

Tarrant Regional Water District (TRWD) samples at their lakes. Sampling consists of passive samplers and plankton tow nets and targets the spring, summer and fall seasons when veligers are likely to be present. TRWD is currently working with the USGS to incorporate their sampling protocol and add CPLM to their standard sampling techniques.

13.3 SAMPLING AGENCIES

There are several agencies equipped and qualified to conduct zebra mussel sampling within the state. The USGS has conducted multiple sampling programs in many north Texas Lakes. The sampling conducted by the USGS includes artificial substrates, veliger plankton tows, and SCUBA dives. Texas Parks and Wildlife Department (TPWD) samples lakes in Texas and will continue to provide zebra mussel monitoring in the state. TPWD has also contracted with Dr. Bob McMahon of the University of Texas at Arlington to monitor 23 reservoirs using cross polarized light microscopy, PCR, and settlement samplers. They are also assessing risks at several of those reservoirs by monitoring water temperature, calcium concentrations, pH, DO and conductivity. The U.S. Fish & Wildlife Service does periodic sampling in Texas and in Oklahoma.

13.4 BOAT INSPECTION

The translocation of boats from infested lakes to non-infested lakes is a major vector of infestation. A number of other states have implemented boat inspection programs to control the transport of mussels to non-infested water bodies. This section reviews several of those programs.

13.4.1 Idaho

As of June 2012, Idaho has no known zebra or quagga mussel infested water bodies. Idaho has taken a preemptive approach to prevention of zebra mussel infestation. The Idaho Department of Agriculture implemented a boat inspection program in 2009 but determined that comprehensive boat inspections of all public water source ramps would be cost prohibitive. Instead, they identified infested water sources in other areas of the country and determined the highways boaters from these sources would most likely use to travel into Idaho. Boat inspection stations were positioned near the state line to inspect all incoming watercraft. All watercraft entering the state are required to stop for inspection anytime the stations are in operation. Since the inception of the program in 2009, the number of inspection stations has ranged between 15 and 20, and the locations of the stations are reviewed annually based on the inspection data obtained.

In 2011, Idaho inspected over 47,000 watercraft from 49 states. During those inspections, 25 boats were identified as having visible zebra mussels. In 2012, as of late June, over 12,000 inspections had identified 45 fouled boats. Inspections in 2012 occurred seven days a week from 7 a.m to 7 p.m. from the opening date in February until the close of the inspection season in late September. Boats entering Idaho outside of these times/dates/locations are not required to stop for inspection.

Idaho funds the boat inspection program through a registration fee for state registered boats. In addition, out of state boaters are required to purchase a stamp after entering the state. The fees range from $10-$20. The cost of the program typically ranges from $480-$500 per sampling station per day with a total operating budget of around $1 million/year. The state also uses public education, including billboards, signage, and flyers, to control the spread of mussels. They also coordinate closely with other agencies, both within the state and in other states. Overall, the inspection program is considered a success since Idaho lakes and rivers continue to remain free of zebra and quagga mussels.

13.4.2 Oklahoma

Oklahoma has established zebra mussel populations in many lakes and is a bordering state to Texas. Currently, Oklahoma does not have an active boat inspection program. The only current enforcement is by state game wardens who can ticket offenders with visible zebra mussels on boats.

13.4.3 Minnesota

Minnesota is known as “the land of 10,000 lakes” and zebra mussels have been established there since the late 1980s. A recent article suggests that inspecting all of the 3,600 public and private boat ramps could cost over $600 million annually (Meersman, 2012). The Minnesota Department of Natural Resources (DNR) implemented a boat inspection program in 1992, which has expanded every year. In 2011, 98 inspectors were used to conduct 76,000 boat inspections at approximately 325 boat ramps (Invasive Species Program, 2011). In 2012, inspectors conducted 102,600 watercraft inspections and 94 watercraft arrived at accesses with zebra mussels in or on their watercraft, compared to 24 in 2011 (Invasive Species Program, 2012). Inspections typically occur on weekday evenings and weekends from sunrise to sunset between April and October.

The Minnesota DNR reports that approximately $1.6 million was spent on boat inspections in 2011 (Invasive Species Program, 2011). Funding for the Invasive species program comes from a variety of state, federal, and local sources. The primary source is a $5 surcharge on the registration of watercraft which generates approximately $1.2 million in revenue. In addition a $2 fee is added to non-resident fishing licenses and generated approximately $400,000 in 2011.

In 2011, zebra mussels were reported at eight new water sources in Minnesota (Invasive Species Program, 2011) and 2012 14 new water sources (Invasive Species Program, 2012). However, six of them were connected to water sources with established zebra mussel populations. The remaining two lakes were infested from a boat lift that was moved from an infested lake. An attempt was made to treat the two lakes with a copper-based product typically used to treat algae. Future monitoring will determine the success of the eradication effort.

The Minnesota DNR also uses an extensive public education program with the use of billboards, newspapers advertisements, and flyers. Although zebra mussels continue to spread throughout the state, the inspection program and increasing public awareness have been credited with reducing the rate of spread. There is some thought that a boat inspection program must be 100% effective to be successful. To the contrary, a member of the Minnesota invasive species program stated that even though Minnesota is not able to inspect all water sources in the state, the effort to slow the spread of zebra mussels is beneficial and, therefore, successful.

13.4.4 California

California has several lakes with sustained populations of quagga mussels and one lake with zebra mussels. Boat inspection stations operated by the state are located at 16 agricultural inspection stations on the state border. All watercraft that cross into the state are required to stop for inspection. Since 2007, the Department of Food and Agriculture inspected almost 700,000 watercraft, and just over 1,000 boats had attached adult mussels. Decontamination stations are used at the agricultural inspection stations to remove zebra mussels.

The state of California does not currently inspect boats at water sources. The burden of boat inspections within the state falls on municipal water utilities. Each water utility determines the level of inspection or control they want to employ. This varies from signage to shutdown of the water source to all public watercraft. Some absorb the cost of inspections while others charge a fee.

Decontamination stations are not widely used by municipal utilities in California. There is concern over how effective they are at removing all zebra mussels since mussels can inhabit small crevices in the vessels and may not be effectively removed. The success of the process is dependent on the inspector’s ability to remove all of the mussels. In addition, the wash water has to be reclaimed and disposed of in an environmentally friendly manner. Instead of using decontamination stations, municipal utility inspectors will confiscate boats with visible signs of zebra mussels and open and drain all compartments. The boat will remain in quarantine for up to 30 days, depending on air temperature, humidity, and level of infestation, until all mussels are desiccated.

13.4.5 Texas Inspection Program

Texas Parks and Wildlife Department (TPWD) officials, including game wardens, biologists, and state park police, investigate and inspect contaminated boats that are reported or seen. In Texas there are nearly 2,400 public access sites. The success of boat inspection programs in many of the states is attributed to inter- and intra-agency cooperation. This cooperation includes boat inspectors; state, county and local police; state game wardens, and bordering states. Boat inspectors rely on police for enforcement, ensuring that boaters stop at the inspection stations. Cooperation with bordering states is also important to control the spread and communicate about infested boats whose destination is another state.

While there is currently no formal boat inspection program in Texas the TPWD plans to utilize interns to conduct boater surveys and inspections at lakes Ray Roberts and Lewisville during the summer of 2013. The City of Waco also partnered with TPWD and the US Army Corps of Engineers to hire interns to conduct boater surveys on Lake Waco. Furthermore, TPWD conducted boat inspections at Lake Travis as part of a large Aquapalooza event where boaters from around the country visited the lake. Data collected from these surveys will be utilized to help direct future efforts

13.4.5.1 Funding

A common method to pay for invasive species boat inspection stations is through boat registration fees. Such a fee could be required for Texas residents and visitors from out of state. In 2011, there were over 600,000 registered boaters in Texas so a fee of $10, for example, could potentially generate $6 million dollars from in state boaters alone.

13.4.5.2 Data Gathering

Boat surveys provide information that can be used to make improvements to future boat inspection programs. Boat inspection surveys may collect information such as:

1. First and Last Name of boater
2. Zip code of residence
3. Destination water source
4. What water source the boat is coming from

An electronic database of this information could be maintained so that the data can be easily stored, shared and analyzed. The 100th Meridian Boater Survey has been used by many western states to analyze boater movements relative to the spread of aquatic invasive species.

13.4.5.3 Public Education

Public education is a vital component of any invasive species prevention program. Signage, newspaper articles, pamphlets, and billboards are a few of the tools that can be used to inform the public. There are many options for public education and many states credit a solid public education program for their successes in dealing with invasive species. Public education is discussed in greater detail in Section 14.

13.4.5.4 Considerations

A boat inspection program should focus on infested water sources in and adjacent to Texas and protect the non-infested water sources in the state. This could be accomplished with state border inspection stations and inspections of boats exiting infested water sources. Known infestations in Texas are currently limited to two water sources, Lake Texoma and Ray Roberts Lake. It should be noted that sustained populations in these lakes could provide veligers to infest other water sources via natural connections and interbasin transfers as well as by boats. Boat inspection stations should be located based on the probability of capturing the greatest number of infested boats with the available resources. Yearly survey data could be reviewed to make adjustments in boat inspection station locations. Boat inspections on infested water sources should also be considered to inhibit intra-state movement of mussels. This would minimize the number of infested boats that are transported to other water sources within the state. Continual evaluation of any boat inspection program is necessary to ensure that it remains relevant and cost-effective. Adjustments are likely and should be made on the basis of changing factors such as threat levels, boat movement patterns, public response, new infestations, and budgets.

14 Legislation, Public Outreach and Funding Opportunities

14.1 INTRODUCTION

This section of the Resource Document addresses three key areas:

1. Public outreach, including public education;
2. Legislation, including a discussion of federal and state authorities and recent appropriations; and
3. Existing funding opportunities, including federal and state appropriations, grants, loans and potential private funding.

The discussion of these issues follows the objectives of the document itself, which is to educate the reader on existing outreach programs, including the Texas Parks and Wildlife Department's current public outreach program; legislation and regulations; and funding opportunities. It is beyond the scope of this document to advocate or recommend specific new programs, legislation, or pursuits of funding. The legislation review lays out existing authorities with the intent to provide the reader with a useful summary, but not to advocate or promote any changes or additions to those authorities. The same is true of the funding and regional management discussions; the discussion is to educate not to advocate.

State laws and associated rules and regulations are reviewed, beginning with Texas and including several states with strong zebra or quagga mussel outreach programs. With respect to zebra mussels in Texas, the latest example is the required dewatering of boats leaving Lake Texoma, Lavon Lake, Ray Roberts Lake, and Lewisville Lake. In some states such as California, local and regional water agencies, under authorities prescribed by state law, implement, manage and fund interception programs, monitoring efforts, and public outreach. In other states, joint funding of these efforts is common. In all cases, collaboration among local, regional, state, and federal authorities and agencies is key.

An understanding of the authorities—regulations, enforcement, funding, and programs—that are provided under current federal law and Texas state law is needed to determine if adequate authority exists to implement a specific zebra mussel response effort or if programs are available to potentially fund them. For comparison purposes, the pertinent laws and authorities found for other selected states are discussed. For example, some states such as Colorado provide in state law for the training and certification of volunteers (for boat inspection, monitoring, etc.).

The history of federal law related to invasive or nuisance aquatic species in general, and to zebra and quagga mussels in particular, is presented. An important aspect of federal authority is Executive Order 13112. Considering that all federal agencies including the U.S. Army Corps of Engineers (USACE) that issue federal permits must consider this Executive Order in any action taken relative to zebra mussels, its ramifications and possible applications to north Texas water operations must be well understood.

As would be expected, funding opportunities are limited at all levels of government. However, although limited appropriations are available, Congressional appropriations committees do recognize the problems and potential problems with zebra and quagga mussels and have gone on record to support programs within the U.S. Bureau of Reclamation (USBR) and USACE to help address them. The Texas Water Development Board (TWDB) provides eligibility or would consider eligibility for addressing zebra mussel infestations as part of grant programs and as part of projects funded through the Drinking Water State Revolving Fund (DWSRF) program. Various federal agencies, but primarily the U.S. Fish and Wildlife Service (USFWS), have programs for funding assistance (for example, funds to help implement State Aquatic Nuisance Species Plans) but at present these are very limited in both amount and scope. There is an obvious need for strong collaboration with these federal and Texas agencies to encourage and support renewed funding.

The sponsoring agencies of this Zebra Mussel Resource Document have both the technical expertise related to zebra mussels and water management experience not only to support the development of this Resource Document but also to establish strong collaborations and partnerships for implementation, research, public outreach, legislation, and funding.

Tables and Figures. A number of tables and figures are included in Appendix D to aid the discussion and to summarize findings. The table of Pertinent Contacts (Table D-1) includes individuals and agencies contacted directly or indirectly on issues discussed in this section. Table D-2, Public Outreach, identifies outreach efforts by agencies that are cross-referenced on the contact table. For several key states, public outreach programs and links to the legal authorities to carry out those programs are summarized in Table D-3. Legislation is divided into several sections of Table D-4. Federal authority is discussed in terms of federal laws and executive orders; federal appropriations are discussed in a separate section. Table D-4 also includes pertinent information on other states' laws and regulations. These can be cross-referenced to the public outreach and mussel interception programs (boat inspections/decontamination) program identified in Table D-2 and D-3.

Figure D-1 provides a summary of the 2012 TPWD zebra mussel public education campaign results. Figure D-2 is an attempt to summarize the federal laws that over time have had some degree of impact on zebra and quagga mussel problems. The red bars represent the relative "spread" of zebra and quagga mussel occurrence so that some relationship between the spread of the problem and the federal law to address the problem can be gained.

14.2 PUBLIC OUTREACH

The discussion of public outreach includes two parts:

(1) A survey of the various approaches implemented throughout the country where zebra or quagga mussels are encountered or where the risk is considered high for their occurrence; and,

(2) Outreach based on identifying methods considered most effective and most applicable to north Texas from both an instruction and cost viewpoint.

A necessary requirement for response to potential or actual occurrence of zebra mussels in north Texas reservoirs is effective outreach to educate the public, particularly the boating and water-recreating public. Most states with zebra or quagga mussel occurrences have some degree of public outreach. From that point, the programs vary considerably. Texas outreach, which is focused on Lake Texoma and North Texas, is developed and managed by TPWD.

14.2.1 Lake Texoma and Considerations for Public Outreach

North Texas public outreach efforts must recognize the intense recreational undertakings—boating, shore-line activities, camping, fishing, and other water contact activities—that take place throughout the year at Lake Texoma. Lake Texoma is the 12th largest USACE reservoir and hosts over six million visitors per year. Part of the reason for this high visitation is the lake's proximity to the Dallas-Fort Worth metroplex—about a one-hour drive north. Sherman, Denison, Gainesville, Durant, Ardmore, and several other mid-sized cities are much closer to Lake Texoma. The attraction of Lake Texoma includes two State parks, 54 USACE-managed parks, two wildlife refuges, 12 marinas, 26 resorts, numerous golf courses, campsites and other attractions. Boating and fishing are very popular activities on Lake Texoma. Lake Texoma is one of only a few lakes in the nation where striped bass naturally reproduce, and anglers travel from around the country to experience the world-class fishery. Zebra mussels could potentially alter the aquatic food chain in Lake Texoma by filtering out plankton and negatively impact this valuable fishery.

As a major fishing and boating destination, the potential of transporting zebra mussels from Lake Texoma particularly into the metroplex and north Texas lakes is a real concern.

14.2.2 Texas Parks and Wildlife Department–Public Awareness Campaign

The starting point for discussing public outreach, particularly the need for additional efforts related to the north Texas reservoirs, is a review of the public awareness campaign being conducted by the TPWD. In August 2011, TPWD implemented the campaign under the banner, "Hello Zebra Mussels, Goodbye Texas Lakes: "Clean, Drain and Dry." This campaign is part of a national effort of the U.S. Fish and Wildlife Service called "Stop Aquatic Hitchhikers!" The focus of the TPWD campaign is Lake Texoma—to educate boaters in and around Lake Texoma about zebra mussels and potential harm posed by them. The campaign education materials discuss the harm to the aquatic ecosystems, water infrastructure, and private property. The campaign is conducted during the boating season from Memorial Day through the summer.

The campaign's "call to action" asks boaters to help prevent the spread of zebra mussels by cleaning, draining and drying their boats and other water vessels. Instructions for properly taking these actions are provided.

The TPWD campaign components have included "…billboards, ads at gas stations around the lake, online advertising, boat-ramp stencils, print ads, radio news features, direct mail postcards, wallet cards, posters, display banners, brochures and buoys." Table D-2 identifies many of these TPWD campaign efforts. The TPWD reports that in 2011 the campaign has resulted in more than 41.8 million impressions, and, in 2012, the campaign resulted in more than 54.8 million impressions.

The TPWD actively engages the public, targeting potential boaters and providing useful information to the public in general. Zebra mussel alert e-mails were sent to over 86,000 registered boaters, and more than 43,000 people subscribed to receive email from TPWD. Zebra mussel postcards were sent to around 220,000 registered boaters in central and north Texas. Billboards, print ads in outdoor recreational magazines, stencils at boat ramps on Lake Texoma, pump-toppers, signage at gas stations near or on the way to Lake Texoma, and 37 custom buoys deployed in Lake Texoma are part of the TPWD campaign.

The level of funding for the TPWD campaign was around $275,000 for the initial year, 2011. For 2012, funding continued at around the $270,000 level. The vast majority of this funding has come from Federal Aid in Sport Fish Restoration grants and the agencies and cities sponsoring this Zebra Mussel Resource Document. The results of the 2012 TPWD public education campaign are provided in Figure D-1.

14.2.3 Public Outreach Programs Implemented in Other States

Through the TPWD, Texas has an active public awareness campaign underway. Surveying several other states with zebra or quagga mussel infested lakes or at high risk for occurrence, many of the public outreach efforts, particularly in public education and boater awareness information, are similar. These programs are to varying extent based on the “Stop Aquatic Hitchhikers!” campaign of the US Fish & Wildlife Service and several national entities provide public education materials. An important point to recognize is the willingness to share information and actively provide access to materials among the federal, state and local agencies engaged in helping prevent the spread of zebra and quagga mussels.

Summary and Key Features. Table D-3 summaries several, selected state programs as well as the primary agencies and organizations. Many other states have active, comprehensive invasive species and zebra/quagga mussel programs, but these four states were selected as representative. Under the column “Materials/Information” in Table D-3, distinctive features that are important for consideration are marked in bold type. For example, a distinctive feature of the Texas program is the TexasInvasives.org website, with links to unique Texas efforts in addressing invasive species -- the “Citizen Scientist” program, the “Eradicator Calculator” and other measures. The USGS website’s unique and most useful feature is the wide array of mapping features available. Research is the key to the USBR’s main features on its quagga and zebra mussel website.

14.3 PERTINENT LEGISLATION

14.3.1 Introduction

This section provides an overview of the federal and state laws and regulations relating to invasive species. Pertinent legislation is presented as a guide to the reader, to provide a general overview. The reader should be aware of these state and federal laws in guiding decisions on the legal authorities available to carry out zebra mussel control programs and related efforts.

The history of federal legislation is presented in Figure D-2. Actually, this is the ‘modern’ history of federal legislation related to pest species as the first laws date back to the late 19th century.

Today, while there are a number of federal statutes that relate, there are only two federal laws with direct application to aquatic nuisance species and one Executive Order.

Texas law is established in the Parks and Wildlife Code, Chapter 66. Specifically, three provisions in Section 66.007 apply. Part (a) makes it illegal to "…import, possess, sell, or place into water…of this state…" any harmful or potentially harmful aquatic species without a permit; part (b) requires the TPWD to publish a list of the harmful species; and part (c) authorizes the TPWD to make rules to carry out these functions. The penalty structure under Section 66.012 has recently changed to be a "progressive scale." Under the TPWD and Texas Penal Code, possession or transporting of zebra mussels in Texas is a Class C misdemeanor punishable by a fine of not less than $25 nor more than $500 for the first offense. However, repeat offenses can be elevated to a Class B misdemeanor, which is punishable by a fine of up to $2,000, jail time of up to 180 days, or both. If an individual is convicted three or more times for this same offense, it becomes a Class A misdemeanor, which is a fine of up to $4,000, jail time not to exceed one year, or both. Under these provisions, the TPWD has recently issued rules requiring boaters departing Lake Texoma and areas of the Red River as well as Lavon Lake, Ray Roberts Lake, and Lewisville Lake to remove all water from their boats.

It is also worth noting that the State of Texas has a conspiracy law that makes it illegal to knowingly assist or facilitate another person or entity in violating state laws. It could be argued that anyone knowingly allowing another to "import, possess, sell, or place into water" zebra mussels is likely putting themselves at risk for conspiracy charges.

Many states operate like Texas in having laws to prohibit import, possession, sale and transmission of harmful invasive species, including zebra and quagga mussels. However, where the states are experiencing zebra or quagga mussel infestations or where the state is striving to prevent their occurrence, laws have been broadened and authorities to intercept boats to prevent the spread increased. Some states like Colorado have added significant provisions and details to existing aquatic nuisance species provisions to authorize private inspectors certified by the State to inspect boats and order decontamination or quarantine, or both. In this case, the law is quite specific on boat inspections, establishing a series of watercraft inspection and decontamination (WID) procedures. Several states provide specific language for "emergency response." Massachusetts has delegated authority to the Office of Fishing and Boating Access from the Department of Fish and Game to post notice and close boat ramps on an emergency basis due to risk of zebra mussels.

14.3.2 Federal Law and Regulations

Even though there are only two federal laws and one Executive Order corresponding to invasive species, the history of related federal law is both interesting and instructive. Prior to the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA), subsequently amended by the National Invasive Species Act of 1996 (NISP), there was a rather long transition from federal law dealing with terrestrial and agricultural pests to laws with provisions for aquatic nuisance species. The first animal quarantine laws date back to 1884; the Lacey Act to 1900. Federal acts dealing with plant pests were passed in 1912, 1939, 1957, and 1975.

(Federal law reacting to aquatic nuisance species did not appear until revisions to the Lacey Act in the 1960s and 1980s). The Great Lakes Fishery Commission was established in 1955 and the Water Resources Development Act of 1958 included provisions related to aquatic nuisance species. The Lacey Act revisions were in response to mollusks, crustaceans, reptiles, and fish species that had become a problem. In 1977, President Carter issued Executive Order 11987 recognizing that exotic species posed a threat to terrestrial and aquatic ecosystems; however, this Executive Order did not mandate specific response. The history prior to NANPCA is important because it shows that federal law was approached in a reactive not proactive manner and that, for the most part, it took a species by species approach.

During the 1980s, the “modern era” of federal reaction to aquatic invasive species coincided with increasing concerns with the occurrence of nonindigenous species in the Great Lakes. The “biology of ballast water” became a topic of interest and recommendations that ships exchange ballast water before entering the Great Lakes were heard. Then, in 1988, zebra mussels appeared. In late 1989, Monroe, Michigan, lost its water supply due to zebra mussel infestation. Drafting of federal legislation began in the same year. Estimates of potential damages amounting to $5.0 billion by 1999 were made by the US Fish and Wildlife Service (USFWS).

NANPCA was certainly a reaction to the zebra mussel infestation of the Great Lakes, but it also set up proactive measures through the USFWS to establish the Aquatic Nuisance Species (ANS) Task Force and work with the States in developing State ANS plans. In addition to the estimated damages of $5.0 billion, the other findings presented in the P.L. 106-580, the NANPCA, are instructive:

> **SEC. 1002. FINDINGS AND PURPOSES.**
> (a) FINDINGS.—The Congress finds that—
> (1) the discharge of untreated water in the ballast tanks of vessels and through other means results in unintentional introductions of nonindigenous species to fresh, brackish, and saltwater environments;
> (2) when environmental conditions are favorable, nonindigenous species become established, may compete with or prey upon native species of plants, fish, and wildlife, may carry diseases or parasites that affect native species, and may disrupt the aquatic environment and economy of affected nearshore areas;
> (3) the zebra mussel was unintentionally introduced into the Great Lakes and has infested—
> (A) waters south of the Great Lakes, into a good portion of the Mississippi River drainage;
> (B) waters west of the Great Lakes, into the Arkansas River in Oklahoma; and
> (C) waters east of the Great Lakes, into the Hudson River and Lake Champlain;
> (4) the potential economic disruption to communities affected by the zebra mussel due to its colonization of water pipes, boat hulls and other hard surfaces has been estimated at $5,000,000,000 by the year 2000, and the potential disruption to the diversity and abundance of native fish and other species by the zebra mussel and ruffe, round goby, and other

nonindigenous species could be severe;

and

(13) if preventive management measures are not taken nationwide to prevent and control unintentionally introduced nonindigenous aquatic species in a timely manner, further introductions and infestations of species that are as destructive as, or more destructive than, the zebra mussel or the ruffe infestations may occur;
(14) once introduced into waters of the United States, aquatic nuisance species are unintentionally transported and introduced into inland lakes and rivers by recreational boaters, commercial barge traffic, and a variety of other pathways; and
(15) resolving the problems associated with aquatic nuisance species will require the participation and cooperation of the Federal Government and State governments, and investment in the development of prevention technologies.

In 1996, Congress reauthorized and expanded NANPCA. The following summary is from a report submitted to the Aquatic Nuisance Species Task Force (ANSTF):

> "The National Invasive Species Act of 1996 (NISA), established a national ballast management program targeted at all U.S. coastal regions, continues the mandatory Great Lakes ballast water management requirements, and expanded invasive species management programs within the Department of Interior and the National Oceanic and Atmospheric Administration (NOAA). NISA established a federal interagency Aquatic Nuisance Species Task Force (ANSTF), co-chaired by the United State's Fish and Wildlife Service (USFWS) and NOAA, responsible for coordinating governmental efforts related to aquatic nuisance species in the United States. ANSTF is charged with developing an Aquatic Nuisance Species Program, describing the responsibilities of individual agencies, and recommending necessary funding levels. NISA also directed States to develop Aquatic Nuisance Species Management Plans. NISA provides the opportunity for Federal cost–share support for a Plan's implementation once it has been approved by the ANSTF."

The Western Regional Panel on Aquatic Nuisance Species (WRP) was included in the NISA to facilitate a coordinated response to the spread and potential spread of invasive species in states west of the 100th Meridian.

Subsequent to NANPCA and NISA, the Lacey Act was amended to add more prohibited aquatic species and the WRDA of 1999 included invasive species controls for the Great Lakes. In 1999, President Clinton signed Executive Order 13112. Unlike the previous Executive Order, this one did prescribe a number of actions and prohibited a number of actions by federal agencies. This Executive Order remains in effect today and is an important consideration for all federal agencies permitting water-related activities. The purpose of this Executive Order was to prevent the introduction of invasive species and to minimize the economic, ecological and human health impacts. Under this Executive Order, federal agency actions that may affect the status of invasive species are to be identified and agencies shall not "…authorize, fund, or carry out actions that it believes are likely to cause or promote the introduction or spread of invasive species….” An Invasive Species Council was established to include the Secretaries of the Departments of State, Treasury, Defense, Interior, Agriculture, Commerce, Transportation and the Environmental Protection Agency. In addition to a series of coordination efforts with the ANS Task Force and states, the Council is also charged with developing a National Invasive Species Management Plan.

Figure D-2 presents the recent history of federal law, including pertinent Executive Orders. The figure also attempts to show federal law in relation to the “spread” of zebra and quagga mussels. The idea is to show federal law response in terms of the growing zebra and quagga mussel problem. The USGS annual progression maps and rough estimates of the distances from the Great Lakes were used to prepare this portion of the table. As the figure shows, the federal law response to aquatic nuisance species with specific provisions for zebra mussels began with the NANPCA passed in late 1990. However, even with the proactive measures established in the NANPCA and the NISP of 1996, zebra and quagga mussels continued to “spread.” From the 1990 NANPCA to the time President Clinton issued Executive Order 13112, the zebra and quagga mussels “spread” had roughly doubled in distance. It is important to note that Executive Order 13122 was the last federal action pertinent to zebra and quagga mussels until the Clean Boating Act of 2008.

14.3.3 Texas Law

As discussed above, Chapter 66, Subchapter A, of the Texas Parks and Wildlife Code provides for the following:

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§ 66.007. EXOTIC HARMFUL OR POTENTIALLY HARMFUL FISH,
SHELLFISH, AND AQUATIC PLANTS.
        (a) No person may import, possess, sell, or place into water of this
state exotic harmful or potentially harmful fish, shellfish, or aquatic plants
except as authorized by rule or permit issued by the department.
        (b)  The department shall publish a list of exotic fish,
shellfish, and aquatic plants for which a permit under Subsection
(a) of this section is required.
        (c)  The department shall make rules to carry out the
provisions of this section.
```

The TPWD has promulgated Rules under Texas Administrative Code: Chapter 57. Fisheries; Subchapter A. Harmful or Potentially Harmful Fish, Shellfish, and Aquatic Plants (see http://info.sos.state.tx.us/pls/pub/readtac$ext.ViewTAC?tac_view=5&ti=31&pt=2&ch=57&sch=A&rl=Y). Under this Rule, the harmful or potentially harmful species are defined by name. This includes zebra mussels. The general rule provided at 57.112, states:

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(a) Scientific reclassification or change in nomenclature of taxa at any level
in taxonomic hierarchy will not, in and of itself, result in redefinition of a
harmful or potentially harmful exotic species.
(b) Except as provided in §57.113 of this title (relating to Exceptions), it
is an offense for any person to release into the water of this state, import,
sell, purchase, transport, propagate, or possess any species, hybrid of a
species, subspecies, eggs, seeds, or any part of any species defined as a
harmful or potentially harmful exotic fish, shellfish, or aquatic plant.
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(c) Except as specifically authorized in writing by the department, it is an offense for anyone to remove a live grass carp from the water of this state where grass carp have been introduced under a permit issued by the department.
(d) Violation of any provision of a permit issued under these rules is a violation of these rules.

Regarding penalties, TPWD Rule 57.137 references penalties applicable under the Texas Parks and Wildlife Code, 66.012.

The TPWD submitted a bill in the current Texas 83rd Legislature to give TPWD more authority to actually "require" boaters to drain all water when leaving a particular lake and would give TPWD game wardens more authority to stop and inspect suspected boats and vehicles.

14.3.4 Other State Laws and Regulations, including use of Local Ordinances

The following is a summary of pertinent state law and regulations for Massachusetts, California, Colorado, and Idaho.

Massachusetts. Massachusetts is an example of several levels of state government having authorities to respond to zebra mussel problems. The Massachusetts General Law (MGL) provides for and protects public access to "great ponds," which are owned by the commonwealth, and recognizes that the public has the right to fish and boat on them. Related to invasive species, MGL provides authority to the Department of Conservation and Recreation (DCR), the Department of Fish and Game (DFG), and, by delegation, to the DFG's Office of Fishing and Boating Access (OFBA). The DCR has authority to oversee and care for the natural resources of the commonwealth and has authority to carry out measures for its protection. Under MGL, the DCR has the authority to establish and maintain an Aquatic Nuisance Control Program and can issue regulations related to the program. However, this section of law does not allow DCR to impose penalties; regulations cannot extend beyond a particular water body.

The DFG is authorized to adopt regulations that govern the use of land and water areas designated as public access locations. The DFG public access regulations are then administered by the OFBA. Finally, with regard to zebra mussel management, it is the OFBA under rule (320 CMR 2.02) that has authority to establish a broad range of management measures governing boat ramps and other public access facilities, including the right to restrict, suspend or prohibit the use of such facilities. The rule sets penalties for violations of the OFBA regulations, including $100 fine and the towing or removal at the owner's cost of any vehicle, trailer or watercraft in violation.

Local authorities may enact regulations for water bodies (great ponds) not exceeding 500 acres. However, any regulations on hunting or fishing require the approval of the DFG; any boating regulations require the approval of the Office of Law Enforcement, referred to as the "Environmental Police."

Under Massachusetts state law, these agencies do respond strongly to zebra mussel concerns. In January 2009, DCR and the Massachusetts Water Resources Agency closed Quabbin

Reservoir to all private recreational boats after discovering one week earlier zebra mussels in a nearby Berkshire County lake. This action was taken even though no zebra mussels had been found in Quabbin Reservoir, a primary water supply reservoir for the Boston area. In January 2010, the DCR set specific boat inspection procedures for Quabbin Reservoir for the fishing season, including boat certification options and a $50 fee.

The DCR actively participates in public meetings at State Parks and public access facilities to educate the public on its zebra mussel and invasive species control programs.

California. In California, it is local and regional water authorities and agencies that have the authority delegated by state law to promulgate regulations at reservoirs and water bodies under their legal jurisdiction. The water bodies and agencies that currently have such regulations in place are:

- Crowley Lake
- Los Angeles Department of Water and Power
    - Lakes Camanche, Pardee, San Pablo, Chabot, Briones, and Lafayette East Bay Municipal Utilities District
- Lake County, Includes Clear Lake
- Lake Casitas
- Lake Cachuma
- Lake Tahoe
- Santa Clara County Parks

Boaters and recreationalists can find a summary of the regulations governing these water bodies at the California Department of Boating and Waterways website.

Lake County is an example of the extent to which a local ordinance can establish programs and take actions under it. In January 2011, the Lake County Board of Supervisors adopted Ordinance 2936, “establishing a fee-based inspection program for all water vessels launched in the County of Lake.” The Ordinance applies to any trailered water vessel intending to launch on a water body in Lake County. Residents of Lake County must submit to screening and inspection to receive a “Resident Mussel Sticker,” which is color-coded and re-issued annually. Non-residents of Lake County must be “…affixed with color-coded, monthly, Non-resident Mussel Stickers…” after successful screening and inspection. The “screening process” procedures are specifically prescribed. Inspection locations are designated in the County, and inspections are carried out by County personnel. A $10.00 fee is established for screening and/or inspection services. Any person violating the Ordinance can be accessed Criminal penalties and be guilty of a misdemeanor and punished by a fine of not less than $1,000 and/or six months in the county jail.

Lake Casitas is another example. The Casitas Municipal Water District has established the following regulations and restrictions to deal with quagga mussels:

- Boats, including canoes and kayaks, are allowed after a clean and dry inspection and a 10-day quarantine of the vessel and trailer. Float tubes and boats with ballast tanks are not allowed.
- Boaters wanting to participate in this program must call the District for a mandatory inspection appointment.
- The program relies on locks and tags that are designed to ensure boats are not used at any other lake. There will be a charge to cover the cost of the inspection, lock and tags. Boats will be locked to their trailer, which can then be stored at a boater's home or at Lake Casitas. Boaters will be able to use Lake Casitas as often as they like after their boat goes through the initial clean and dry inspection and the 10-day quarantine period. Once a boater decides to use another lake, they will need to start the process all over again.

In summary, local regulation for individual water bodies or for water bodies within a single agency's jurisdiction is site-specific and very prescriptive. It is clear that individual agencies in California understand the threat to their waters and are willing to enforce and finance the programs and practices to deal with it.

Colorado. Aquatic nuisance species are dealt with under Section 1, Title 33 of the Colorado Revised Statutes, Article 10.5. The rules are established under Chapter 8, Article 1 General Provisions of the Aquatic Nuisance Species Code to provide the Division of Parks and Outdoor Recreation (Division) with certain authorities. Section #800 identifies the aquatic nuisance species that include both zebra and quagga mussels. Other sections of these rules that should be noted include:

- Section #802 – provisions for Division to certify private inspectors and/or decontaminators. Training is prescribed for certification as an authorized agent to conduct these duties. The section provides that an authorized agent shall perform decontaminations at the direction of a qualified peace officer or at the voluntary request of the vessel owner.
- Section #803 – provisions for inspections of vessels. Inspections may be conducted by any qualified peace officer or any authorized agent, properly trained by the Division and having a certification. This section and others refer to and prescribe the Watercraft Inspection and Decontamination (WID) procedures that must be followed.
- Section #804 – provisions for decontamination. The only acceptable method will be rinsing and flushing with water of 140 degrees F or hotter. A WID seal will be issued after proper decontamination.
- Section #805 – provisions for impounding vessels where the owner refuses to allow inspection by certified agent or where there is refusal to allow decontamination when it is ordered by a qualified peace officer.

The Colorado rules also include provisions for monitoring and reporting of ANS. These provisions went into effect in April 2009.

Idaho. The Idaho statutes are under Title 22 Agriculture and Horticulture, Chapter 19, the Idaho Invasive Species Act of 2008. The rules are under IDAPA 02.06.09, "Rules Governing Invasive Species." The law and rules are set up to govern all invasive species, but recent additions are specific to zebra and quagga mussels:

- Section 200 – establishes an "Early Detection and Rapid Response Aquatic Invertebrate Invasive Species" list. Any species on this list is to be reported to Department of Agriculture (Department) immediately. At this time the only two species on the EDRR AIIS list are zebra and quagga mussels. The sections makes it illegal to transport on any roadway, waterway or by any other means these species. Any person identifying these species is requested to immediately report it to the Department.
- Section 202 – deals with inspections for the EDRR AIIS species. Inspections can be conducted by any authorized agent, private inspector or peace officer qualified and trained in accordance with the Department's requirements. For vessels that have been in infested waters, a document of inspection must be received; for all other vessels, inspections may be conducted. Inspection methods are described. Decontamination is required if a vessel is found or reasonably believed to contain EDRR AIIS species.
- Section 204 – hold orders may be issued if any vessel owner refuses inspection or decontamination.
- Section 205 – lays out the decontamination protocols and requirements for re-inspection and proof of decontamination.

Even though to date Idaho does not have zebra or quagga mussel infested water, the state has the authority in place and invests heavily in the program. The following is a breakout of the Idaho Invasive Species Fund Program Budget for 2011:

Inspection Station Operations: $490,083 (77%)
Monitoring: $73,882 (12%)
Outreach: $18,831 (3%)
Supplies: $51,389 (8 %)

14.4 FUNDING OPPORTUNITIES

The opportunities for funding are limited both at the State and Federal levels. The State of Texas cut TPWD funding to support the agency's Aquatic Nuisance Species programs, including zebra mussels. The federal funding for invasive programs has been cut significantly in recent years. However, at the Congressional level, there is recognition and support for the various federal programs dealing with zebra and quagga mussels. Other invasive species control programs have been recently funded, including the USACE program to stop the potential spread of Asian Carp into the Great Lakes. The Western States Council, the Northwest Power and Conservation Council, and others are petitioning for federal funding to help States implement approved ANS plans.

14.4.1 Federal Grants

The USFWS established several grant programs for aquatic invasive species efforts under NANPCA/NISP authorities. At this time, these grant funds are limited and, if available, the amounts are minor compared to the cost of many control options. However, these types of grants can be beneficial in completing local or state zebra mussel control plans.

For example:

- In FY210 the USFWS spent $2 million on zebra/quagga projects. $800,000 went to Lake Tahoe for an inspection and decontamination program. $600,000 was divided among all entites with an ANS Task Force approved state or interstage management plan, and another $600,000 was divided among projects addressing the highest priorities of the 2010 Quagga/Zebra Mussel Action Plan for Western U.S. Waters.
- In FY2011, under a continuing resolution, the USFWS decided to allocate this $2 million to other priorities.
- In FY2012, under another continuing resolution the USFWS decided again not to fund quagga/zebra mussel projects, but Congress intervened and directed the USFWS to spend $1 million on the issue. That money was directed largely to the lower Colorado River.
- In FY2013, the USFWS may have another $1 million for zebra/quagga projects, depending on budget decisions.

Only one recent grant opportunity has been posted related to invasive species. The USFWS posted an Aquatic Invasive Species in the Southwest grant announcement on June 13, 2012. As recognized by the USFWS, the funding was very limited with total estimated program funding at $25,000 and an award ceiling of $10,000. The USFWS's description of the objectives and limitations of the grant highlight the limited funding available:

> Our objective is to provide assistance in preventing, managing, and controlling aquatic invasive species within the U.S. Fish & Wildlife Service's Southwest Region (TX, OK, NM, & AZ). This includes a process to fund State Aquatic Nuisance Species (ANS) Management Plans officially approved by the Aquatic Nuisance Species Task Force and authorized by the Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990. It may also include a process to fund cooperative agreements with entities, including institutions of higher education, who partner with the U.S. Fish & Wildlife Service in coordinating the prevention, management, and control of aquatic invasive species. Current program funding is considerably limited and well below the estimated total program funding listed elsewhere in this announcement. Current funding priorities include, first, state aquatic invasive species management plan implementation, and then, if additional funding is available, prevention programs for only the most severe aquatic invaders threatening Arizona, Texas, Oklahoma, and/or New Mexico. Although new projects may be considered, they must focus on invasive species that threaten or impact Texas, Oklahoma, Arizona, or New Mexico. Priority will be given to existing, successful, long-term collaborative projects. Any grant or cooperative agreement awarded through this funding opportunity will be limited to a maximum of 15% for indirect costs.

Other grant and financial assistance through the USFWS related to invasive species include (descriptions taken from the USFWS website):

- The *Partners for Wildlife Program* provides financial and technical assistance to restore degraded fish and wildlife habitat, including habitats degraded by invasive species.
- The *Coastal Program* provides financial and technical assistance to restore degraded coastal habitats, including those that have been degraded by invasive species.
- The *National Coastal Wetlands Conservation Grant Program* provides matching grants to States for acquisition, restoration, management or enhancement of coastal wetlands. Projects funded can include an invasive species component.

- After habitat loss, invasive species is the second most common reason for species endangerment. The *Endangered Species Program* has numerous Tools for State and private landowners to help them protect endangered species on their property.
- The *Neotropical Migratory Bird Conservation Act Grants Program* supports public-private partnerships carrying out projects in the United States, Canada, Latin America, and the Caribbean that promote the long-term conservation of Neotropical migratory birds and their habitats. Conservation projects can include habitat restoration projects which could include an invasive species component.
- The *North American Wetlands Conservation Act of 1989* provides matching grants to organizations and individuals who have developed partnerships to carry out wetlands conservation projects in the United States, Canada, and Mexico for the benefit of wetlands-associated migratory birds and other wildlife. Conservation projects can include habitat restoration projects which could include an invasive species component.
- The *Landowner Incentive Program* establishes or supplements state landowner incentive programs that protect and restore habitats on private lands, to benefit species identified in a State's Comprehensive Wildlife Conservation Strategy or classified as Special Concern by the state, or Federally listed, proposed, or candidate species or other species determined to be at-risk, and provide technical and financial assistance to private landowners for habitat protection and restoration.
- The *Wildlife Restoration Act* provides funding to states for the selection, restoration, rehabilitation, and improvement of wildlife habitat and other projects including those for controlling invasive plants.

These grant programs have only limited funding and only remote opportunity to provide significant support for zebra mussel response in North Texas.

"Pulling Together" is a coordinated effort through the National Fish and Wildlife Foundation. The USFWS, USDA Forest Service, Bureau of Land Management, NRCS and others provide grants to non-profit organizations and government agencies interested in managing invasive and noxious plant species.

The Environmental Protection Agency has provided grants to communities, state agencies, universities, and other institutions for programs related to habitat and watershed restoration. Specific grants for zebra or quagga mussel projects were not identified.

NOAA Sea Grant program includes some opportunities for invasive species. No recent postings have been made; however, this is another potential opportunity to be monitored. The 2010 posting provides information on the programs supported and the amounts that can potentially be available.

2010 NOAA Sea Grant Aquatic Invasive Species **CLOSED MAY 17, 2010**

NOAA Sea Grant will make available $2,000,000 in 2010 and up to $2,000,000 in 2011, if appropriations are available, to Sea Grant programs to support integrated projects of research, outreach, extension, education and/or management, addressing regional aquatic invasive species priorities for U.S. coastal, ocean, and Great Lakes areas. This opportunity seeks especially to support projects that address NOAA-relevant regional aquatic invasive species priorities identified by Sea Grant Regional Research Plans, by NOAA Regional Collaboration Teams, by the Aquatic Nuisance Species (ANS) Task Force Regional Panels, and in ANS State Management Plans. Up to eleven projects of median federal funding $400,000 are anticipated. Some projects selected in this competition may be awarded in 2011 and funded with 2011 funds.

Open to the following Sea Grant Programs and Projects: all Sea Grant Colleges and Institutions, Guam Sea Grant, Lake Champlain Sea Grant, and the National Sea Grant Law Center. Proposals may request up to $400,000 in total. (But proposals addressing multiple regions may request up to $400,000 times the number of regions.) 50% Non-federal matching funds are required.

Conclusion: After review, it is clear that at least for the short-term future, the availability of federal grant funds is not a realistic expectation. Monitoring of grant availability should continue in the future.

14.4.2 Texas Water Development Board (TWDB)

The TWDB has several financial assistance programs where an invasive species project or component of a project could potentially be funded. These possibilities would include the Water Research Grant Program if the TWDB designates zebra mussels or invasive species as a research topic. The Regional Facility Planning Grant Program could support regional water planning and include a component for zebra mussels.

14.4.4 Others

At this time, no TPWD grants directly related to zebra mussels could be identified. There have been in the past conservation type grants, including habitat restoration, that were supported by private companies or contributors. As mentioned above, State appropriations for the TPWD's ANS programs were totally eliminated.

The Texas A&M University system is the NOAA Sea Grant recipient for projects along the Texas gulf coast. These are research or public outreach based efforts. Funding for large-scale zebra mussel control projects is not available.

15 Research and Development

There are many needs for additional research to further develop knowledge and understanding of zebra mussels, their control, and mitigation. This includes further understanding their ability to survive in various water conditions and developing future control methods. This section provides summaries of some research opportunities that could be especially significant in dealing with zebra mussels in Texas.

15.1 TURBULENCE

It is generally accepted that turbulence has an impact on veliger survival. However, what is not well understood is the ability of veligers to survive pipeline transfers. In order to survive, veligers must successfully navigate pump impellers, the pipeline, and outfall turbulence. Proven inability to survive pipeline transfers could provide another form of control for zebra mussel veligers. Filters could be used to remove adults. In addition, outfall structures could also be designed to increase turbulence. This is consistent with current design of many outfalls which contain energy dissipaters to reduce the velocity and erosion potential of water.

A recent inspection of a pipeline at Lake Texoma showed a heavy infestation of zebra mussels attached to the pipeline in the first 2,000 feet. It should be noted that the flow rate in the large diameter pipeline has been low since the detection of mussels in Lake Texoma. The level of infestation decreased substantially with further distance away from the pump station. Eight miles down the pipeline there were no observed zebra mussels attached to the pipeline. At low velocities the “ready to settle” veligers will attach to the pipeline as soon as possible, mainly in the first 1,000 feet; the not ready to settle veligers will remain suspended and travel down the pipeline. Veligers were detected in water quality samples taken approximately 10 miles down the pipeline.

The challenge for turbulence as a viable treatment would be to prove with accuracy the mortality of veligers under various conditions.

15.2 TURBIDITY

Turbidity is a water quality parameter that impacts zebra mussel survival. The Trinity River and Red River in Texas are turbid rivers that may restrict the further expansion of zebra mussels. The Red River downstream of the zebra mussel-infested Lake Texoma has not been studied. Zebra mussels have been found attached to bridges and rocks in slack water areas downstream of the Red River. However, it is unknown whether these mussels are self-sustaining or simply a result of veligers coming downstream from Lake Texoma. Further research could provide knowledge on the ability of zebra mussels to survive in a turbid water environment.

15.3 AIR BURST SYSTEMS

Air burst systems are typically used to remove debris from intake screens. However, they have not been designed to remove mussels. Air burst systems could provide an easy solution to intake screen cleaning. If air burst systems could be designed to remove mussels effectively, they could eliminate, or at least reduce, the need for chemicals or manual cleaning.

15.4 ELECTRIC CURRENT AND ACOUSTICS

These treatment methods have been shown to impact veliger, juvenile, and adult survival. However, further development is needed to find cost-effective solutions that can be implemented in piped systems. In addition, negative impacts need to be identified and mitigated to prevent catastrophic failures. Electrical currents and acoustics might provide effective treatment in place of chemicals.

16 References

1. Alexander, J.E. Jr., J.H. Thorp, and R.D. Fell. 1994. Turbidity and temperature effects on oxygen consumption in the zebra mussel (*Dreissena polymorpha*). *Canadian Journal of Fisheries and Aquatic Sciences* 51: 179-184.
2. Benschoten, J.E., J.N. Jensen, T.J. Brady, D.P. Lewis, J. Sferrazza, and E.F. Neuhauser. 1993. Response of Zebra Mussel Veligers to Chemical Oxidants. *Water Resource* 27: 575-582.
3. Benson, A.J., D. Raikow, J. Larson, and A. Fusaro. 2012. *Dreissena polymorpha*. USGS Nonindigenous Aquatic Species Database, Gainesville, FL. http://nas.er.usgs.gov/queries/factsheet.aspx?speciesid=5 Revision Date: 6/6/2012
4. Bobeldyk, A.M., J.M. Bossenbroek, M.A. Evans-White, D.M. Lodge, and G.A. Lamberti. 2005. Secondary spread of zebra mussels (*Dreissena polymorpha*) in lake-stream systems. *Ecoscience* 12: 339-346.
5. Bodamer, B. and J. Bossenbroek. 2008. Wetlands as barriers: effects of vegetated waterways on downstream dispersal of zebra mussels. *Freshwater Biology* 53: 2051-2060.
6. California Department of Fish and Game, 2012. Zebra and Quagga Mussels Veliger Sampling Protocol Available: nrm.dfg.ca.gov/FileHandler.ashx?DocumentVersionID=74134 Accessed: January 18, 2013.
7. Churchill, C.J., and S. Baldys, 2012, USGS Zebra Mussel Monitoring Program for North Texas: U.S. Geological Survey Fact Sheet 2012–3077, 6 p.
8. Cohen, A.J., and A. Weinstein, 1998, Methods and Data for Analysis of Potential Distribution and Abundance of Zebra Mussels in California. San Francisco Estuary Institute. Richmond, CA.
9. Cohen, A.J. 2007. Potential Distribution of Zebra Mussels (*Dreissena polymorpha*) and Quagga Mussels (*Dreissena bugensis*) in California Phase 1 Report. California Department of Fish and Game.
10. De Kock, W., Bowmer, C., 1993. Bioaccumulation, biological effects, and food chain transfer of contaminants in the zebra mussel (Dreissena polymorpha). In: *Zebra Mussels Biology, Impacts, and Control*, T.F. Nalepa and D.W. Schloesser, eds, pp.503-536. Boca Raton: Lewis Publishers.
11. Ekroat, L.E., E.C. Mastellar, J.C. Schaffer, and L.M. Steele, 1993. The byssus of the zebra mussel (*Dreissena polymorpha*): Morphology, byssal thread formation, and detachment. In: *Zebra Mussels Biology, Impacts, and Control*, T.F. Nalepa and D.W. Schloesser, eds, pp. 239-263. Boca Raton: Lewis Publishers.
12. Hincks, S.S. and G.L. Mackie, (1997). Effects of pH, calcium, alkalinity, hardness and chlorophyll on the survival, growth, and reproductive success of zebra mussels (*Driessena polymorpha*) in Ontario Lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 54:2049-2057.
13. Horvath, T.G., Lamberti, G.A., Lodge, D.M., and W.L. Perry, 1996. Zebra Mussel Dispersal in Lake-Stream Systems: Source-Sink Dynamics. *Journal of the North American Benthological Society* 15(4); 564-575.
14. Indiana Department of Natural Resources, 2005. Aquatic Invasive Species-Zebra Mussels. Available: http://www.in.gov/dnr/files/ZEBRA-MUSSEL.pdf. Accessed: May 4, 2012.
15. Invasive Species Program. 2011. Invasive Species of Aquatic Plants and Wild Animals in Minnesota: Annual Report for 2011. Minnesota Department of Natural Resources, St. Paul, MN.

16. Invasive Species Program. 2012. Invasive Species of Aquatic Plants and Wild Animals in Minnesota: Annual Report for 2012. Minnesota Department of Natural Resources, St. Paul, MN.
17. Jenner, H.A., 1978. Chlorine minimization in macrofouling control in the Netherlands. In: *Water Chlorination: Environmental Impact and Health Effects, Proceedings of the Third Conference on Water Chlorination*, Colorado Springs, USA, October 28 to November 2.
18. Johnson, L.E. and J.T. Carlton. 1996. Post-Establishment Spread in Large-Scale Invasions: Dispersal Mechanisms of the Zebra Mussel *Dreissena Polymorpha*. *Ecology,* 77(6) 1686-1690.
19. Johnson, L.E., J. M. Bossenbroek and C.E. Kraft. 2006. Patterns and pathways in the post-establishment spread of non-indigenous aquatic species: the slowing invasion of North American inland lakes by the zebra mussel. *Biological Invasions* 8:475-489.
20. Kozlowski, S., C. Page, and J. Whetstone. 2002. Zebra Mussels in South Carolina: The Potential Risk of Infestation. South Carolina Zebra Mussel Task Force.
21. Kraft, C.E., P.J. Sullivan, A.Y. Karatayev, L.E. Burlakova, J. C. Nekola, L.E. Johnson & D.K. Padilla, 2002. Landscape patterns of an aquatic invader: Assessing dispersal extent from spatial distributions. *Ecological Applications*, 12: 749-759.
22. Lubner, J.F. (1995). Zebra Mussels. Problem Organisms in Water: Identification and Treatment- Manual of Water Supply Practices, M7 (2nd edition). (pp. 62). American Water Works Association (AWWA).
23. Mackie, G. and R. Claudi, 2010. *Monitoring and Control of Macrofouling Mollusks in Fresh Water Systems*. Boca Raton: CRC Press.
24. McMahon, R.F. and T. Ussery. 1995a. Thermal Tolerance of Zebra Mussels (*Dreissena polymorpha*) Relative to Rate of Temperature Increase and Acclimation Temperature. United States Army Corps of Engineers Technical Report EL-95-10.
25. McMahon, R.F. and T. Ussery. 1995b. Comparative Study of the Desiccation Resistance of Zebra Mussels (*Dreissena polymorpha*) and Quagga Mussels (*Dreissena bugensis*). United States Army Corps of Engineers Technical Report EL-95-6.
26. Meersman, T. 2012. Zebra Mussel Inspections Could Prove Very Costly. Available: http://www.startribune.com/local/west/142258935.html?page=2&c=y Access: June 25, 2012.
27. Miller, S.J. and J.M. Hayes, (1997). Factors limiting colonization of western New York Creeks by the Zebra Mussel (*Dreissena polymorpha*). *Journal of Freshwater Ecology*, 12, 81-88.
28. Minnesota Department of Natural Resources. 2011. Q&A Copper and zebra mussels. Available: http://www.bigcormorant.com/copper.pdf
Accessed December 15, 2011.
29. Neumann, D.J. Borcherding, and B. Janz, 1993. Growth and seasonal reproduction of *Dreissena polymorpha* in the Rhine River and adjacent waters. In: *Zebra Mussels: Biology, Impacts, and Control*, T.F. Nalepa and D.W. Schloesser, eds, pp. 95-109. Boca Raton: CRC Press.
30. Rajagopal, S.G. van der Velde, and H. Jenner. 2002. Effects of low-level chlorination on zebra mussel, *Dreissena polymorpha*. *Water Research* 36: 3029-3034.
31. Ram, J.L., P.P. Fong, and D.W. Garton, 1996. Physiological Aspects of Zebra Mussel Reproduction: Maturation, Spawning, and Fertilization. *Amer. Zool*. 36:326-338.
32. Skaja, A. 2012. Coatings for Mussel Control- Three Years of Laboratory and Field Testing. Bureau of Reclamation Technical Memorandum No. MERL-2012-11.
33. Smythe, G. and E.A. Dardeau, Jr, 1999. Overview of electrical technologies for controlling dreissenids, with emphasis on pulse-power systems, *Zebra Mussel Technical Notes Collection* (ZMR-3-22), U.S. Army Engineer Research and Development Center Vicksburg, USA.

34. Sprecher, S. and K. Getsinger. 2000. Zebra Mussel Chemical Control Guide. Environmental Laboratory, United States Army Corps of Engineers. ERDC/EL TR-00-1.
35. Sprung, M. 1987. Ecological requirements of developing *Dreissena polymorpha* eggs. *Archives of Hydrobiology Supplement* 79:69-86.
36. Sprung, M. 1993. The other life: An account of present knowledge of the larval phase of *Dreissena polymorpha*. *In* T.F. Nalepa and D.W. Schloesser (eds.), *Zebra mussels: Biology, impacts, and control*, pp. 39-54. Lewis Publishers, Boca Raton, Florida.
37. Stanczykowska, A. and K. Lewandowski, 1993. Thirty years of studies of *Dreissena polymporha* ecology in Mazurian Lakes of Northeastern Poland. In: Zebra Mussels Biology, Impacts, and Control, T.F. Nalepa and D.W. Schloesser, eds, pp.3-38. Boca Raton: Lewis Publishers.
38. Stoeckel, J.A., C.R. Rehmann, D.W. Schneider & D.K. Padilla, 2004a. Retention and supply of zebra mussel larvae in a large river system: Importance of an upstream lake. *Freshwater Biology* 49. 919-930.
39. Stoeckel, J.A., D. K. C.R. Rehmann, D.W. Schneider & D.K. Padilla, 2004b. Laboratory culture of *Dreissena polymorpha* larvae: spawning success, adult fecundity, and larval mortality patterns, *Canadian Journal of Zoology* 82:9. 1436-1443.
40. Tatem, H. 1994. Bioaccumulation of Contaminants by Zebra Mussels. Technical Note ZMR1-16 (Prepared and published by the Zebra Mussel Research Program US Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS 39180)
41. Texas Parks and Wildlife Department (TPWD). 2011. Boating Facts, Available: http://www.tpwd.state.tx.us/learning/boater_education/boating_facts/ Access: July 11, 2012.
42. Timar, L. and D. Phaneuf. 2009. Modeling the human-induced spread of an aquatic invasive: The case of the zebra mussel. *Ecological Economics* 68:3060-3071.
43. United States Geological Survey-A, 2011. Progression of Zebra Mussel (*Dreissena polymorpha*) and Quagga Mussel (*D. rostriformis bugensis*) Distributions in North America. Available: http://fl.biology.usgs.gov/Nonindigenous_Species/ZM_Progression/zm_progression.html. Accessed: May 4, 2012.
44. United States Geological Survey-B, Great Lakes Science Center, 2011. “Zebra Mussels Cause Economic and Ecological Problems in the Great Lakes” GLSC Fact Sheet 2000-6.
45. Virginia Department of Game and Inland Fisheries (VDGIF). Milbrook Quarry Zebra Mussel Eradication. Available: http://www.dgif.virginia.gov/zebramussels/ Accessed: December 13, 2011.
46. Whitby, G.E. 2011. Control of Zebra Mussels with Ultraviolet Light. Presented at Zebra Mussel Management Conference in Fort Worth, Texas. September 28, 2011.
47. Wu, Y., Bartell, S., Orr, J., Ragland, J. and Anderson, D. (2010). “A risk-based decision model and risk assessment of invasive mussels.” *Ecological Complexity* 7, 243-255.

APPENDIX A- LAKE SWQMIS WATER QUALITY SAMPLING LOCATION MAPS

Figure A-1- B.A Steinhagen SWQMIS Water Quality Sampling Stations

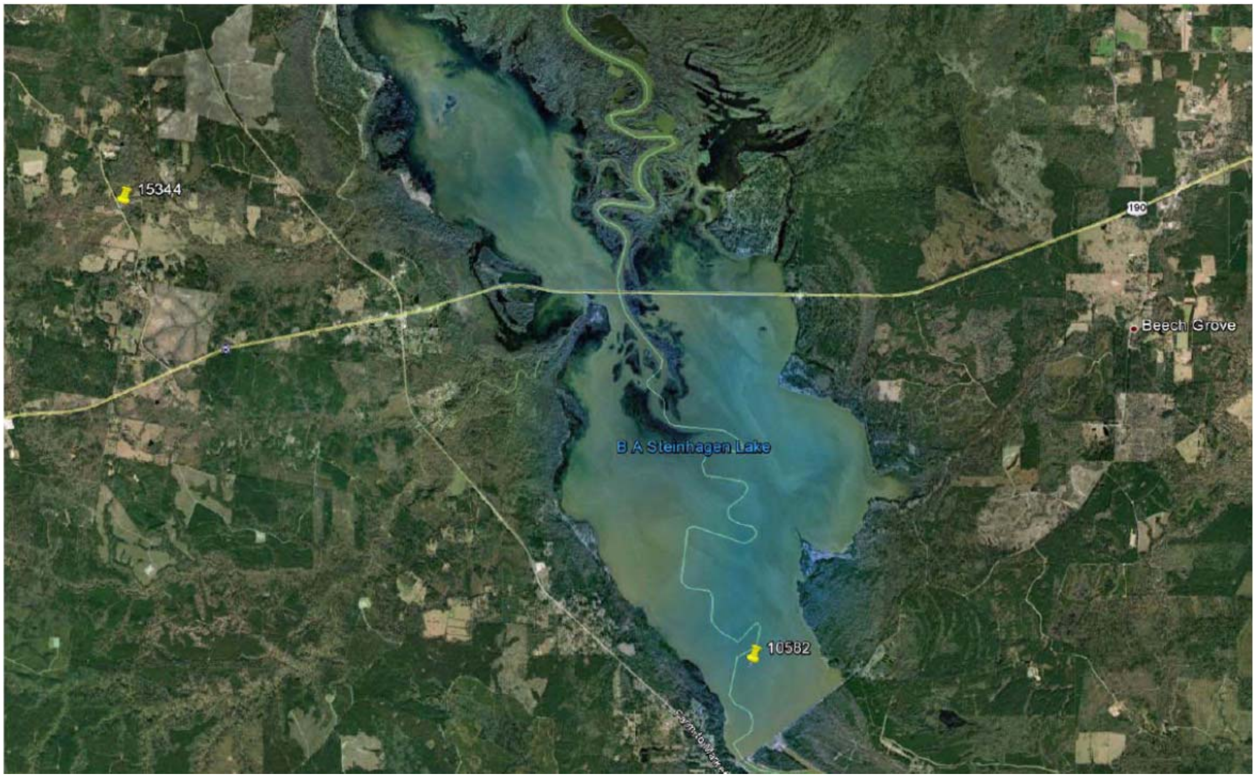


Figure A-2- Bardwell Lake SWQMIS Water Quality Sampling Stations

Figure A-3- Benbrook Lake SWQMIS Water Quality Sampling Stations

Figure A-4- Cedar Creek Reservoir SWQMIS Water Quality Sampling Stations

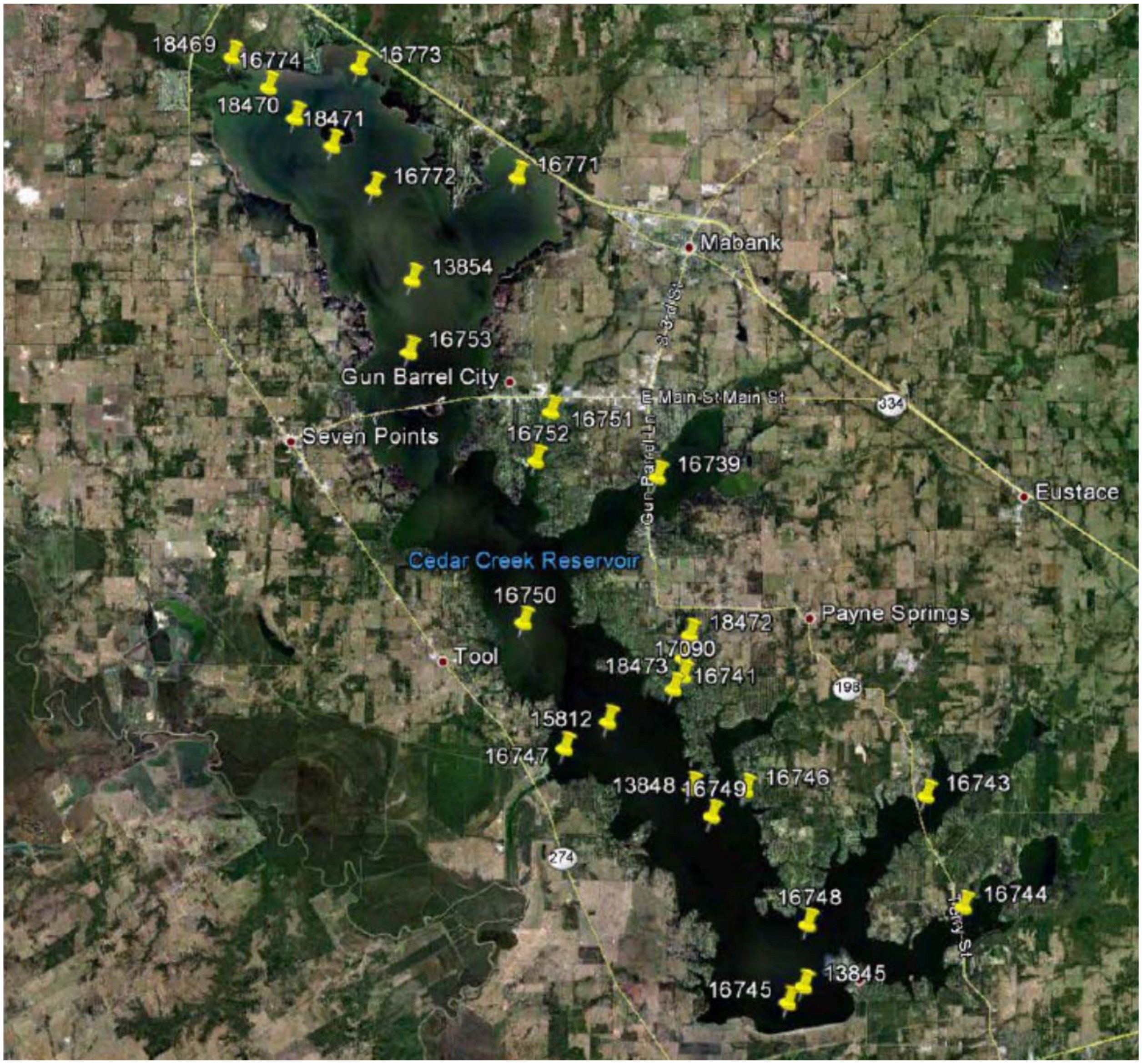


Figure A-5- Eagle Mountain Lake SWQMIS Water Quality Sampling Stations

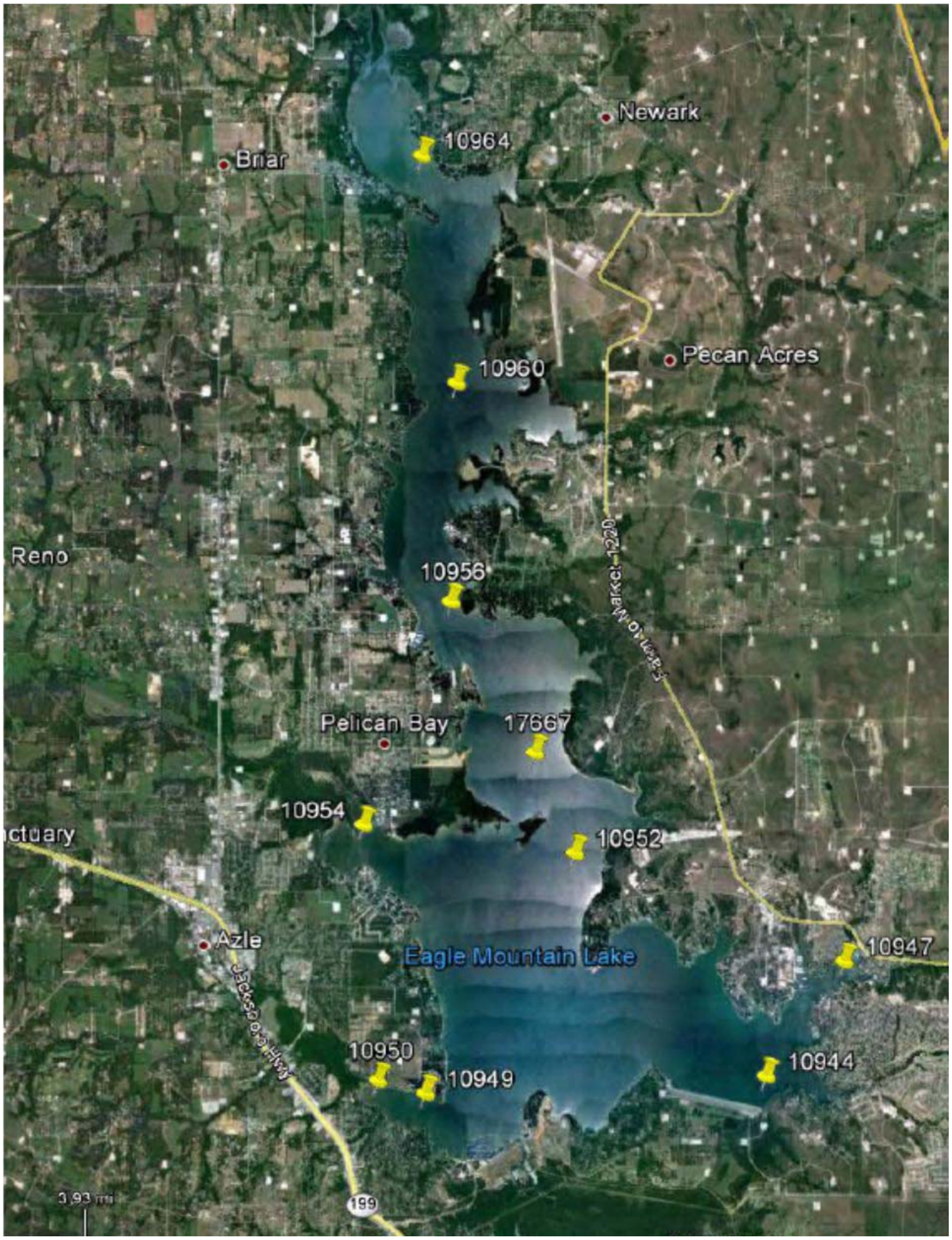


Figure A-6- Grapevine Lake SWQMIS Water Quality Sampling Stations

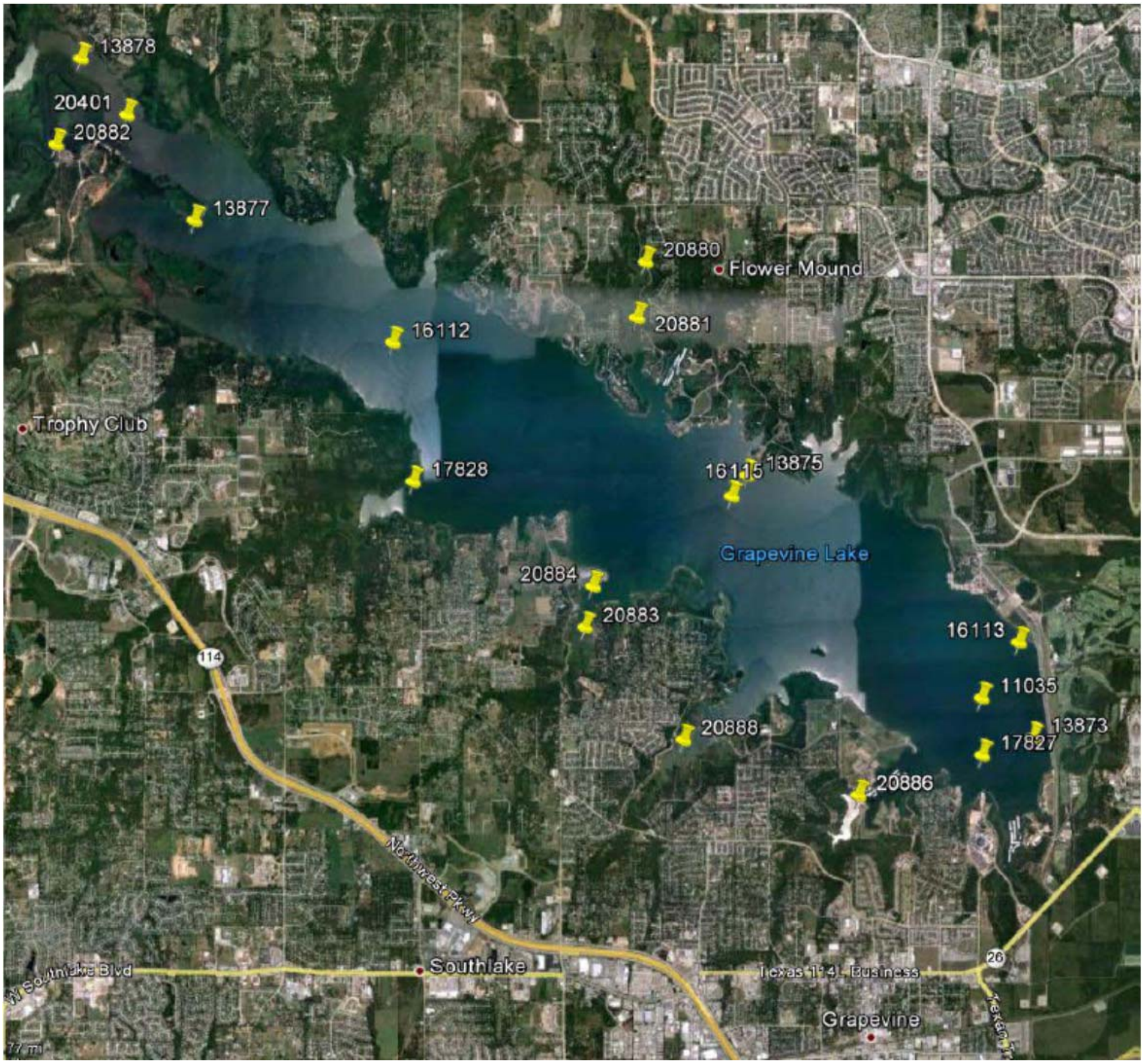


Figure A-7- Jim Chapman Lake (Cooper) SWQMIS Water Quality Sampling Stations

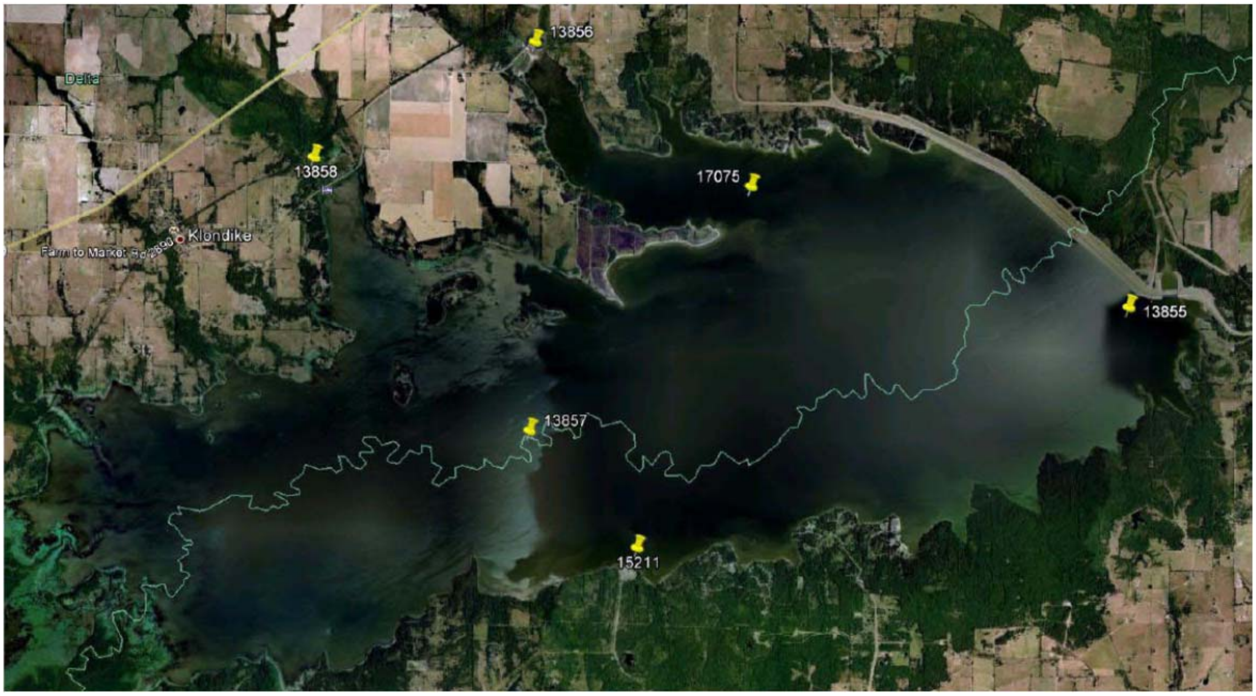


Figure A-8- Joe Pool Lake SWQMIS Water Quality Sampling Stations

Figure A-9- Lake Arlington SWQMIS Water Quality Sampling Stations

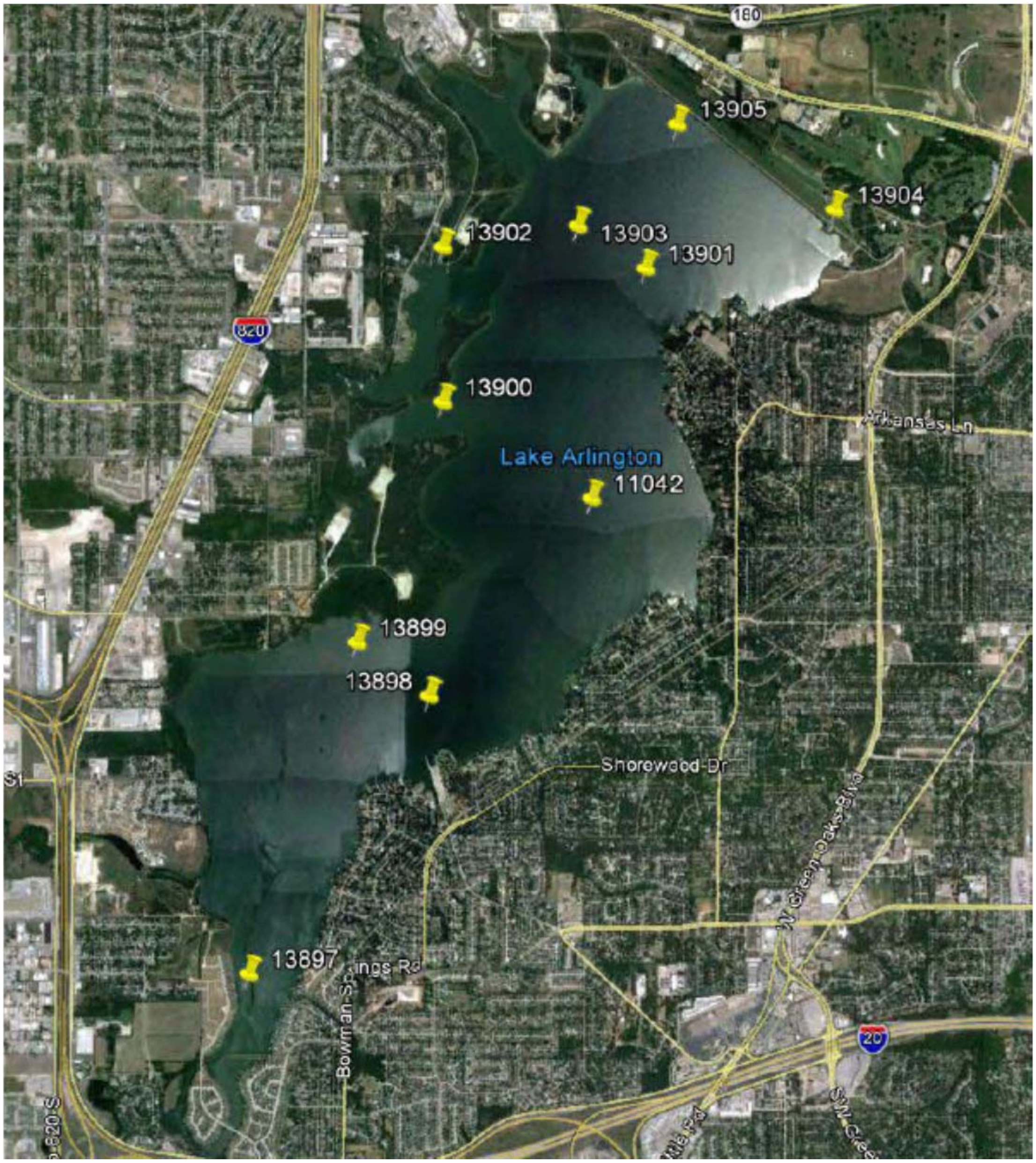


Figure A-10- Lake Bonham (No SWQMIS Water Quality Sampling Stations)

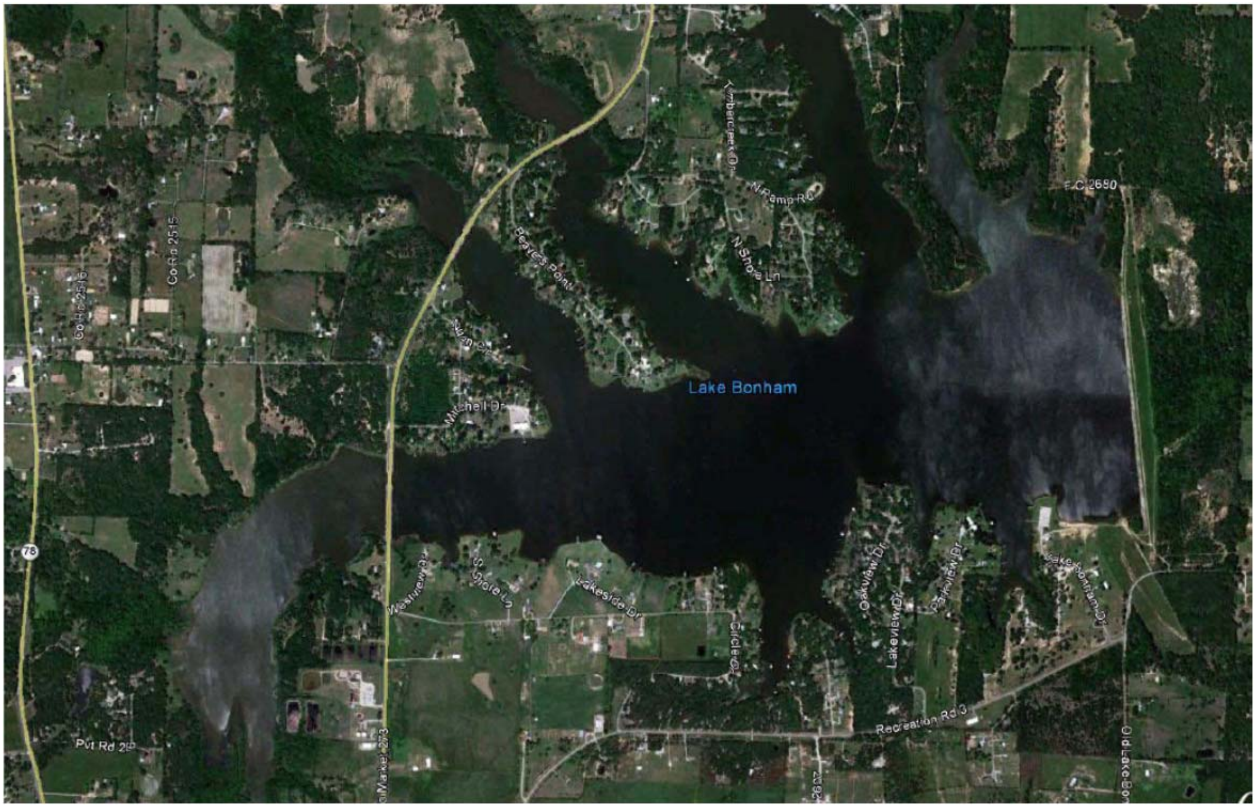


Figure A-11- Lake Bridgeport SWQMIS Water Quality Sampling Stations

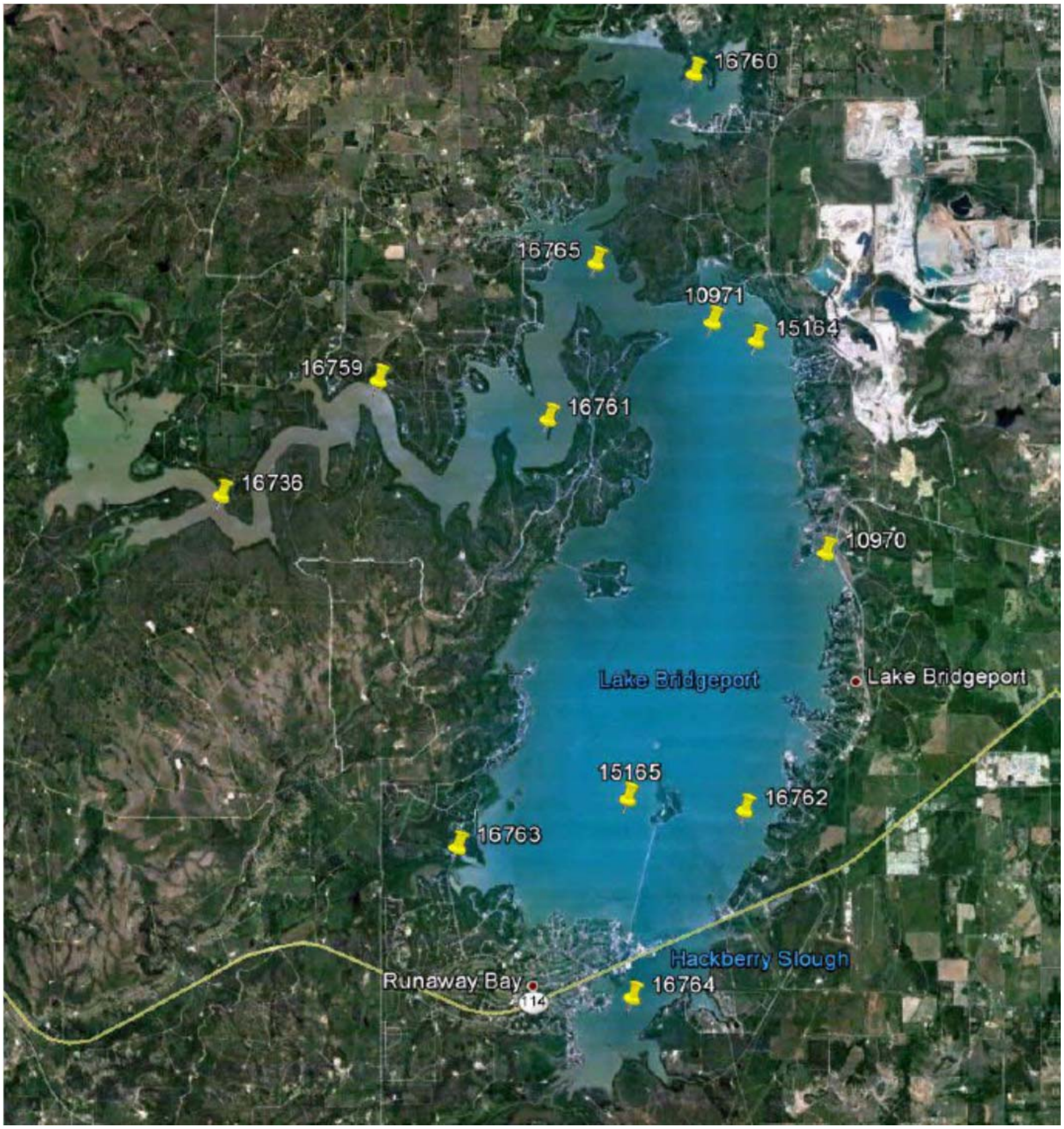


Figure A-12- Lake Conroe SWQMIS Water Quality Sampling Stations

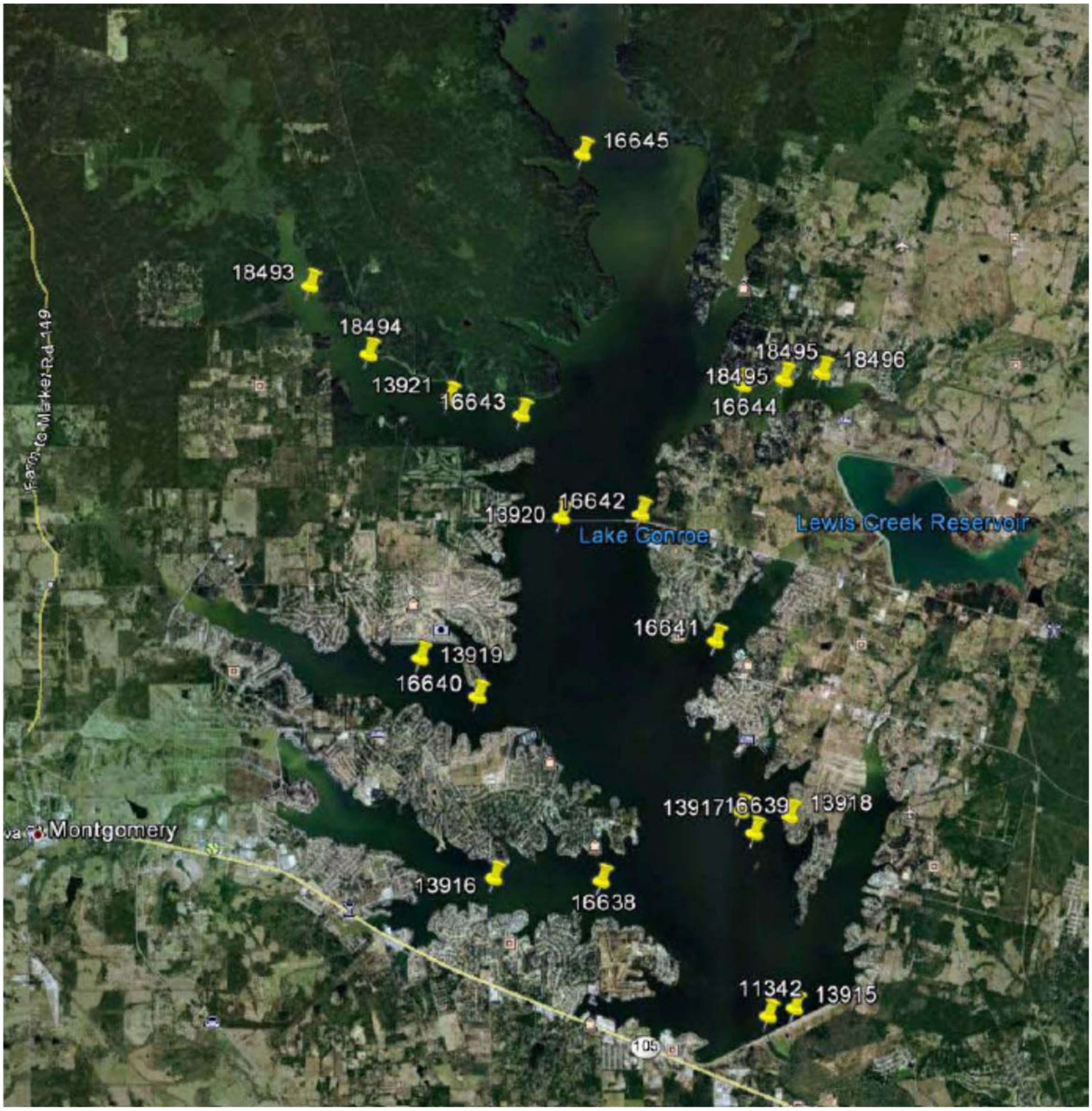


Figure A-13- Lake Fork Reservoir SWQMIS Water Quality Sampling Stations

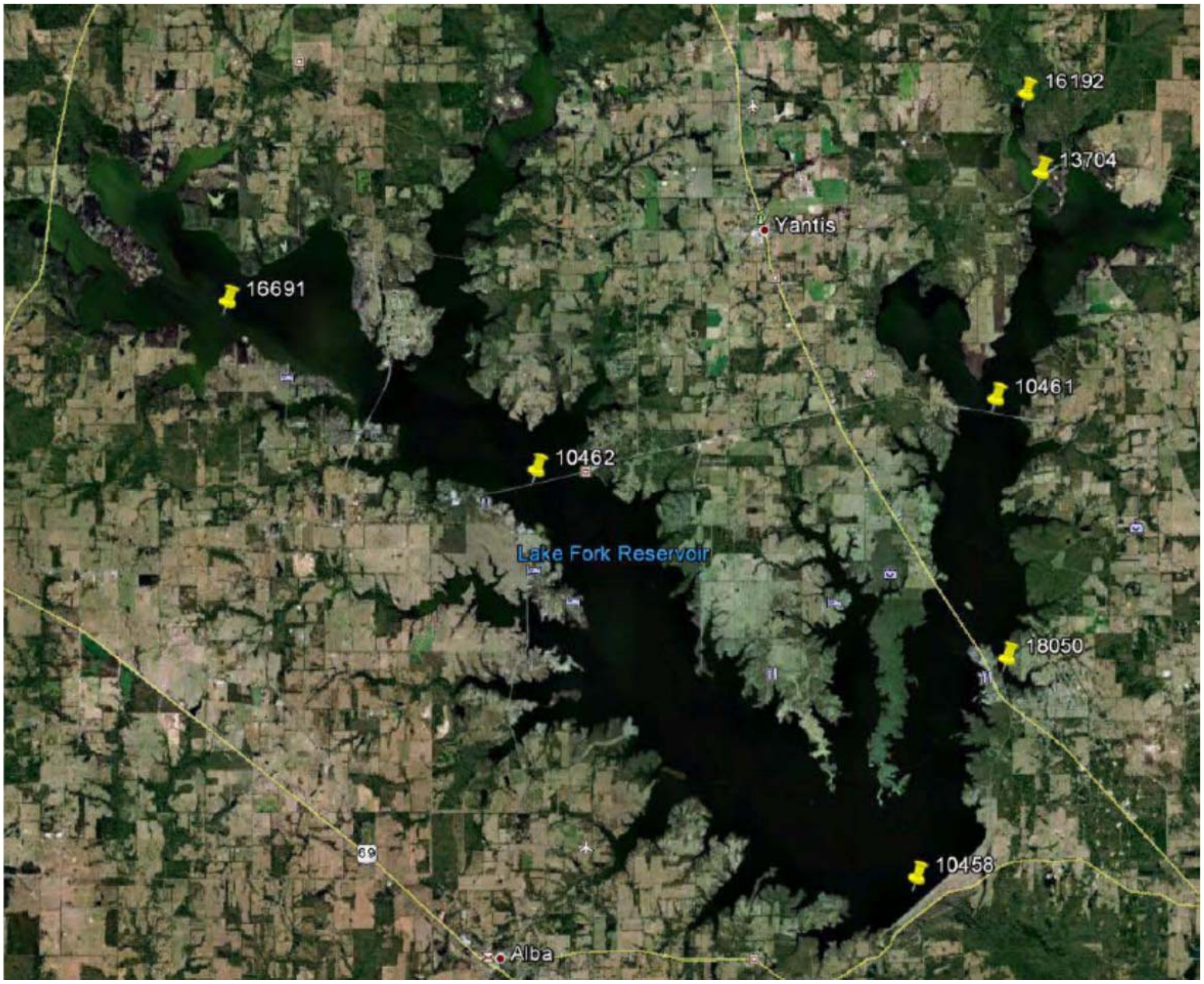


Figure A-14- Lake Houston SWQMIS Water Quality Sampling Stations

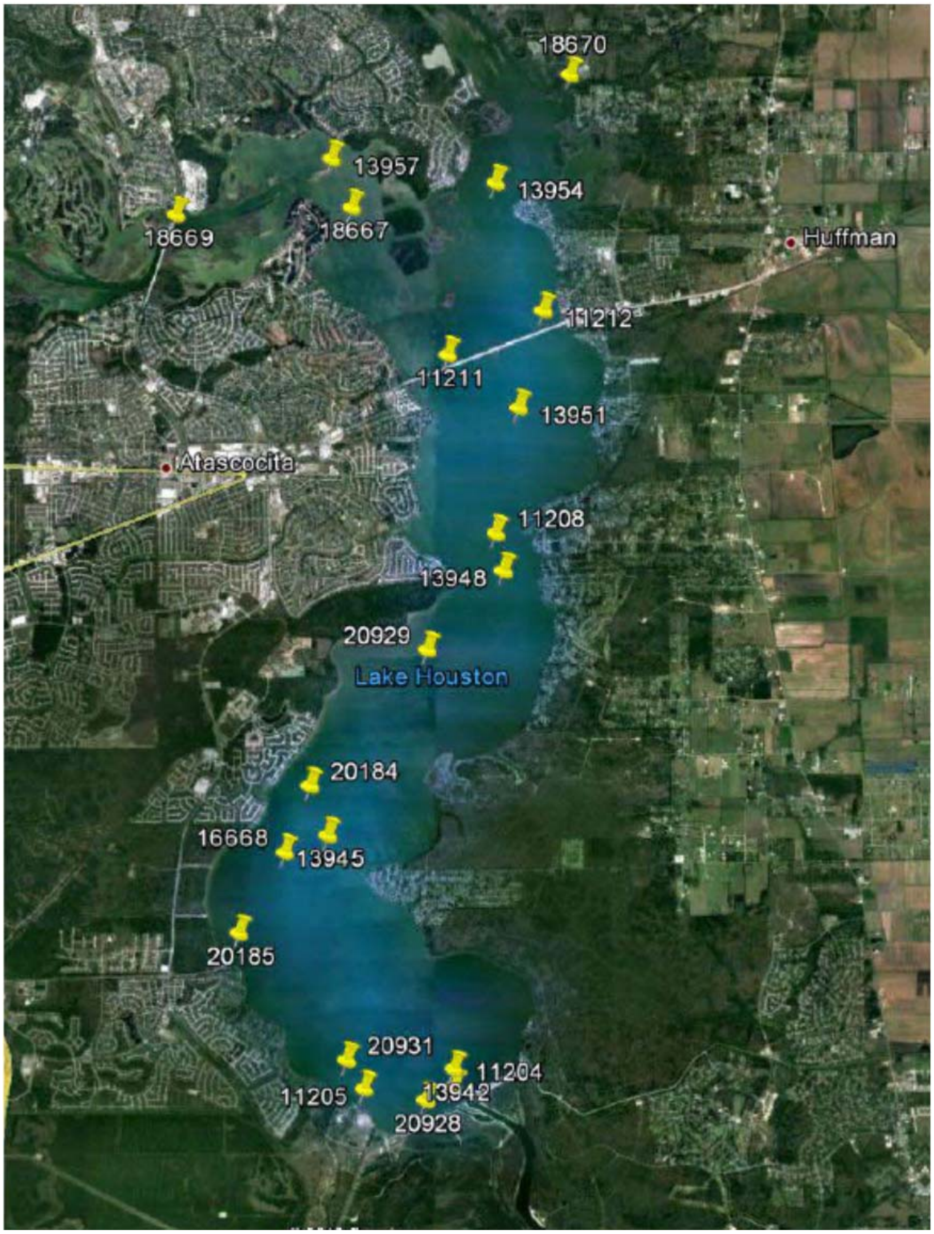


Figure A-15- Lake Livingston SWQMIS Water Quality Sampling Stations

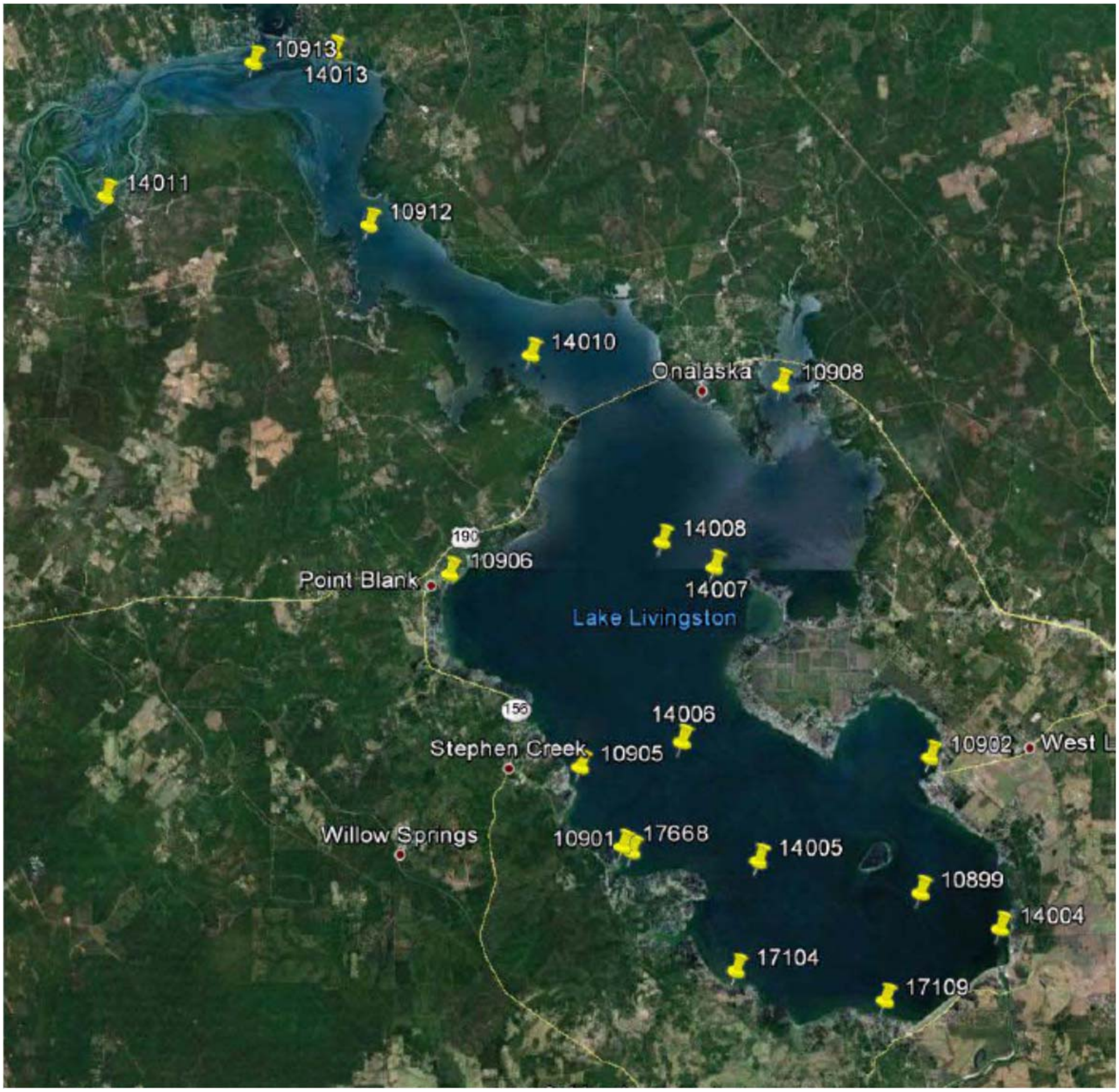


Figure A-16- Lake O' The Pines SWQMIS Water Quality Sampling Stations

Figure A-17- Lake Palestine SWQMIS Water Quality Sampling Stations

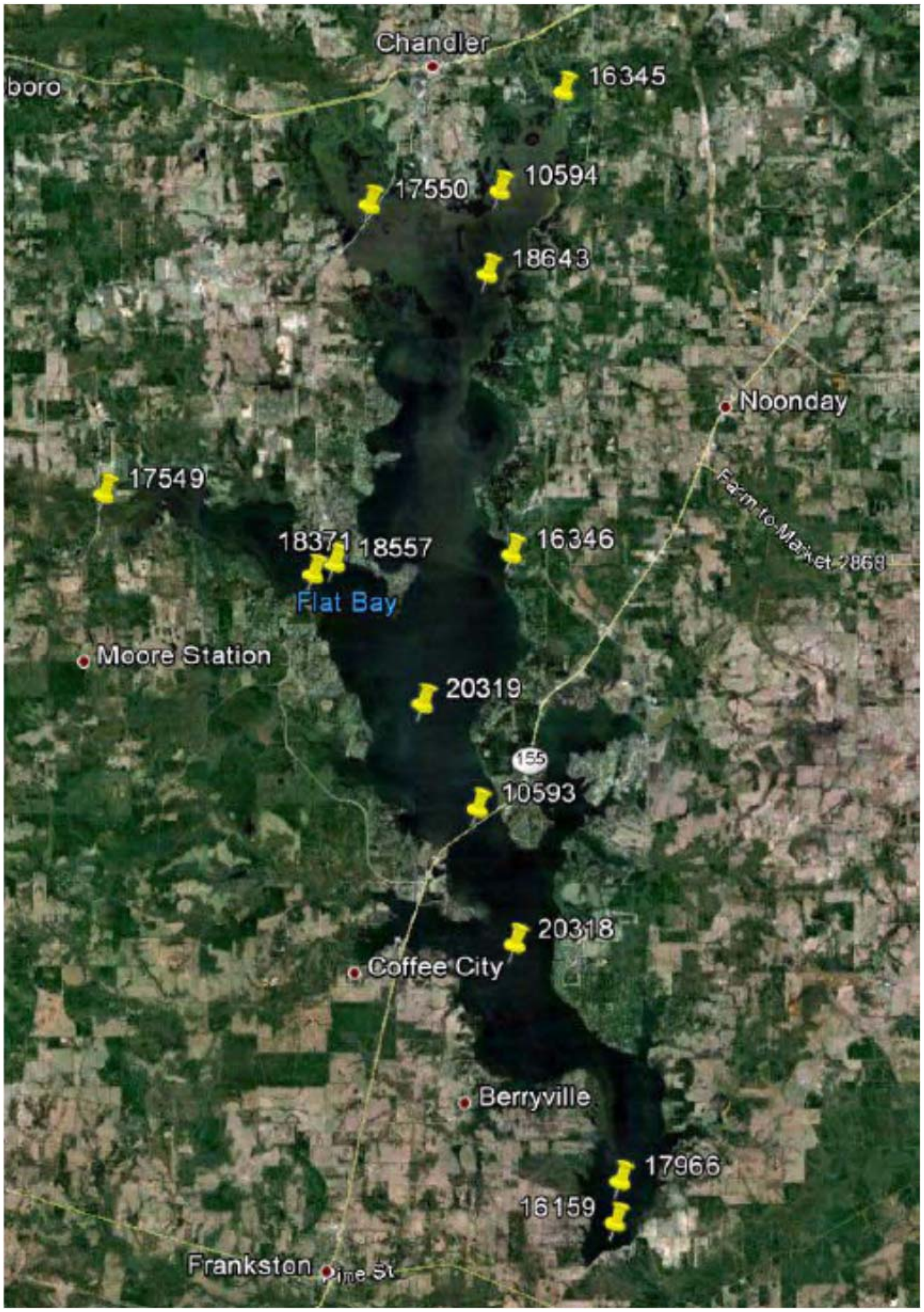


Figure A-18- Lake Ray Hubbard SWQMIS Water Quality Sampling Stations

Figure A-19- Lake Tawakoni SWQMIS Water Quality Sampling Stations

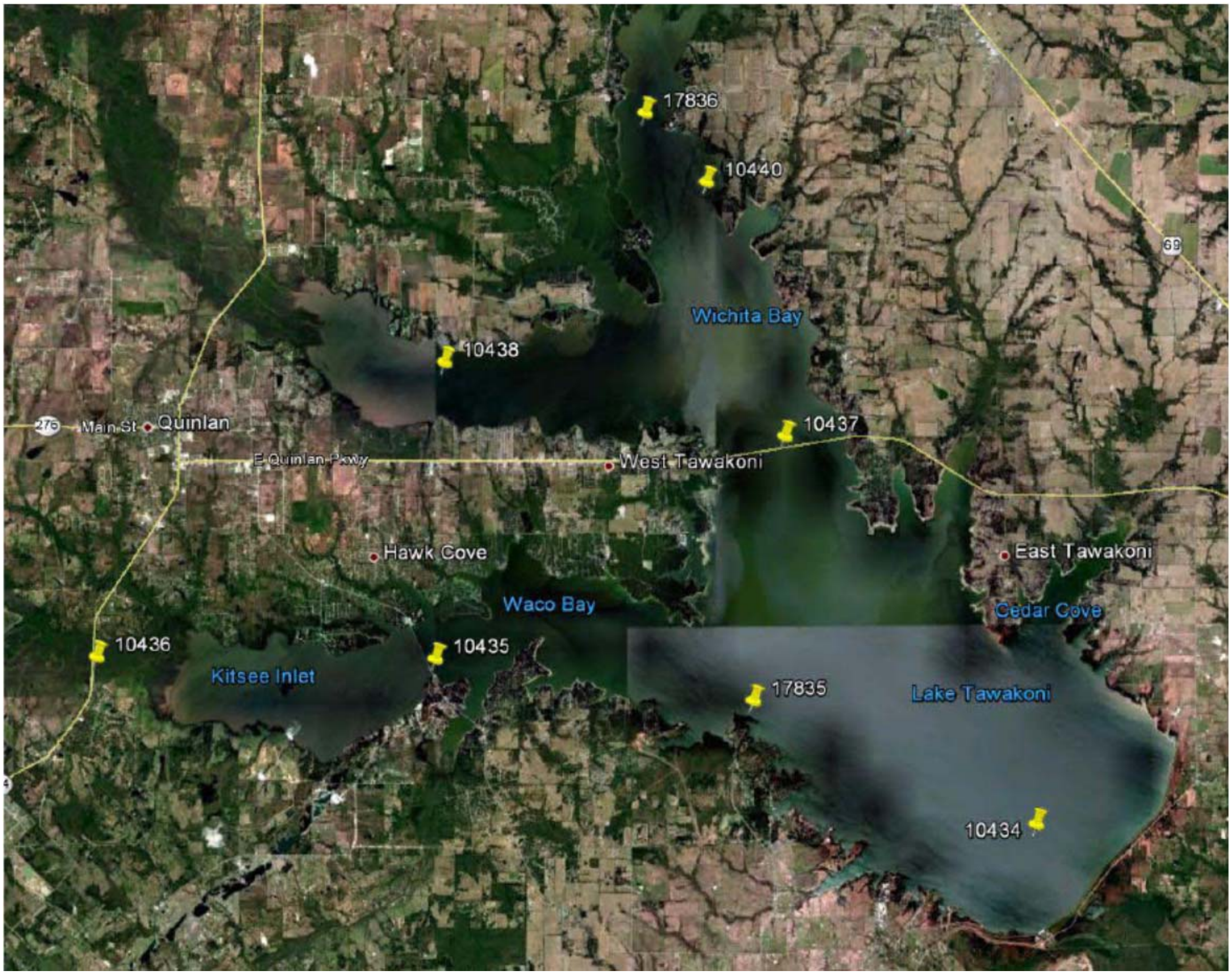


Figure A-20- Lavon Lake SWQMIS Water Quality Sampling Stations

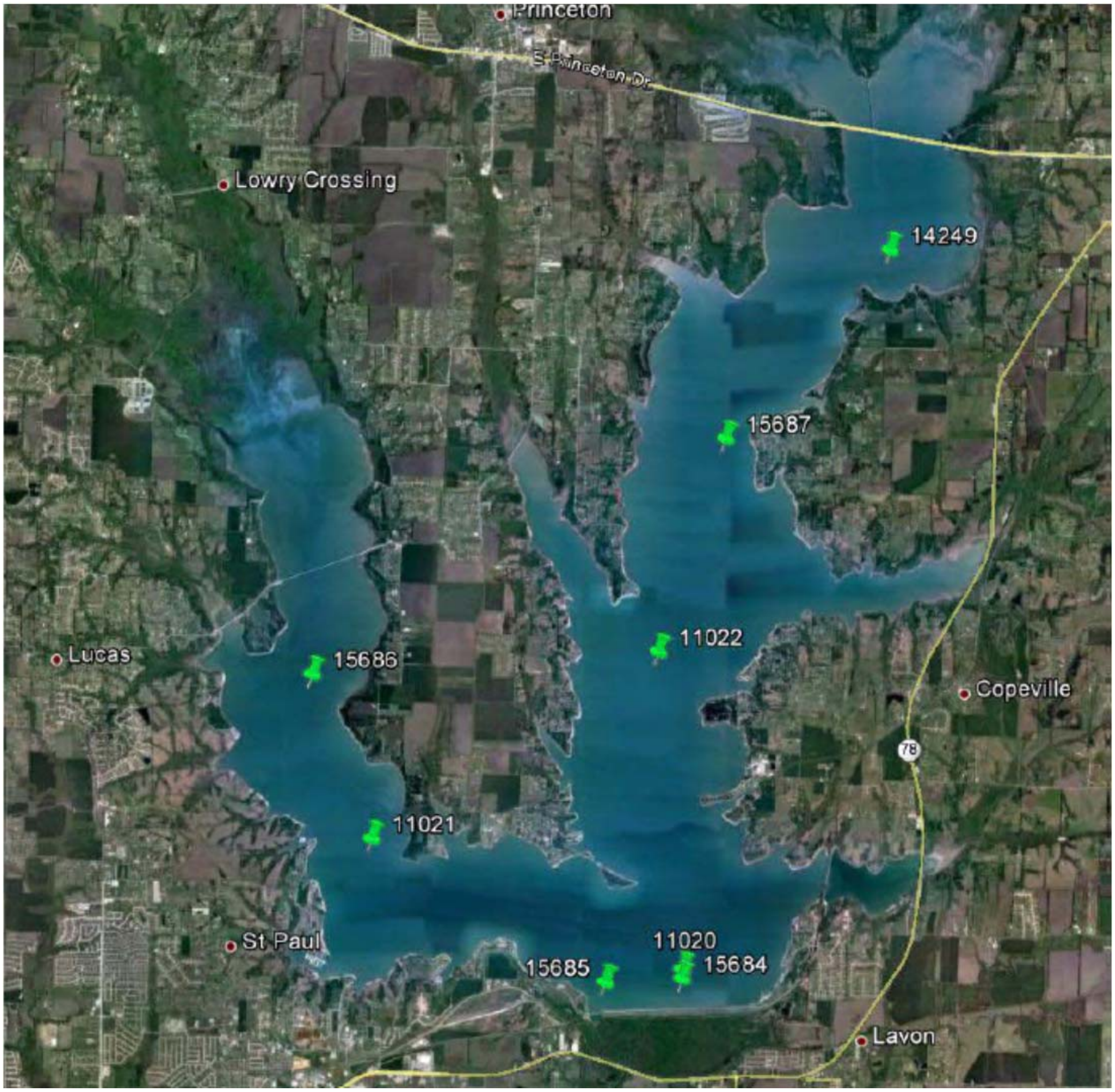


Figure A-21- Lewisville Lake SWQMIS Water Quality Sampling Stations

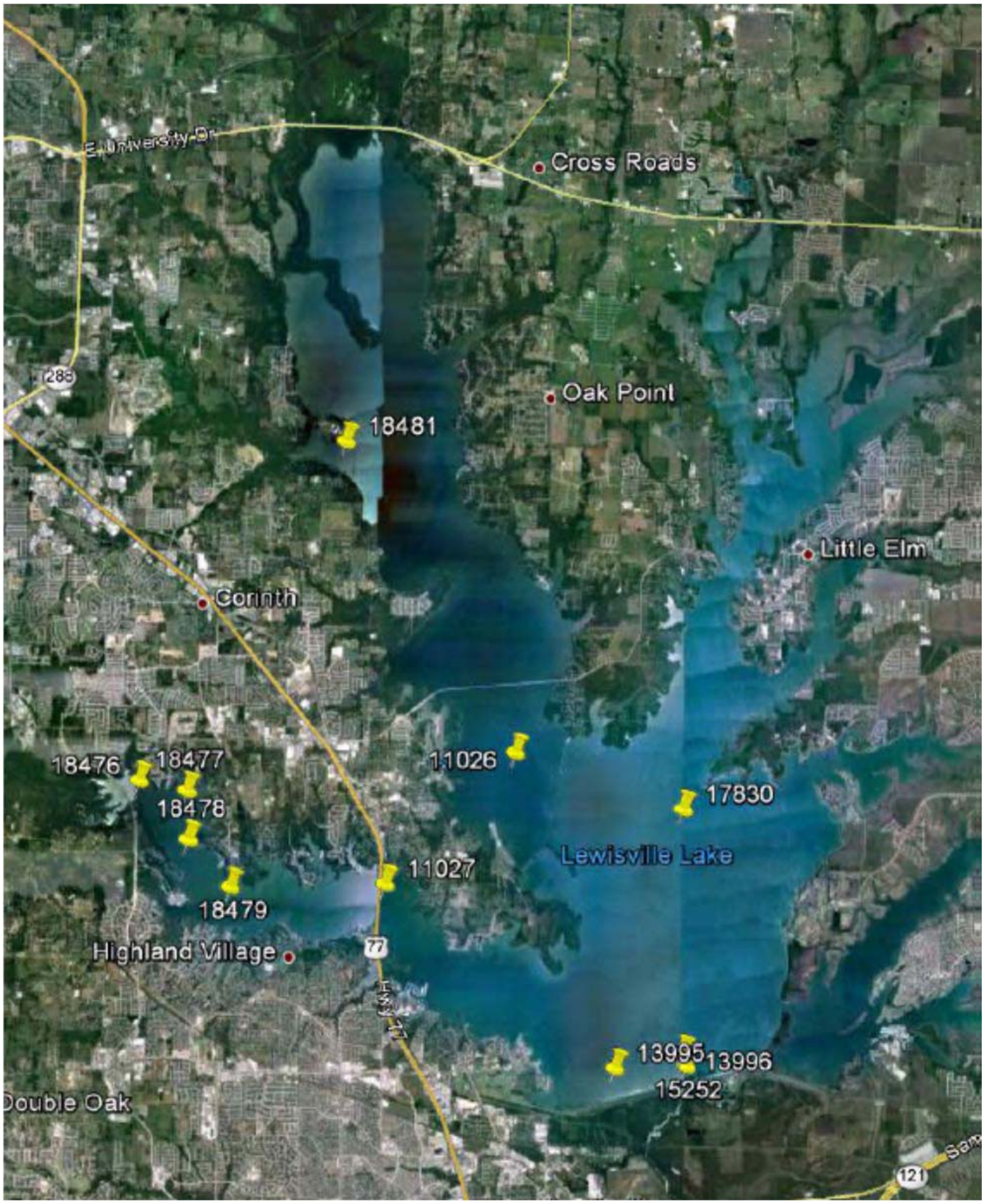


Figure A-22- Ray Roberts Lake SWQMIS Water Quality Sampling Stations

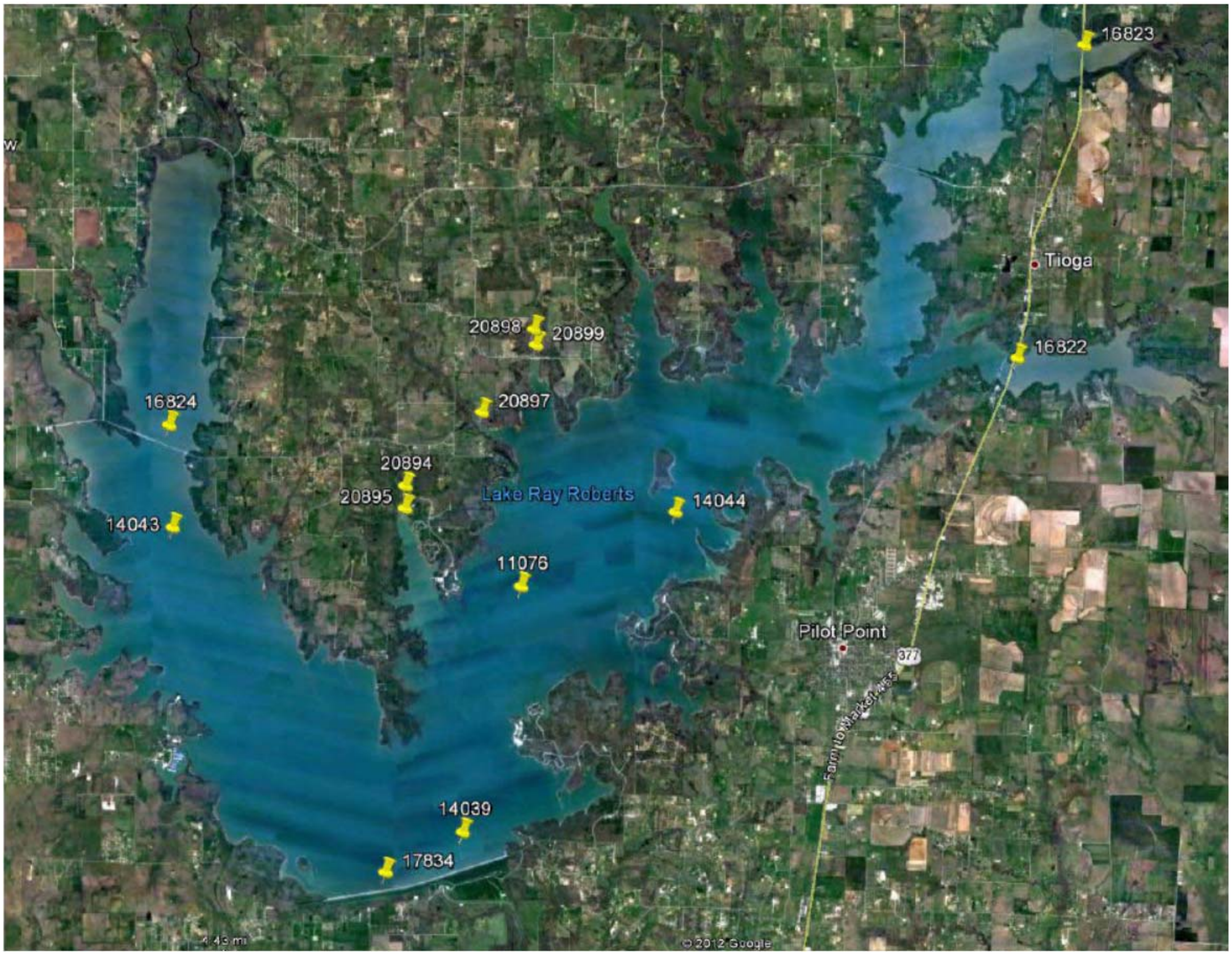


Figure A-23- Richland-Chambers Reservoir SWQMIS Water Quality Sampling Stations

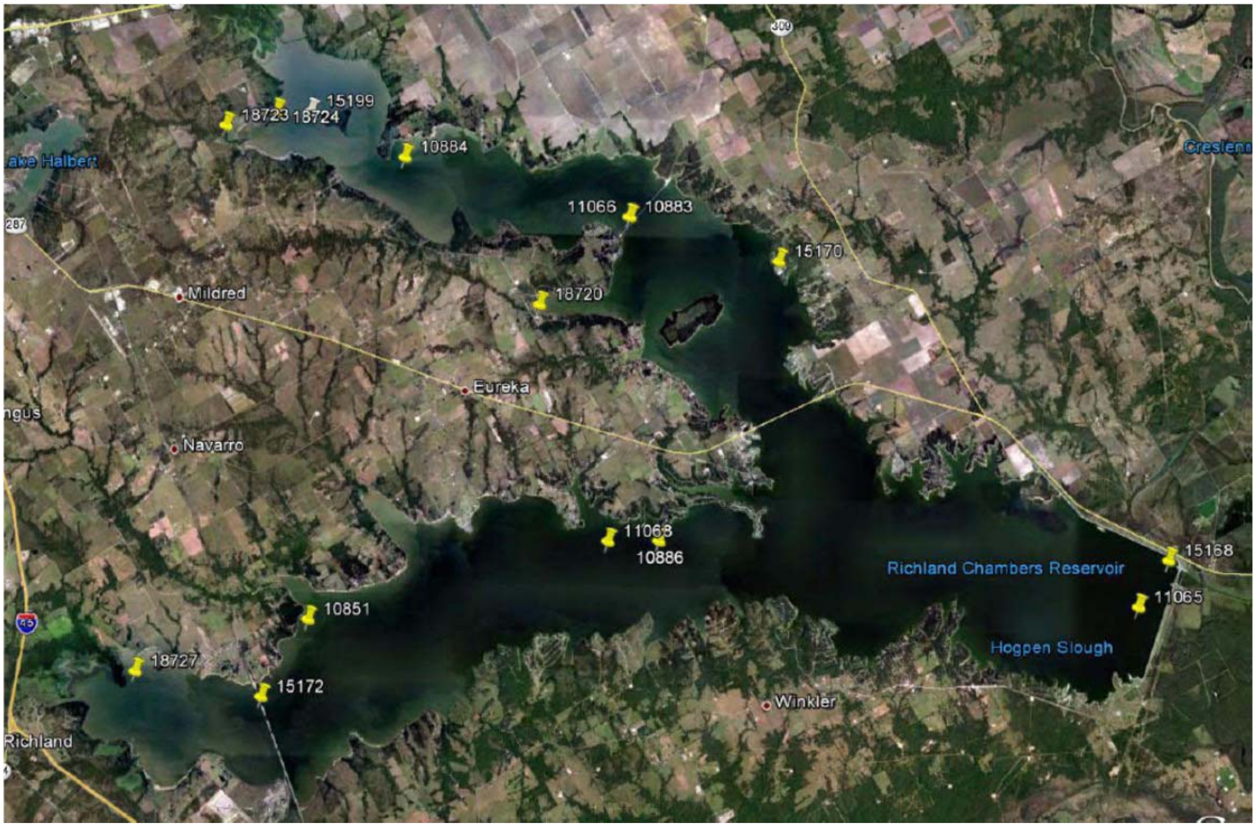


Figure A-24- Sam Rayburn Reservoir SWQMIS Water Quality Sampling Stations

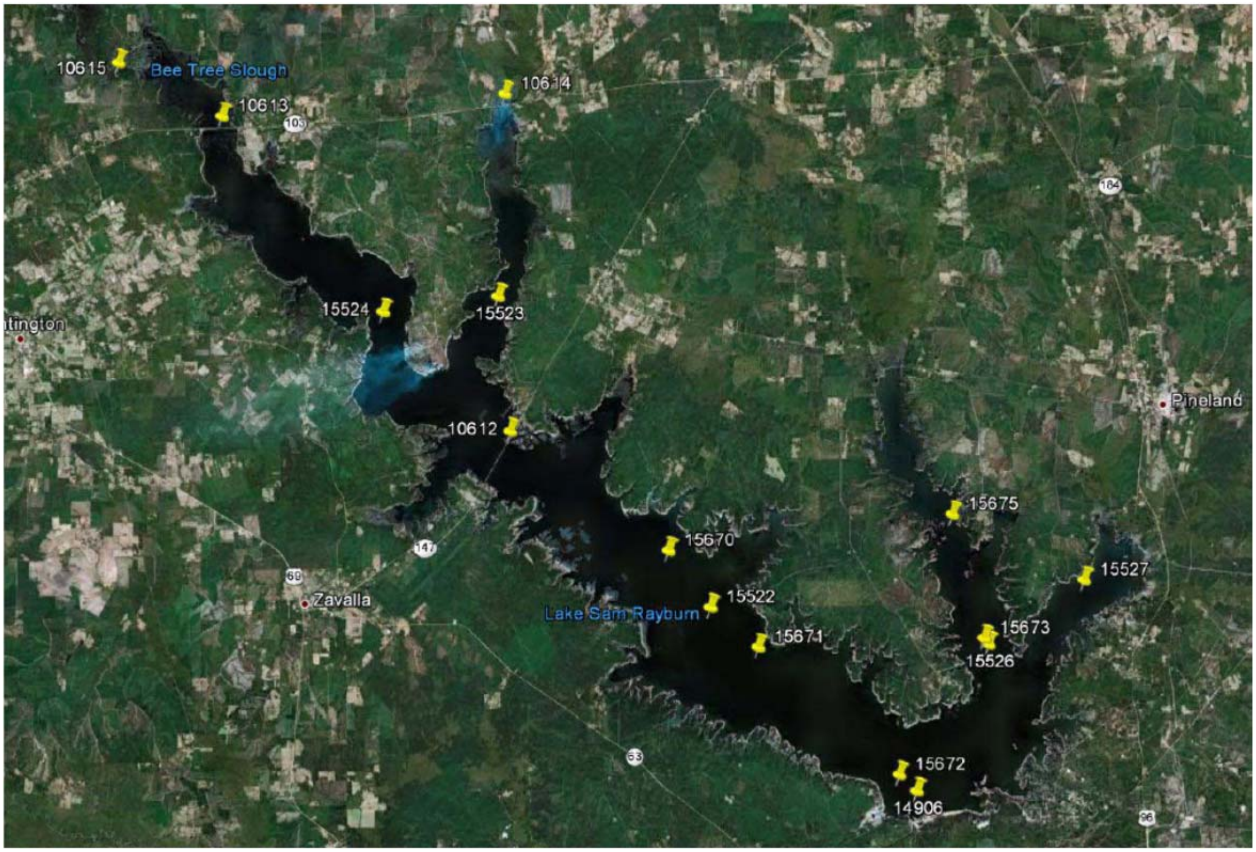


Figure A-25- Toledo Bend Reservoir SWQMIS Water Quality Sampling Stations

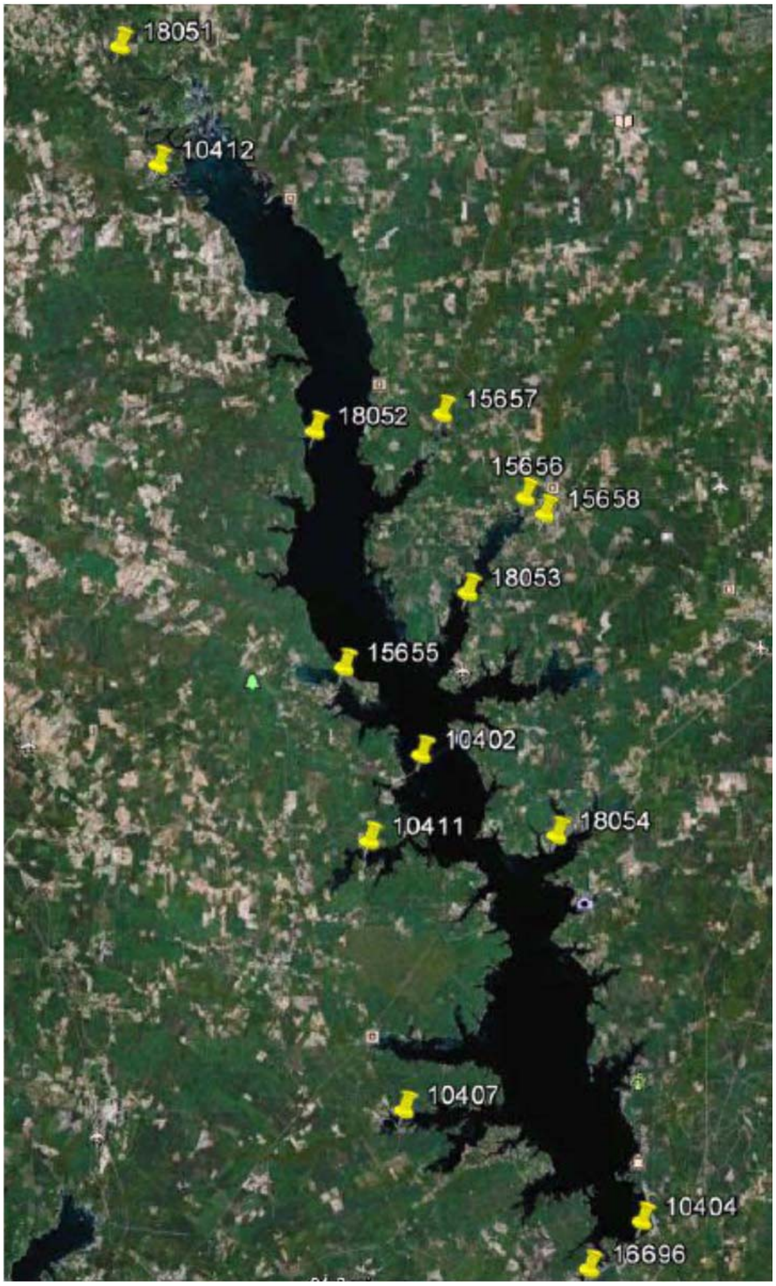


Figure A-26- Wright Patman Lake SWQMIS Water Quality Sampling Stations

APPENDIX B- RIVER SWQMIS WATER QUALITY SAMPLING LOCATION MAPS

Figure B-1- Trinity River Segment 1 SWQMIS Water Quality Sampling Stations

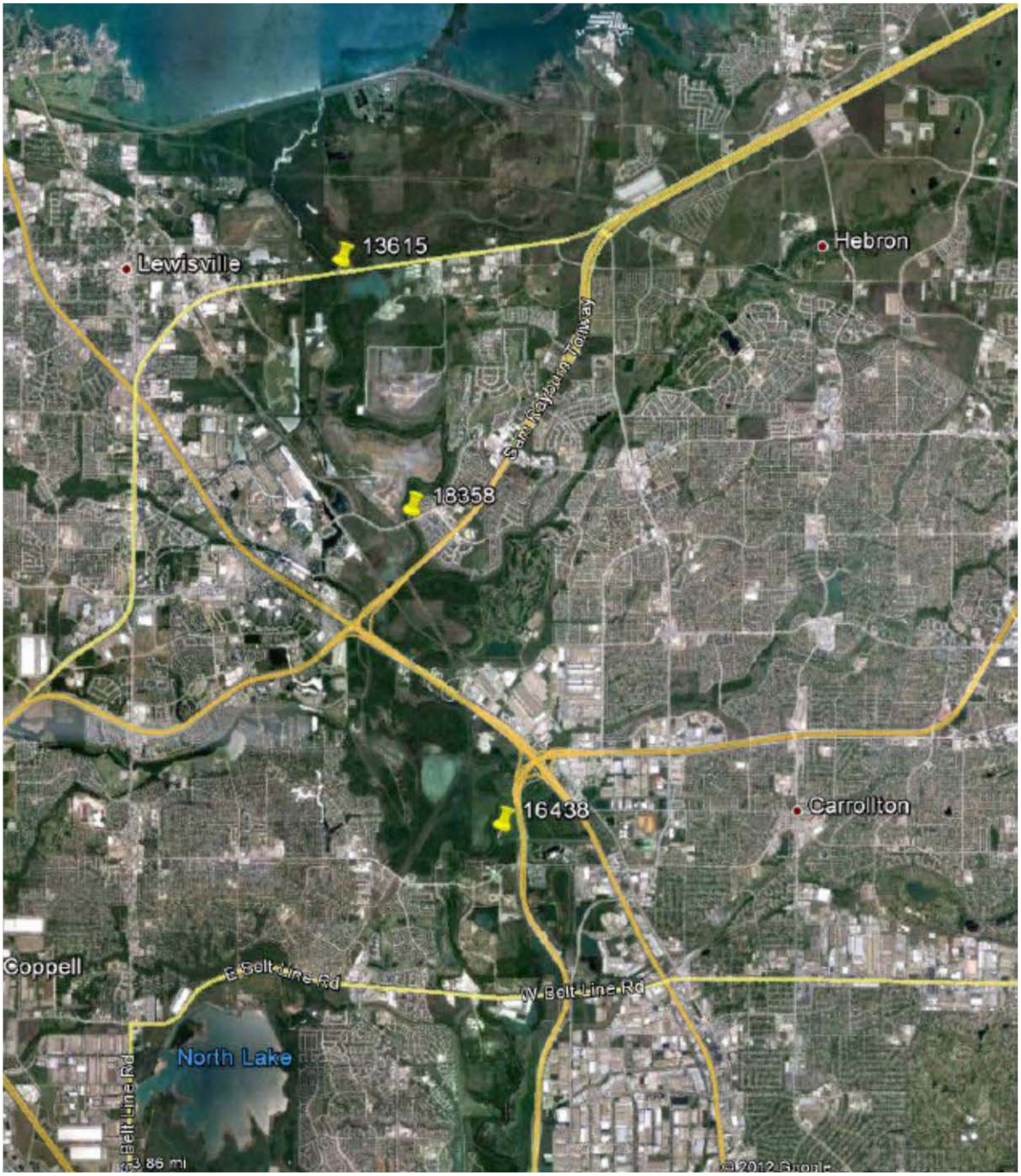


Figure B-2- Trinity River Segment 2 SWQMIS Water Quality Sampling Stations

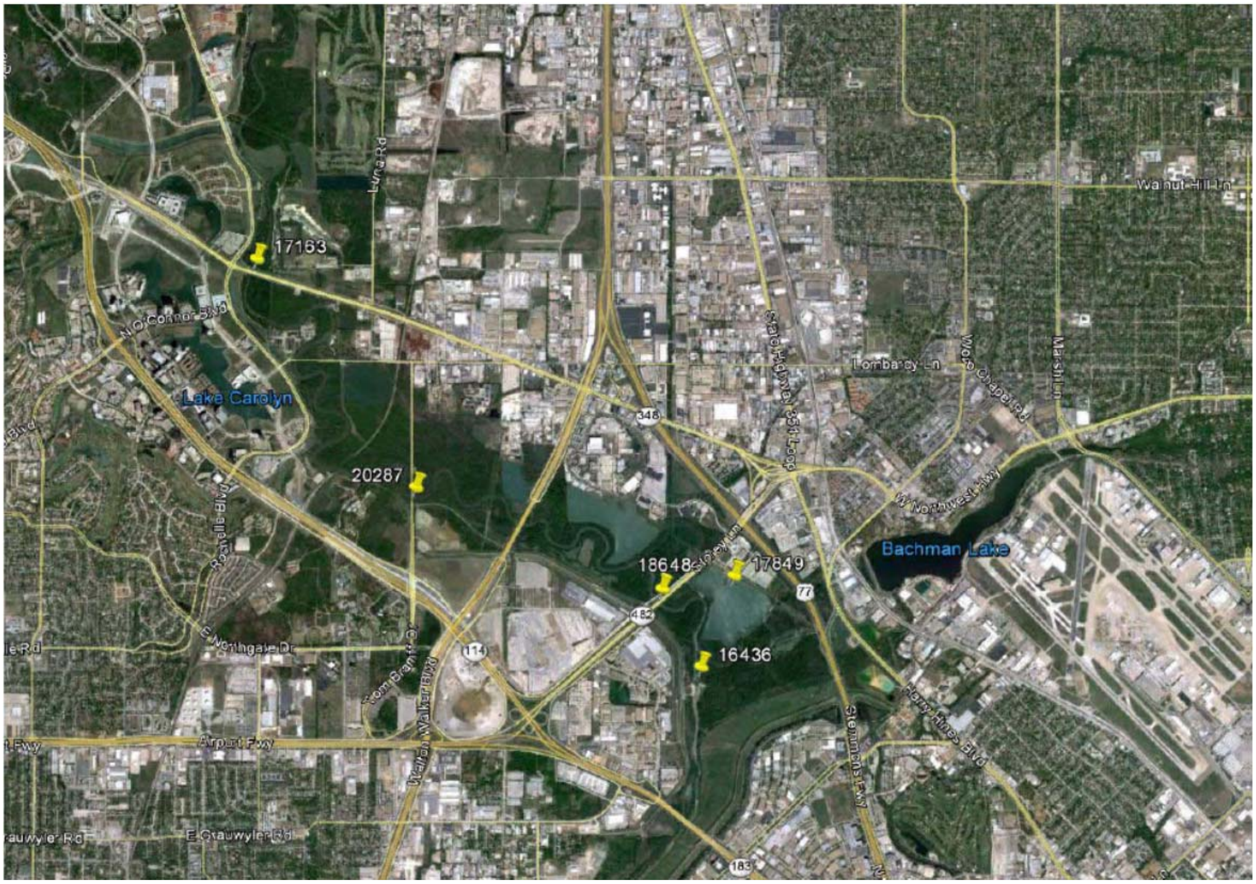


Figure B-3- Trinity River Segment 3 SWQMIS Water Quality Sampling Stations

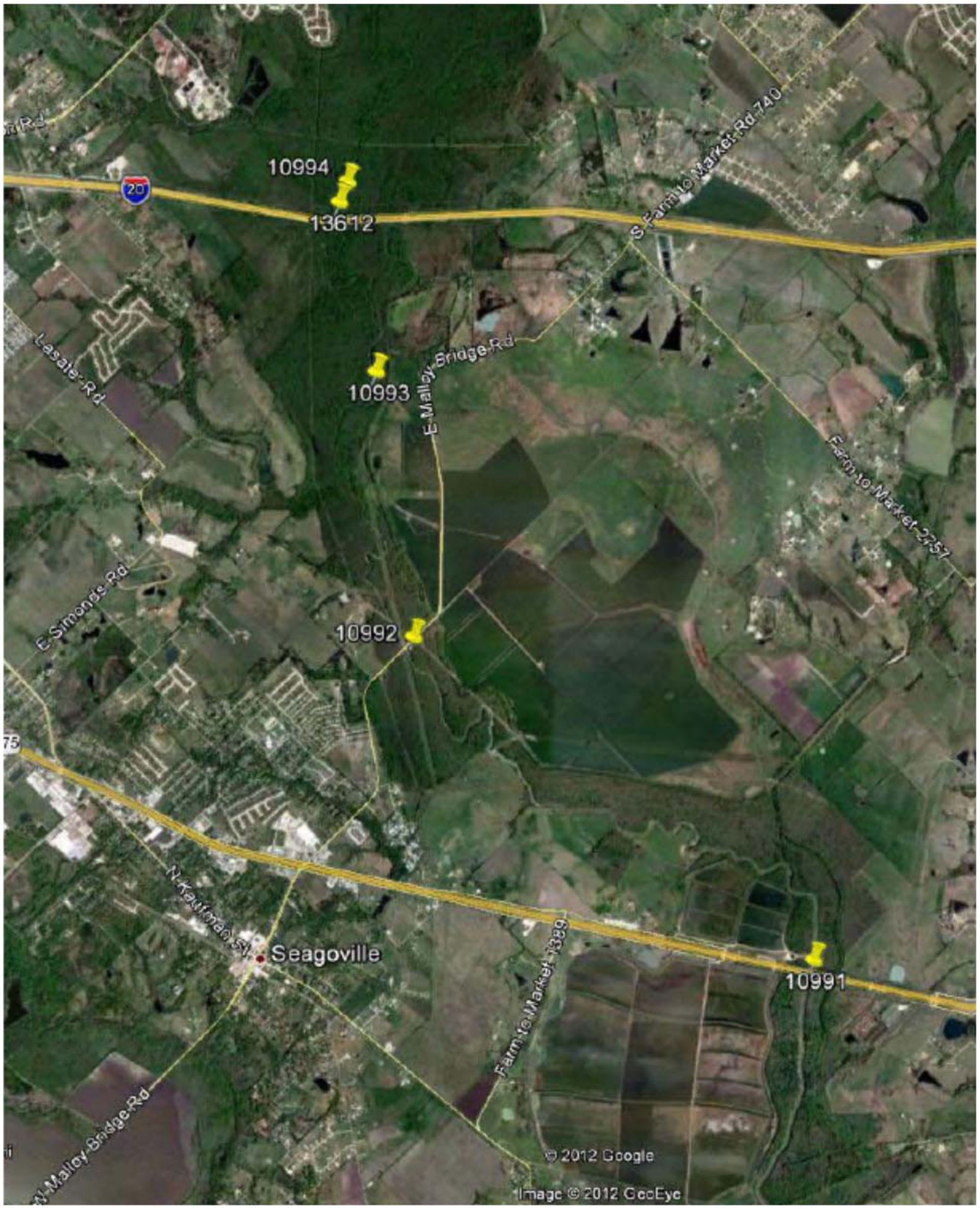


Figure B-4- Trinity River Segment 4 SWQMIS Water Quality Sampling Stations

Figure B-5- Trinity River Segment 5 SWQMIS Water Quality Sampling Stations

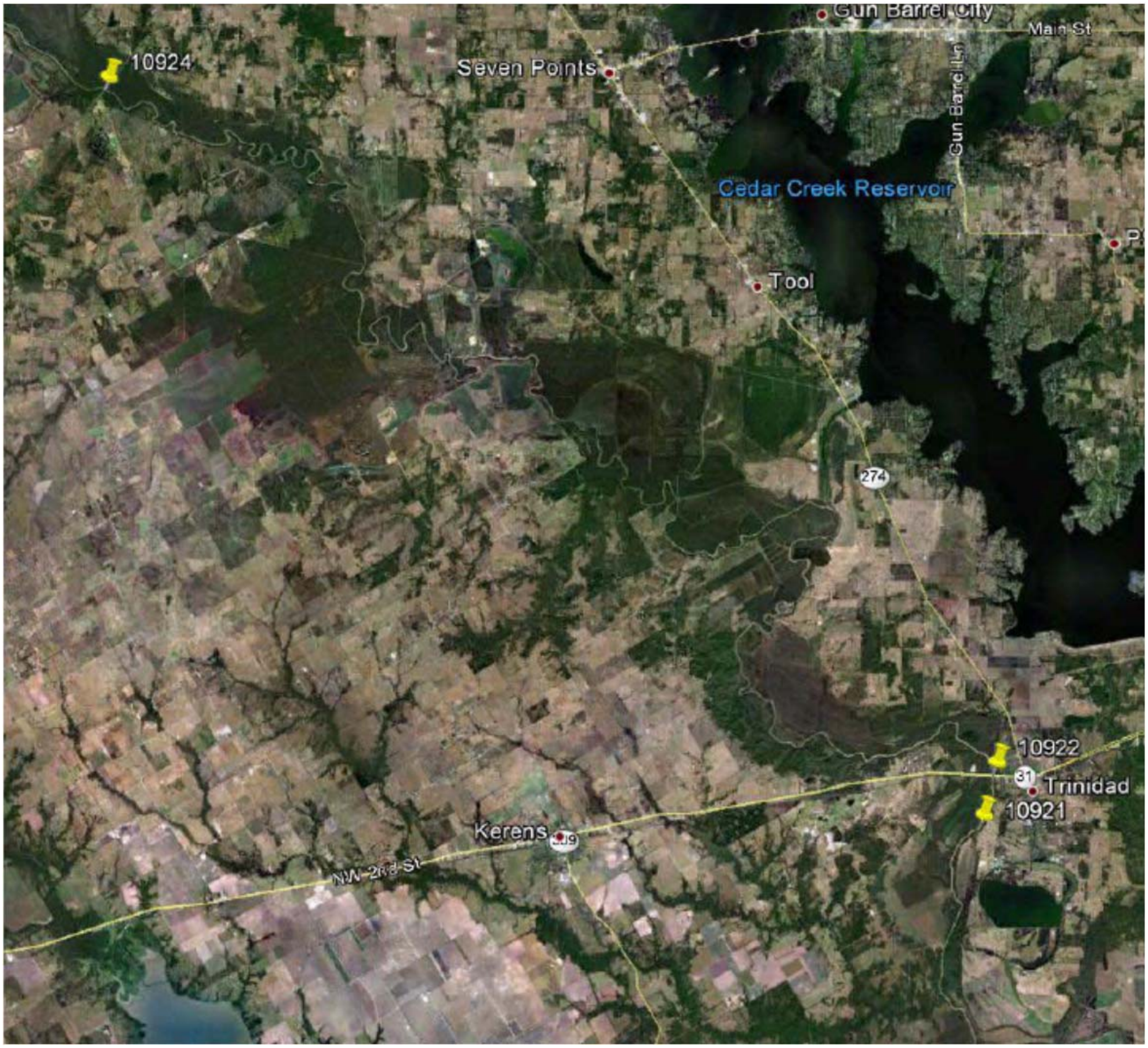


Figure B-6- Trinity River Segment 6 SWQMIS Water Quality Sampling Stations

Figure B-7- Sabine River Segment 1 SWQMIS Water Quality Sampling Stations

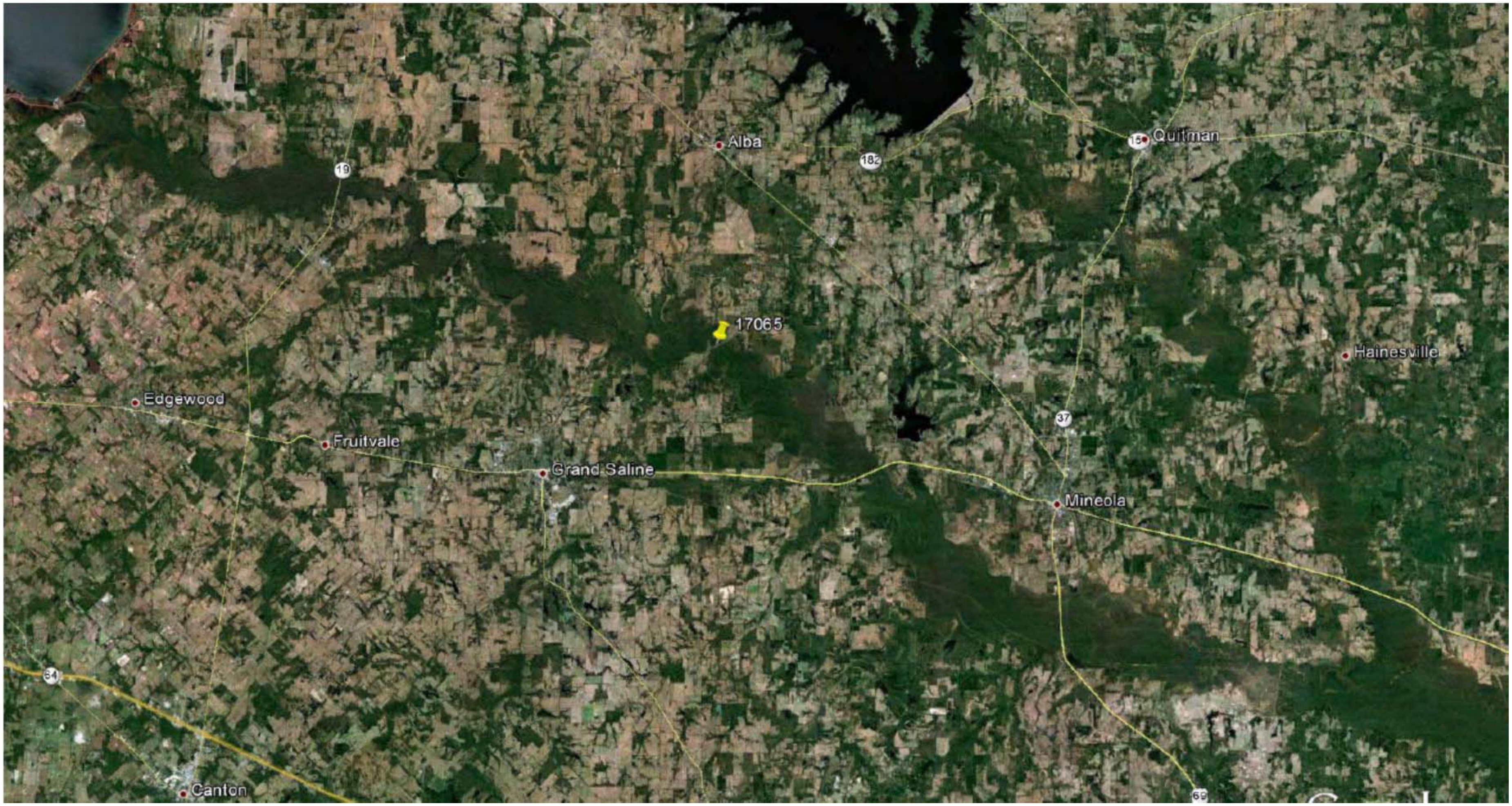


Figure B-8- Sabine River Segment 2 SWQMIS Water Quality Sampling Stations

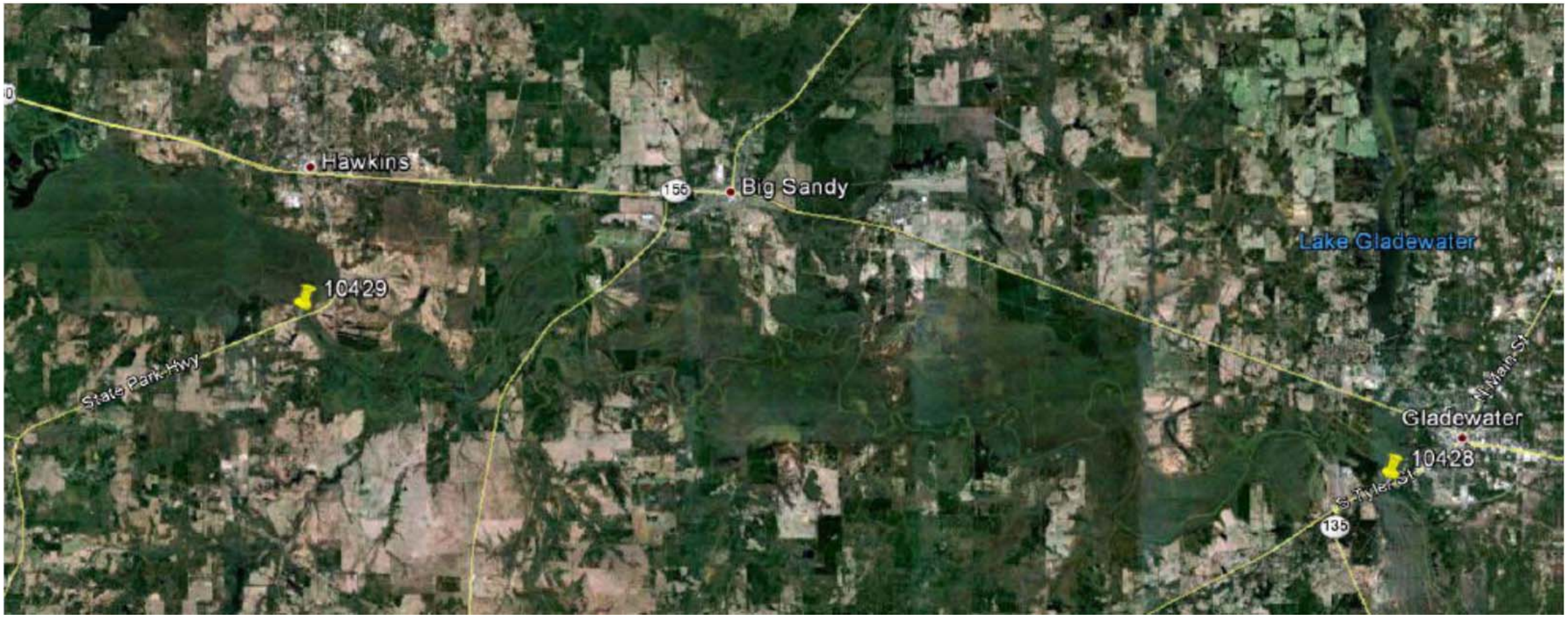
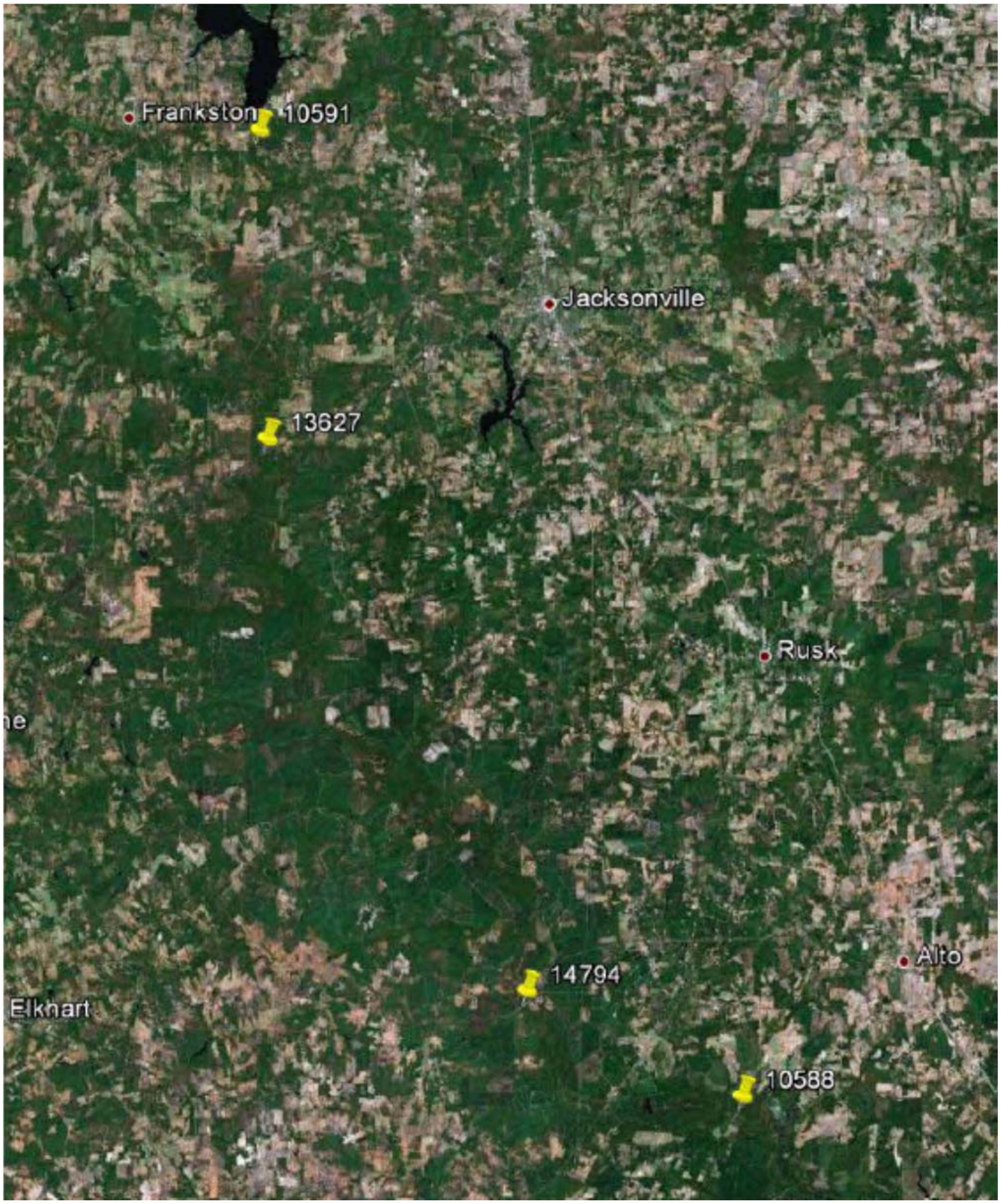


Figure B-9- Neches River SWQMIS Water Quality Sampling Stations



APPENDIX C- FUTURE WATER SOURCE SWQMIS WATER QUALITY SAMPLING LOCATION MAPS

Figure C-1- George Parkhouse (North) SWQMIS Water Quality Sampling Stations

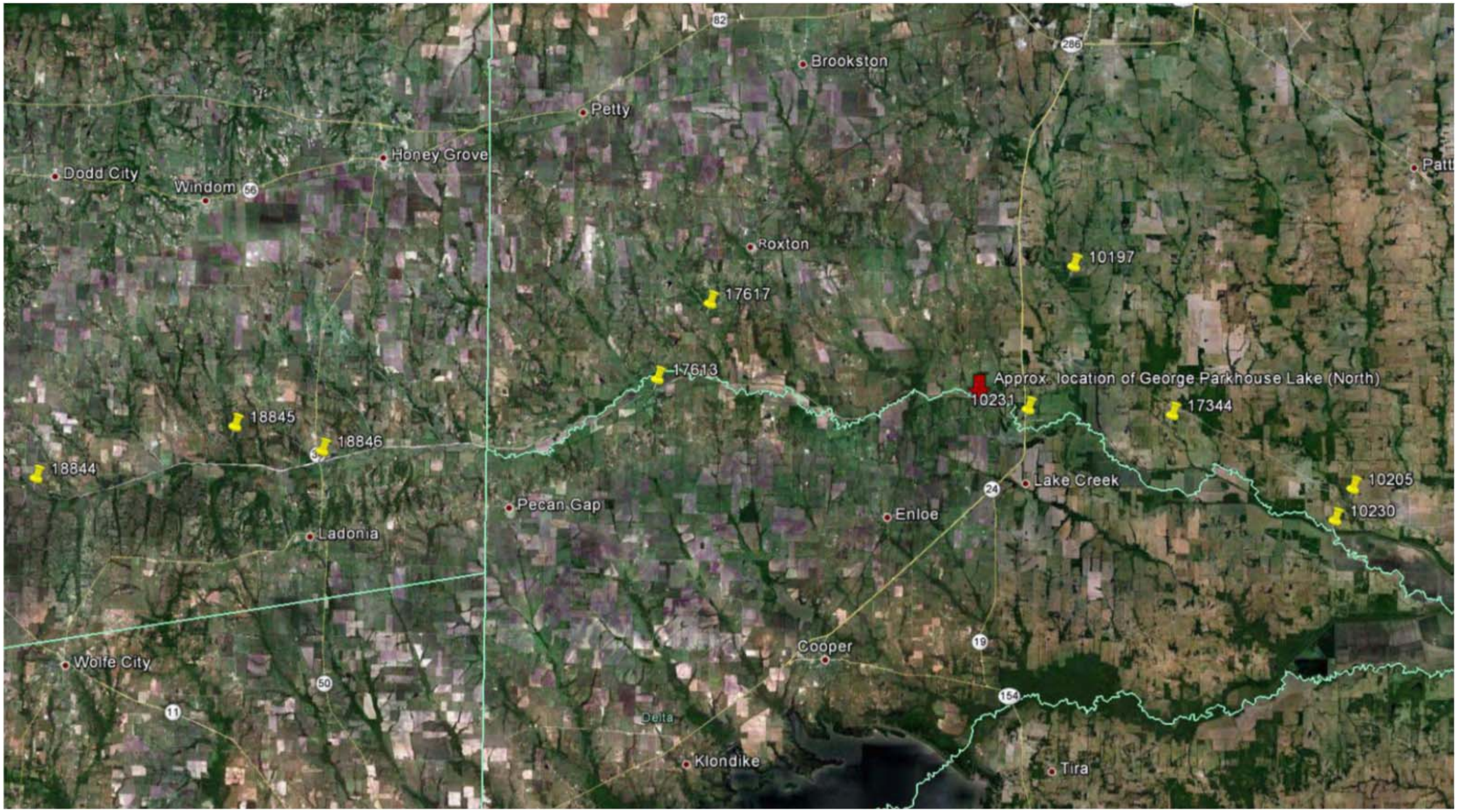


Figure C-2- George Parkhouse (South) SWQMIS Water Quality Sampling Stations

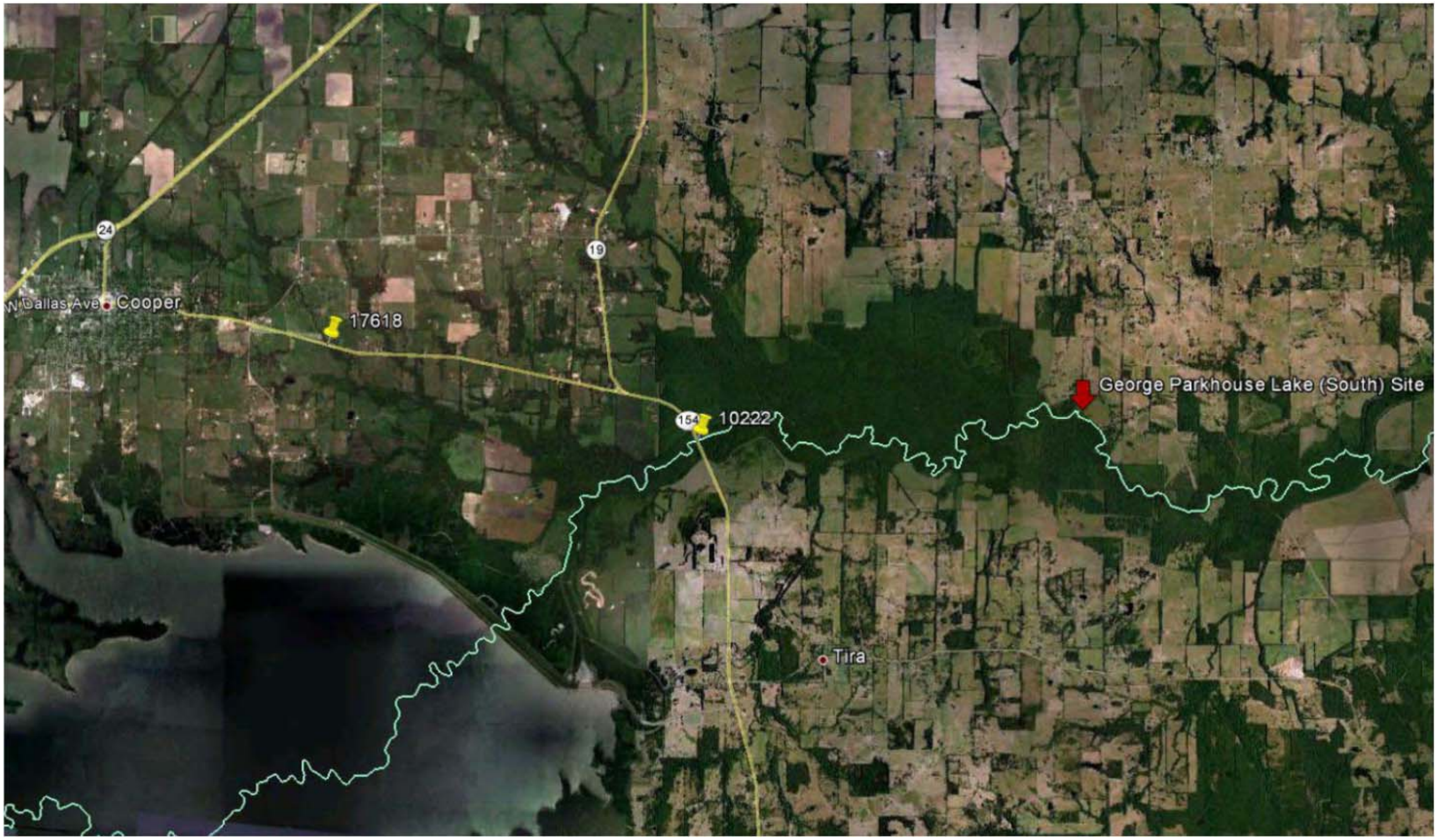


Figure C-3- Lake Columbia SWQMIS Water Quality Sampling Stations

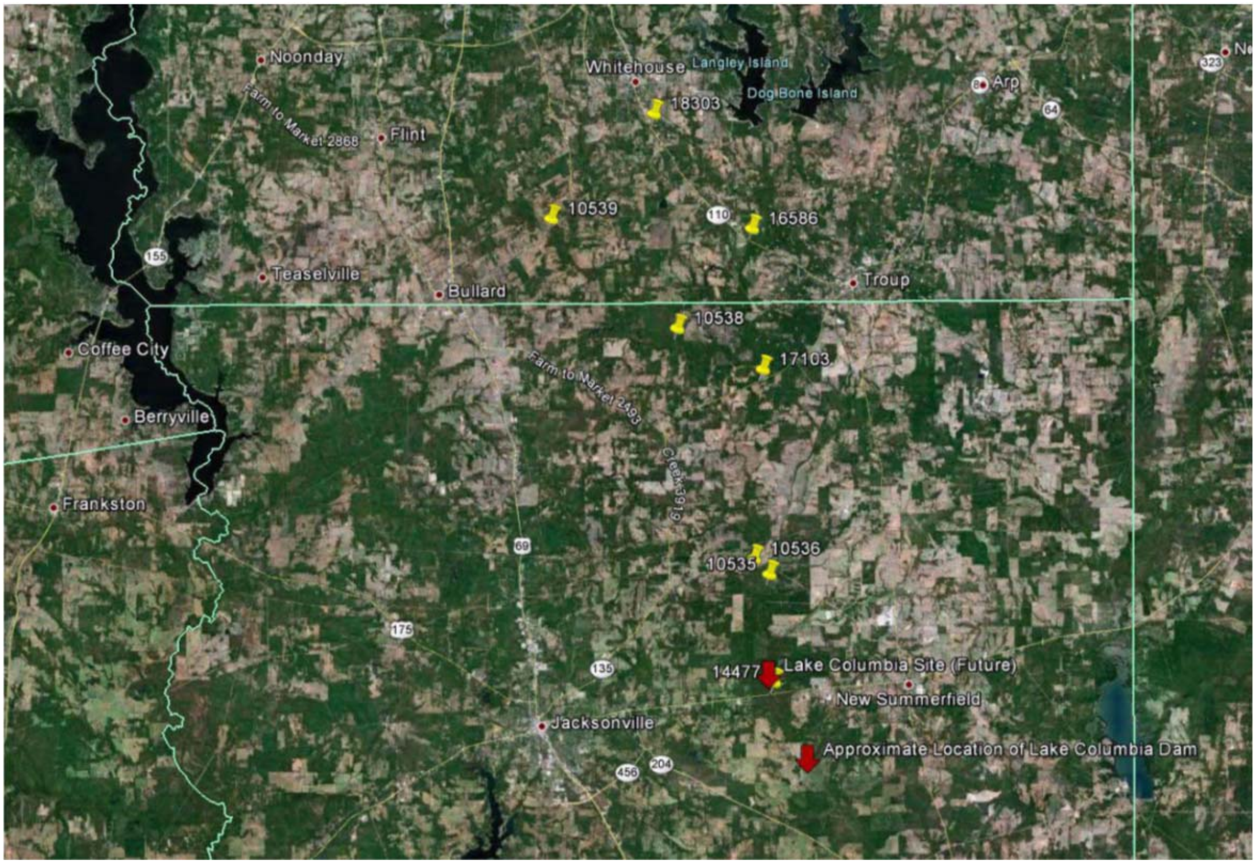


Figure C-4- Marvin Nichols Reservoir SWQMIS Water Quality Sampling Stations

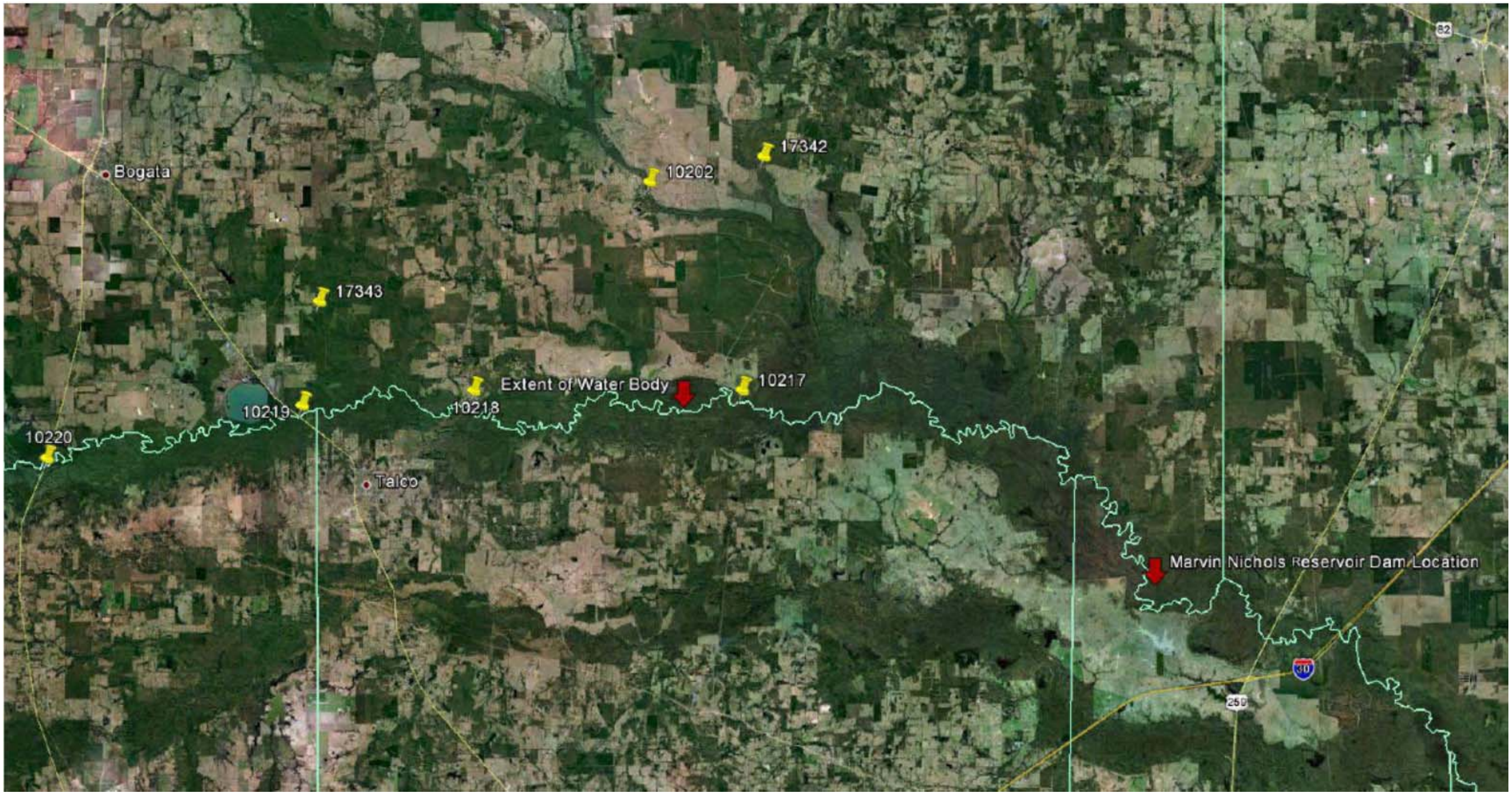
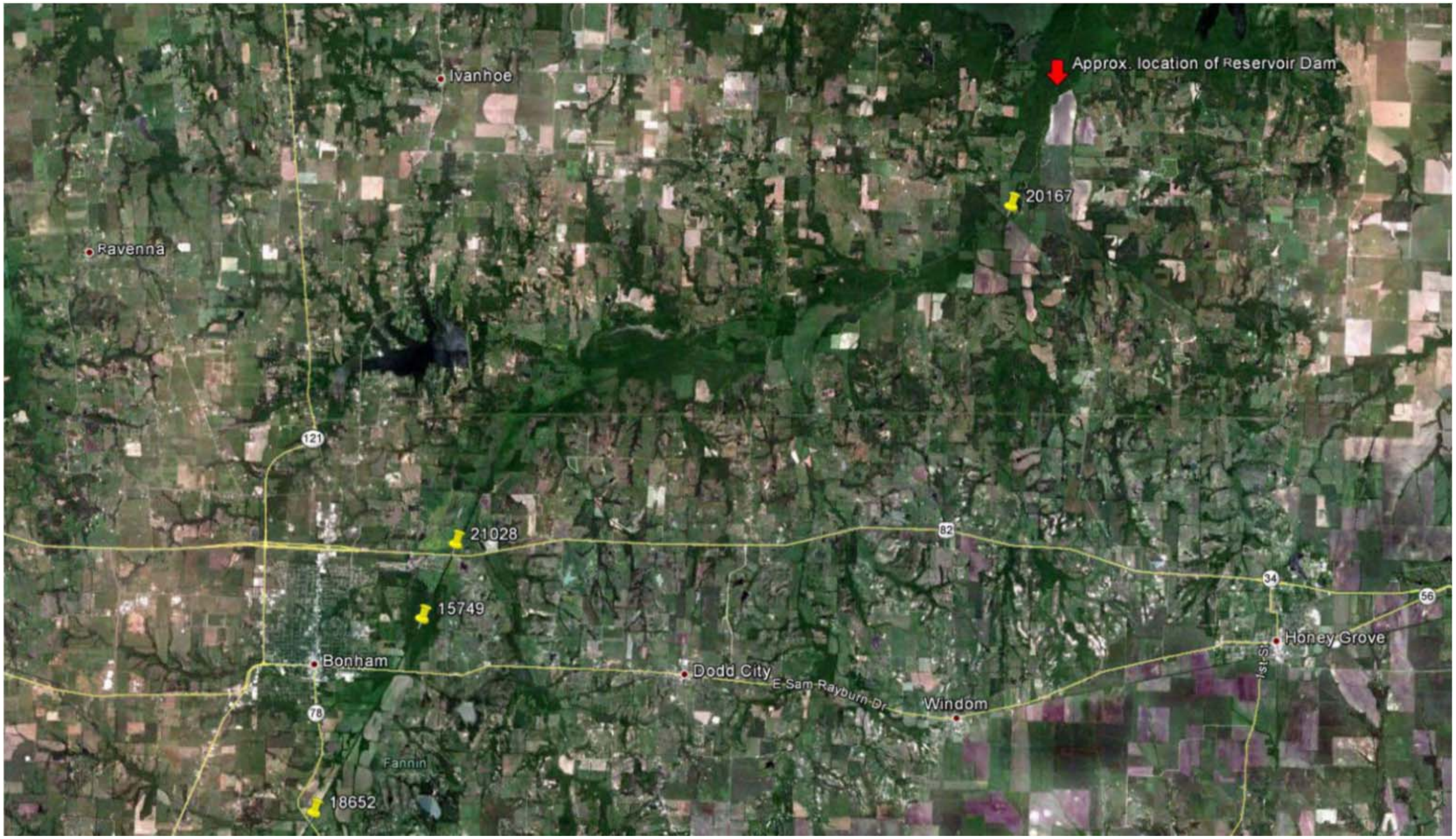


Figure C-5- Lower Bois d'Arc Creek Reservoir SWQMIS Water Quality Sampling Stations



Appendix D- Legislation, Public Outreach and Funding Opportunities

Table D-1-List of Pertinent Contact Agency and Subjects Discussed or Reviewed

Agency	Contact Name / Title	Program / Issues Discussed	Phone/email
Massachusetts Department of Conservation and Recreation	Jonathan Yeo / Director of Water Supply Protection; S. J. Port, Public Outreach	Zebra Mussel Prevention Effort; Laurel Lake and Quabbin Reservoir examples (closing boat ramp issues)	(617) 626-1453
Massachusetts Municipal Water Authority	Kristin MacDougall, Public Affairs	Public outreach using press releases and public meetings	(617) 788-1197
Bureau of Reclamation, Denver Office Research & Development	Curtis Brown, Director	Zebra/Quagga Mussel Research (funding questions)	(303) 445-2098
Texas Parks and Wildlife Department	Darcy Bontempo, Marketing Group Director	North Texas/Lake Texoma Zebra Mussel Awareness Campaign for 2011 and pending 2012 campaign	(512) 389-4574
Metropolitan Water District of Southern California	Ric De Leon, PhD; Microbiology Director and Zebra/Quagga Mussel Program Director; Brad Hiltscher, Regional Government Relations Representative	Current program including cost and budgeting; Potential federal funding; opportunity for jointly supporting funding; California legislative efforts – funding and controls [AB 1929 from 2010 Leg and AB 2443 current session]	(213) 217-6139
Association of California Water Agencies,	David Reynolds, Director of Federal Affairs	California bill AB2443, supported by ACWA; federal legislative and funding issues related to zebra/quagga mussels; provisions of the CA bill and why needed; strong support for bill—limited funds	(202) 434-4760
Coachella Valley Water District; Coachella, California	Steve Bigley, Environmental and Water Quality Director	Irrigation system operation to prevent the introduction and spread of zebra/quagga mussels; no recreational boating on CVWA reservoir; use of biological (fish), etc.	(760) 398-2651
US Fish & Wildlife Service	David Britton, AIS Coordinator, Fisheries and Aquatic Resource Conservation, Division of Fisheries	AIS Coordination with partner agencies; very limited funding opportunity for implementing ANS plans through USFWS	(817) 272-3714

Agency	Contact Name / Title	Program / Issues Discussed	Phone/email
Colorado River Water Conservation District, Glenwood Springs, CO	Mike Eytel, Water Resources Engineer	Discussed Colorado programs in general, including mandatory boat inspection programs; outreach efforts by state	(970) 945-8522
Lake County, California	Scott De Leon, Lake County Water Resources Manager (email only and website review)	Use of local ordinance for boat inspection requirements; use of public notice of changes in requirements; website as an excellent example of general info outreach and specific requirements, including enforcement; copy of local ordinance provided	(707) 263-2344 www.nomussels.com
California Department of Water Resources, Invasive Species Program	Jeff Janik, PhD, Aquatic Biologist	Information on boat inspections, provided legal info on CA regulations on invasives; numerous examples of public outreach and education items; use of brochures and volunteers; partnerships	jjanik@water.ca.gov
Central Arizona Project	Al Graves, Senior Maintenance Engineer (now retired)	Presentation on CAP issues with quagga/zebra mussels; follow up discussions after presentation	
San Juan Water Commission, Farmington, NM	Randy Kirkpatrick, Executive Director	Potential of zebra/quagga mussel infestation in San Juan and Animas River systems; preliminary steps to delay; public outreach	(505) 564-8969
San Juan Water Master, State of New Mexico, Office of State Engineer	Shawn Williams	Field review of potential impacts to the San Juan system; concerns with zebra/quagga mussels; need for coordination	(505) 334-4571
Minnesota Department of Natural Resources	Gary Montz, Zebra Mussel Monitoring Coordinator	Volunteer monitoring, time requirement, effectiveness, etc.	(651) 259-5100

Table D-2- Summary of Public Outreach / Education Programs

Outreach/Education Program Implemented	Cost Estimate	Agency	Appropriate for North Texas Agencies	Discussion Recommendation level
Public news releases (mailed, emailed, posted)	Low to Open-ended; adds to Public Relations or requires new staff / outside consultant	Most (see particularly, MDC&R; Lake County, CA; TPWD	Yes, particularly for specific events, issues, restrictions	North Texas group should coordinate to degree possible
Newsletters (public audience) • **Email or website distribution** • **Mailings**	Moderate cost for new publication; moderate to low cost to add to existing public	Several Fed., State, local agencies	Yes, announces events, provides status, and room for explanation	Consider a joint North Texas publication
Logos - message statements (e.g., "Hello Zebra Mussels, Goodbye Texas Lakes"/ "Texas Must Declare Independence from Zebra Mussels")	Low cost	TPWD	No, should continue to use and support TPWD branded logo	
Signage/Posters				
• **Boat ramps at infested lakes**	Low cost; requires maintaining (use of volunteers and readily available formats)	Note agencies use at infested locations (TPWD, Lake County, MET, etc)	Yes, TWPD currently in second year of program	North Texas group will need to continue this effort
• **Boat ramps in potentially impacted areas**	As above	As above	As above	
• **Event banners, posters (emailed and posted)**	Low to moderate cost	TPWD, MET, others	Yes, provides event message for participants	
• **Wallet cards**	Moderate cost	MDC&R, others?		
Educational materials				
• **Audiences**				
o **Adult (single topic brochures, how-to instructions, posters, etc)**	Moderate to Open-ended	Many Fed., State, local agencies	Yes, can be updated as needed	Many professional quality materials developed by TPWD
o **Student**	As above, use of social media and web	See website examples	Yes	Could incorporate in other water education materials or use same media (e.g., Texas Rivers, conservation messaging)
o **Elementary school age**	As above, use of social media and web	See website examples	Yes	As above
• **Webcasts, videos (downloadable)**	Moderate to Open-ended	MET, AWWA, California DWR, others	Yes, provides lower cost outreach; public and technical to wide audiences; difficulties providing direct feedback, interaction	Add video of specific events; local interest, etc
• **Workshops (technical/professional) (volunteer training, monitoring, boat inspection/cleaning, etc)**	Moderate to High Cost	AWWA, others	Yes, Provides direct instruction; face to face interaction, planning, etc	Consider hosting technical (research agenda) as well as public (volunteer) training
• **Public meetings (purpose specific – closing of boat ramps, etc)**	Low to Moderate	MDC&R, several others	Yes, as needed	North Texas group should coordinate or jointly host
Email lists (registered voters in area, boat registrations, etc)	Low to Moderate	TPWD, MET, CVWD, Lake County, others	Yes, TPWD has accomplished for both boaters and voters in Central/North Texas	Practice that should continue, provide updates
Print ads in outdoor, pertinent area magazines/newspapers	Low to Open-ended	Many agencies	Yes, TPWD has professional quality, North Texas oriented ads	
Mailings (targeted to citizens in potentially impacted area)	Moderate (can be combined with water or boat registrations)	Many agencies	Yes, provides method to provide alerts, updates, new concerns, etc	Another coordination effort
• **Boat renewals inserts**				
• **Registered voters mailings**				

Outreach/Education Program Implemented	Cost Estimate	Agency	Appropriate for North Texas Agencies	Discussion Recommendation level
Agency websites (pointers to pertinent external links and references)	Open-ended (typically an add-on to existing with some expections)	Lake County, CA; TPWD (Texas Invasives)	Yes, website can be referenced and provide links, references, history, etc	North Texas group should consider separate website (cf. www.nomussels.com
Electronic message media (facebook, twitter, etc)	Low to moderate	Several mention use and have links on websites	Yes, particularly for e-generation	
Partnerships (Federal/State/Regional/Local/Citizen levels)	Low to moderate; travel cost and meeting time; staff investment	Several excellent partnerships established (Federal – ANS Task Force; NICS)	Yes, continued at North Texas agency level	Should consider expanding to other Texas resources agencies, Governor's office; Natural Resources in Leg (at least periodically); also to include Volunteer-based groups (existing or created solely for zebra mussel response)
Citizen volunteers	Would depend on level of support; using volunteers effectively would require investing in training and support	Several agencies use Volunteers for monitoring, boat dock monitoring (e.g., Lake County, Portland State Univ., 100th Meridian, USFWS)	Yes, the PSU Zebra Mussel Monitoring Program – has volunteers in 12 states	Should consider Volunteers and volunteer training and support for number of tasks: 1) Monitoring for presence 2) Substrate monitoring 3) Boat ramp monitoring history of individual boats 4) School and civic group speakers
• **Lake monitoring (substrate monitoring and collection)**				
• **Boat ramp monitors (boat history, interviews, license plate, boat registrations)**				
Surveys to monitor and obtain feed-back (measures of effectiveness)	Low to moderate, but worth the investment	Only TPWD but others may	Yes	Yes
Deploy custom signage buoys on infested lakes	Low to moderate capital, site specific investment; need to maintain	Only TPWD	Yes	Yes

Table D-3- Examples of State and Federal Agencies - Public Outreach Information and Materials, Links to Law and Regulations

Agency	Website address	Materials/Information	Link to Regulations	Contacts
		Representative State Programs		
Texas Parks and Wildlife	Protect Our Waters *http://www.tpwd.state.tx.us/fishboat/boat/protect_water/*	• Provides link to *TexasInvasives.org* • Instructions (what boaters and anglers should do to help) • Roundup - News release link on zebra mussels at http://www.tpwd.state.tx.us/newsmedia/releases/news_roundup/zebra_mussels/zebra_mussel_fast_facts.phtml • Links to TPWD regulations	TPWD Section 66.007 http://www.statutes.legis.state.tx.us/Docs/PW/htm/PW.66.htm See recent rules promulgated March 29, 2012 related to zebra mussel and Lake Texoma: http://www.tpwd.state.tx.us/newsmedia/releases/?req=20120329c	
***TexasInvasives.org* Partnership**[3]	TexasInvasives.org http://www.texasinvasives.org/action/	• Excellent website with pertinent information on Texas invasive species • "Eradicator Calculator" accounts for volunteers eradication efforts • "Citizen Scientists" volunteer groups throughout Texas monitoring and reporting occurrence (to date, 1,544 citizens volunteers; 14,420 observations; 4,613 observation hours) Related to zebra mussels: • Imbedded instructional video • "Spread the Word" brochures and poster to download • Instructions to boaters, anglers, travelers, hikers and other outdoor recreationalists • "Report It" – relates to all invasive species but includes zebra mussels		
Massachusetts Department of Fish & Game	*Mass Wildlife* *http://www.mass.gov/dfwele/dfw/nhesp/conservation/invasives/invasive_zebra_mussel_management.htm*	• Instructions (what boaters can do) • Chronology of management efforts • **Notice of emergency measures (e.g., closed boat ramps)** • Reports on boat monitors, mussel monitoring, and water quality • Notice of upcoming workshops, seminars, training, etc.	Office of Fishing and Boating Access (OFBA) 320 CMR 2.02(4) http://www.mass.gov/dfwele/pab/index.htm	Jonathan Yeo, Director of Water Supply Protection
California Department of Fish & Game	Invasive Species website *http://www.dfg.ca.gov/invasives/quaggamussel/*	• Instructions to boaters • History of quagga mussel occurrence and problems • Maps, training materials, guidance manuals • Protocols for cleaning and decontamination • News releases, FAQs, Fact Sheets • Outreach & public educ materials (download brochures, posters, etc.) • Links to research efforts • External links to other states, federal agency sites	Regulations by local agency http://www.dbw.ca.gov/boaterinfo/quaggaloc.aspx	
Idaho State Department of Agriculture	Zebra and Quagga Mussels website *http://www.idahoag.us/Categories/Environment/InvasiveSpeciesCouncil/Quagga_Zebra_Mussels.php*	• Instructions to boaters • How to help (volunteer opportunities) • **Inspections and inspection stations** • Additional information on State requirements and regulations (e.g., **boat tags, mandated inspections requirements, etc.**)	Regulations governing invasive Species IDAPA 02.06.09 http://www.idahoag.us/Categories/Environment/InvasiveSpeciesCouncil/InvasiveSpeciesLawsandRules.php	

[3] The TexasInvasive.org is a partnership of the TPWD, Texas Invasive Plant and Pest Council, Lady Bird Johnson Wildflower Center, Texas Forest Service, Texas AgriLife Extension, Texas State University System, and several USDA agencies

Agency	Website address	Materials/Information	Link to Regulations	Contacts
Minnesota Department of Natural Resources	Zebra mussel (*Dreissena polymorpha)* *http://www.dnr.state.mn.us/invasives/aquaticanimals/zebramussel/index.html*	Links to: • What you can do? • Programs and reports • Educational, outreach, downloads • **Training and permits** • "Contact an Expert" • Imbedded video	Chapter 84D – recent 2011 updates http://www.dnr.state.mn.us/lsp/deconfaq.html	
Federal Agencies – National				
USFWS/UT Arlington	100th Meridian Initiative *http://www.100thmeridian.org/*	Links to **extensive related information & data** Examples: decontamination, outreach, technical documents, educational brochures, summaries of states and federal law, partners	For State laws summary: http://www.100thmeridian.org/Laws/usmap.htm	
USGS - Nonindigenous Aquatic Species	Zebra and Quagga Mussel Information Resource Page *http://nas.er.usgs.gov/taxgroup/mollusks/zebramussel/*	Links to • Factsheets, FAQs, news • **Maps: real-time, sightings map, animated annual distribution map** • Photo gallery Link to the NAS database	Not provided	
US Bureau of Reclamation	Quagga and Zebra Mussels *http://www.usbr.gov/mussels/*	Links to • History and background • **Research** • Activities by River Basin • Documents and maps	Not provided	

Table D-4-Federal and State Law, Rules and Regulation Review

Title	Description/Pertinence to NT Zebra Mussel	Penalties, funding and other pertinent provisions	Discussion
Existing Federal Law - Pertinent			
Aquatic Nuisance Prevention and Control Act of 1990 (amended as the National Invasive Species Act of 1996 and 2000)	Specifically calls for states to develop comprehensive non-indigenous aquatic nuisance species management plans. This Act authorizes federal matching funds for plans that are approved by the Federal Aquatic Nuisance Species Task Force (The ANS Task Force, also established by the 1990 Act)	No penalties but set the Act-- under which the USFWS Branch of Invasive Species manages the Aquatic Nuisance Species Task Force and its Aquatic Nuisance Species Program. Funding authorized in past for states to implement ANS plans; Funding to USFWS and NOAA Sea Grants No funding in FY12 (CR) even though renewed funding in Committee at $6.9M FY13 DOI appropriation bill is not available	
Lacey Act	The Secretary of Interior has designated zebra mussels "injurious wildlife" under federal law and therefore the importation and interstate transport of zebra mussels are prohibited by the federal Lacey Act (16 USC 3371; 18 U.S.C. 42). Although zebra/quagga mussels are not listed as injurious, various levels of prohibition (transport, possession, etc.) are in place in many western states. State prohibitions offer other opportunities under other provisions of the Lacey Act for coordination by state and federal law enforcement agents.	Both civil and criminal penalties are provided; Act under which the USFWS Branch of Invasive Species conducts its activities pertaining to listing an organism as Injurious Wildlife. Can cause major problems for transfer of water across state lines that contains or facilitates invasive species	
Executive Order 13112	Signed by President Clinton on February 3, 1999, requires that a Council of Departments dealing with invasive species be created to prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause.	No criminal or civil penalties, but restricts any federal agency from taking actions that would facilitate or spread an invasive species Corps of Engineers 404 permit can be affected by an interpretation that a water transfer (intrastate or interstate) could cause spread of invasive species	
FUNDING IN 2013			
2013 Energy & Water Conference Report	*"The bill continues a provision allowing the Corps to implement actions to prevent aquatic nuisance species from dispersing into the Great Lakes by way of any hydrologic connection between the Great Lakes and the Mississippi River Basin. The Committee does not consider hydrologic separation of the Great Lakes Basin from the Mississippi River Basin to be an emergency measure authorized by this Act. The issue should be fully studied by the Corps of Engineers and considered by the appropriate congressional committees."* and following, *"The Committee remains concerned by the threat of aquatic nuisance species to the nation's water bodies and* ***recognize the critical role of the Army Corps of Engineers in preventing, controlling, and managing the threat of Asian carp.*** *The Committee notes that the Corps cooperates with other federal, state, and local government agencies through the Asian Carp Regional Coordinating Committee to execute a comprehensive strategy to deal with Asian carp."*	Proposed funding of Corps' "Aquatic Nuisance Research Program" at $690 Million but limited to Asian Carp	

Title	Description/Pertinence to NT Zebra Mussel	Penalties, funding and other pertinent provisions	Discussion
PRIOR appropriations bill add-ons (prior to 112th Congress) and authorizing legislation – IN PROGRESS			
Prior Energy & Water appropriations bills	Corps of Engineers: Great Lakes invasive species produced significant federal investment, including recent actions for Asian Carp barrier project Bureau of Reclamation	Corps' Invasive Species program FY08 - $0.75M Inv; $7.87 M constr FY09 - $.50M Inv; $5.75 M constr FY10 – 0.27M Inv; $5.86M constr FY11 – Work plan - $12.65M FY12 – request $21.8M FY10 – add-on for research $0.5M FY11 – add-on for research $1.0M	
Water Resources Development Act 2007	Provided additional authority for the Corps of Engineers to study and take measures to address Asian Carp	Authorizing legislation	Corps of Engineers has been directed and authorized by Congress to undertake significant studies and implement measures to control the potential threat of Asian Carp infesting the Great Lakes. The estimated damages to the Great Lakes fisheries are estimated in the billions of dollars. Great Lakes' states' Congressional delegation worked together to support these authorizations
Congressional Hearings	Natural Resources hearing on the "Comprehensive Control Plan for Giant Salvinia" – Rep Gohmert		Potential for similar hearings by this Committee on zebra mussels Rep. Gohmert and Rep. Flores are members of the Natural Resources Committee (112th Congress)

State Law Review

Title	Description/Pertinence to NT Zebra Mussel	Penalties and other provisions	Discussion
Colorado – Chapter 8 – Aquatic Nuisance Species (ANS)	PERTINENT PROVISIONS: #802 – Private inspectors, authorized agents, training, certification, and quality assurance #803 – Inspections # 804 – Decontamination # 805 – Impoundment (of vessels)	Provides authority for certifying inspectors by Division (State agency) Specific requirements for boats transported from lakes known to be infested; must have documentation of inspection & decontamination; Decontamination methods and practices specified Subject to impoundment if inspection or decontamination is refused;	

Title	Description/Pertinence to NT Zebra Mussel	Penalties and other provisions	Discussion
Massachusetts Code	Massachusetts General Law (MGL) protects right of access to lakes ("great ponds"); MGL authorizes agencies of the state to protect those waters, including adopting regulations pertaining to 'incompatible uses' The Department of Conservation and Recreation (DCR) has the authority to carry out measures for the protection and conservation of the State's Natural Resources; this includes the State's Aquatic Nuisance Control Program The Office of Fishing and Boating Access (OFBA) has the authority to establish a broad range of protective measures at boat ramps and access points. Local authorities may enact control measures for smaller lakes, but any boating regulations require approval	Penalties for violations of regulations governing use of land and water designated as public access areas is a fine of not more than $100. The OFBA can fine up to $100 for violation, including the towing or removal at the owner's expense	Massachusetts is an example of several levels of state government having authorities to respond to zebra mussel problems. A number of State resource agencies have delegated authority for different aspects of recreation and other public activity that could spread zebra or quagga mussels. The General Law provides for the delegation of authorities used by the State to address zebra and quagga mussel problems.
Local Ordinances			
Lake County, CA Ordinance 2936, February 2011	Ordinance requires inspection of any water vessel intending to launch on any water body in the County. Requirements are stipulated for "Resident" and "Non-Resident" water vessels Resident vessels must be inspected to receive a Resident Mussel Sticker, these stickers are required prior to launching, and expire after one year, for renewal vessels must be screened and inspected Non-Resident vessels and trailers must be screened and inspected, then affixed with non-resident sticker. The non-resident sticker expires after one month, then vessel and trailer must be re-inspected.	If the owner refuses to have vessel inspected, then the boat may not launch in the County The fee for screening and/or inspection performed by the County is $10.00. Any person violating the Ordinance shall be guilty of a misdemeanor (for each illegal boat launch) Fine for violation of not less than $1,000 and illegally launched boat is subject to impoundment	This local ordinance and other similar ordinances are enacted pursuant to the California Constitution (Article XI, Section 7) that authorizes counties to adopt and enforce regulations for the protection of the public health, safety and welfare providing these do not conflict with California general law.

Figure D-1- TPWD 2012 Zebra Mussel Public Education Campaign Results

TEXAS PARKS AND WILDLIFE DEPARTMENT
ZEBRA MUSSEL PUBLIC EDUCATION CAMPAIGN RESULTS

Paid Media

- Nine billboards (six extensions, three nonextensions; six originally planned) near Texoma from mid May to mid July garnered 16.5 million impressions with $11,500 in added value
- Pumptoppers at 47 gas stations near Texoma (24 estimated); 188 placards. Additional 23 stations negotiated
- Forty-seven gas stations (six originally estimated) participated in "station domination" by displaying window clings, floor stickers, standees, and beverage door clings for two months (one month originally planned)
- Interactive advertising (Google AdWords, Facebook, banner ads on AccuWeather.com for two months and geofencing for a month garnered 31.9 million impressions with 16,700 clicking through to TexasInvasives.org
- Placed 33 billboard-sized stencils at 15 marinas on ramps, boat landings, boardwalks and sidewalks midMay using striping paint

Paid Media Budget: $113,062

Added Value: $72,491 (includes overrides on out-of-home advertising, additional stencils, additional months on pumptopper/station domination program)

Known Impressions: 48.35 million for billboards and interactive (pumptopper, station domination and stencil impressions not tracked by the industry)

PSA Program: Lone Star Radio Network

- Three :60 radio features describing the zebra mussel problem and what to do about it using three distinct formats, 50 stations contracted

Lone Star Budget: $11,145

Lone Star Value: $42,163

Return on Investment: 3.8-to-1 ROI

Impressions: 2.92 million

Added Value: 3 additional stations delivered

Outreach Materials 2012

- Brochures: 75,000 to marinas, water authorities, partners
- Buoys: 37 produced and placed in Lake Texoma
- Posters: two versions developed; 2,000 each for marinas, boat dealers, partners
- Display banners: 24 for area boat dealers and marinas
- Fishing rulers: 5,000 for outreach activities

Email Blasts

- 5/24 email to 43,220 subscribers (http://content.govdelivery.com/bulletins/gd/TXPWD-414d40)
- 5/24 email to 91,760 registered boaters (http://content.govdelivery.com/bulletins/gd/TXPWD-414d56)

Online Advertising

- Texas Tribune ad garnered 509,216 impressions, 348 clicks from 5/1/12 - 6/15/12 (screen shot attached)
- Free advertising from campaign funding partners and other supporters such as the City of Weatherford and http://lakehub.com (impressions not known)

Print Ads

- Full-page ad in the 2011-2012 *Outdoor Annual* garnered 2.8 million impressions
- 1/3-page ad in June 2012 issue of *Texas Parks & Wildlife* garnered 148,039 impressions
- 1/2-page ad in June 2012 issue of *Texas Monthly Ads* garnered 321,138 impressions

Public Relations

- 5/24 Media event
- Press releases:
  - http://www.tpwd.state.tx.us/newsmedia/releases/index.phtml?req=20120524a
  - http://www.tpwd.state.tx.us/newsmedia/releases/index.phtml?req=20120718a
  - http://www.tpwd.state.tx.us/newsmedia/releases/index.phtml?req=20120731a

Campaign website www.texasinvasives.org

2012 Budget
$268,343

Figure D-2 Federal Laws and Regulations related to Zebra Mussels and Invasive Species

FUNDING?	Approp	None		Limited																				
	Authorized	None	Limited		Limited		Limited	Moderate		Moderate					Moderate		Moderate			Moderate				
	Agency bgt				Limited	NA						Directed												
Relevance to ZM?		High	Low	Low	High	Low	Medium	Low	Low	Medium		High	Low	Medium	High		High			Medium	Medium	Medium		Low
		HR 6007 North Texas Zebra Mussel Barrier Act of 2012"	**Asian Carp Prevention and Control Act**	**FY10 - Ag Bill; Energy & Water; DOI**	**Clean Boating Act of 2008**	**Nat'l Defense Authr Act (NDAA)** - Brown Tree Snake	**WRDA 2007** - org in & around Great Lakes	**Great Lakes Fish Restoration Act of 2006**	**Brown Tree Snake Control Act**	**Nutria Control & Eradication Act**		**Executive Order 13112** - Invasive Species	**WRDA 1999** - Great Lakes species controls	**Lacey Act (1998 Amd)** - prohibited list for import or transport	**National Invasive Species Act of 1996** Amends the NANPCA		**Nonindigenous Aquatic Nuisance Prevention & Control Act of 1990**			**Executive Order 11987** Ecological Impacts	**Endangered Species Act**	**National Environmental Policy Act (NEPA)**		**Convention on Great Lakes** (US & Canada) - Sea lamprey
			PL 111-307		PL 110-288	PL 110-181	PL 110-114	PL 109-326	PL 108-384	PL 108-016		EO	PL106-53	18 USC § 42			16 USC §4701				16 USC §1531	PL 91-190		
Year		**2012**	**2010**	**2009**	**2008**		**2007**	**2006**	**2004**	**2003**	**2000**	**1999**		**1998**	**1996**	**1992**	**1990**	**1989**	**1988**	**1977**	**1973**	**1970**		**1955**
ZM Spread