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Vulnerability Assessment to Quagga Mussel Infestation for Olivenhain, Hodges and San Dieguito Reservoirs and Associated Facilities, Including a List of Viable Control Strategies

Assessment Report

August 02, 2011

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San Diego County Water Authority.

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Executive Summary

Zebra and quagga mussels (collectively referred to as dreissenid mussels) are non-native, invasive mussels. They represent an environmental and economic nuisance, with the potential to harm ecosystems, affect water system reliability, and damage equipment and infrastructure. They may require significant investment to control. Since the discovery of live quagga mussel veligers in raw water delivered by the Metropolitan Water District of Southern California (MWD), the San Diego County Water Authority (SDCWA) has taken various measures to prevent dreissenid mussels from further infesting its raw water conveyance system and impacting facilities.

RNT Consulting Inc. was contracted to review the vulnerability of three reservoirs (Olivenhain, Hodges and San Dieguito), as well as the Olivenhain Pump Station, Olivenhain-Hodges Headworks, Hodges Pumped Storage Facility, Rancho Cielo Raw Water Pump Station, and R. E. Badger Filtration Plant.

As part of the assessment, RNT reviewed the environmental suitability of the reservoirs for mussel infestation. Estimating the potential for dreissenid populations to become established in various bodies of water is essential when assessing the vulnerability of facilities and structures. In general, the physical and chemical water quality characteristics determine the nature and extent of possible infestation. All three reservoirs have sufficient calcium to support significant populations of dreissenid mussels. Under present conditions, Olivenhain Reservoir and Lake Hodges have low pH and low dissolved oxygen in the deeper water at various times of the year. In addition, Olivenhain reservoir has low chlorophyll "a" levels suggesting very low food levels. These environmental variables may limit the size of the mussel population. Existing water quality conditions will likely change as Olivenhain and Hodges water becomes mixed through operation of the

pump/generation station. After mixing, it is possible that pH, dissolved oxygen, and chlorophyll "a" will no longer be limiting factors in either reservoir.

Large diameter piping and tunnels are not at risk of plugging from mussels, but they are at risk of mussel settlement on the walls. Some increased hydraulic roughness is to be expected from mussel attachment, and the increased hydraulic friction will reduce the maximum flow that can be achieved. Even if mussel settlement is acceptable from a hydraulic perspective, settled mussels will eventually become a source of shell debris that will be transported along the piping and deposited in areas of low flow velocities. Therefore, some increased operations costs for cleaning will be necessary.

Similarly, large valves are minimally impacted by mussels. Smaller components such as air release valves, blow off valves, instrument lines, and level gauges are typical components that may have increased maintenance or sometimes impaired performance.

It is recommended that the current monitoring program be maintained. We also suggest that maintenance personnel continue to include mussel surveillance as part of their routine activities and report findings to a single point of contact.

As some critical areas are already at risk from mussel fouling, we suggest immediate implementation of some short term mitigation options while SDCWA formulates the long term mitigation strategy for each facility. In particular, the Hodges Pumped Storage Facility appears to have the greatest exposure of the facilities reviewed due largely to the need for a variety of raw water uses.

1 Project Description, Background and Scope

1.1 Background

The San Diego County Water Authority's (SDCWA) mission is to provide a safe and reliable supply of water to its member agencies serving the San Diego region.

Historically, 90% of the County's water is imported through the Metropolitan Water District (MWD) from the Colorado River and the State Water Project. In 2010, approximately 50% of SDCWA water was Colorado River water from MWD. The percentage of Colorado River water varies from 20% to 100% depending on water supplies in Northern California and Colorado River Basin.

Discovery of quagga mussels in Lake Mead in January 2007 and subsequent spread throughout the lower Colorado River system have created significant concern among owners and operators of water supply systems throughout the West.

SDCWA prepared a Mussel Response and Control Plan to identify the actions needed to address the consequences of mussel arrival. One management action was to carry out vulnerability and risk assessments of facilities. A preliminary assessment was completed in October 2007 prior to documented infestation of SDCWA waters.

This present assessment is part of the continuing program to manage the effect of quagga mussels in the SDCWA system.

1.2 Overview of Evaluated Water System

Imported water flows to San Diego County through five large diameter pipelines. SDCWA takes ownership of these pipelines approximately six miles south of the Riverside county line. The main pipelines range in size from 48 to 108 inches and carry either fully treated potable water or untreated water that is then treated within the county. The system has the capability of delivering more than 900 million gallons per day. The pipelines and associated facilities run north to south along two routes known as the First and Second Aqueducts.

Historically, San Diego County imports more than 90% of the water consumed by its residential, commercial, industrial, and agricultural users. Pipelines used to transport water into the county cross several major fault lines, including the San Andreas, Elsinore, and San Jacinto faults. A major earthquake could seriously damage water supply pipelines, resulting in water supply interruption for up to 6 months.

SDCWA initiated the Emergency Storage Project (ESP) to address supply interruption concerns. The ESP is a system of reservoirs, interconnected pipelines and pumping stations designed to ensure water is available to all communities in the San Diego region in the event of an interruption in supply caused by a drought or major earthquake. The Olivenhain Dam and Reservoir, the interconnection to Lake Hodges via the Hodges Pumped Storage facility, and the Olivenhain Pump Station are all part of the ESP.

Interagency interties are essential to the success of the ESP as they create options for both water storage and delivery. The Olivenhain-Hodges portion of the ESP connects Lake Hodges, a city of San Diego owned reservoir, to the Olivenhain Reservoir. Lake Hodges is connected to the San Dieguito Reservoir and supplies water for use by Santa Fe Irrigation District and San Dieguito Water District following treatment at the R.E. Badger Filtration Plant, owned and operated jointly by Santa Fe and San Dieguito.

1.3 Scope of Work

The evaluation consisted of:

1. Analyzing environmental parameters and water quality data for the targeted reservoirs
2. Estimating the size of the potential infestation and vulnerability of facilities
3. Performing site assessments
4. Preparing a list of available prevention/treatment options
5. Preparation of a summary report

Summarized in this report are the findings on:

- Calcium-based assessment of environmental suitability for mussel establishment
- Assessment of additional environmental parameters to determine if any may be limiting factors to the population size of the mussels
- Descriptions of systems vulnerable to mussel fouling
- Preliminary descriptions of possible practices for coping with invasion and control options for raw water systems

This report focuses on identifying those structures and facilities which are vulnerable to mussel-related impacts. This report contains what RNT Consulting Inc. believes are practical options for dreissenid mussel mitigation at each facility, but it does not include an engineering evaluation of these options.

2 Assessment Process and Method

SDCWA provided RNT with the following key documents to assist in completing our assessment:

1. Data on water quality parameters
2. A copy of the SDCWA Quagga Mussel Response and Control Plan, October, 2010
3. SDCWA drawings # S-5463 and S-5482, "Olivenhain Dam I/O Works General Arrangements, Plan and Elevation"
4. SDCWA drawings # S-5501 and S-5503, "Lake Hodges Headworks Plan and Profile"
5. SDCWA drawings # S-10185,186, and187, "Olivenhain-Hodges Pumped Storage General Arrangements"
6. Olivenhain-Hodges Pumped Storage System Flow Diagrams for: Cooling Water (S-10314), Unwatering and Filling (S-10313), Fire Protection (S-10315) and Service Water (S-10316)
7. SDCWA drawings # S-8116, S-8128 and S-8129, "Olivenhain Pump Station General Plan and Sections
8. Additional documents that were used to complete this assessment are listed in Section 5.0: Literature Reviewed

The SDCWA /RNT team, accompanied by staff from Santa Fe Irrigation District and city of San Diego, conducted site assessments on January 18 and 19, 2011. The site assessments included the Olivenhain Reservoir and Pump Station, Olivenhain-Hodges Headworks, Hodges Reservoir and Pumped Storage Facility, San Dieguito Reservoir and Pump House, Cielo Pump Station, and R. E. Badger Filtration Plant.

3 Results of the Assessment

3.1 Environmental Requirements for Mussel Infestation

Understanding the environmental suitability of the reservoirs to sustain mussel populations is helpful when assessing the mussel-related vulnerability of facilities and structures. There is a positive correlation between mussel population size and threat to facilities: the larger the projected mussel population, the greater the vulnerability of associated structures. Calcium is considered the most important parameter for mussel establishment. Dreissenid mussels need calcium in order to build their shells. The larval forms (veligers) of dreissenid mussels require higher levels of dissolved calcium for shell formation than is required by adult mussels for survival. All three reservoirs examined have high levels of calcium capable of supporting massive populations of dreissenid mussels. Therefore, calcium will not be a limiting factor.

Table 1 was derived from the values reported by various authors and gives the ranges of values for each of the parameters as they relate to success of dreissenid mussel populations.

In the presence of adequate calcium levels, dreissenid mussels can proliferate unless another environmental parameter is limiting. Water pH influences shell development and maintenance due to the impact on calcium. A pH value in the range of 7.5 to 9.0 (alkaline) may result in moderate to high dreissenid mussel populations, with high infestations likely in a pH range of 8.2 to 8.8 (Table 1).

In mild climates, temperature is unlikely to be a limiting factor. However, additional important parameters to consider are levels of dissolved oxygen and levels of chlorophyll "a".

Dissolved oxygen in lakes and reservoirs may become a limiting factor during portions of the year when deeper water becomes low in dissolved oxygen.

The nutrient parameters (e.g. total phosphorous and nitrogen), chlorophyll *"a"* levels, and Secchi depth are known as "trophic indicators" and are all related. The higher the values of the nutrient variables, the greater the biomass of algae (chlorophyll *"a")*, the higher the dissolved oxygen (at the surface), and the lower the Secchi depth values (i.e. water is more turbid). Since mussels feed on algae, the values of the trophic indicators are also important for predicting dreissenid population densities.

Table 1. Criteria used in determining the levels of infestation in the temperate zone of the eastern portion of North America and Europe (Mackie and Claudi, 2009)

Parameter	No sustained Infestation (Adults do not survive long-term)	Low Infestation (Uncertainty of veliger survival)	Moderate Infestation	High Infestation
Calcium (mg/L)	<8 to <10	<15	16-24	≥24
Alkalinity (mg $CaCO_3$/L)	< 30	30-55	45-100	>90
Total Hardness (mg $CaCO_3$/L)	<30	30-55	45-100	≥90
pH	<7.0 or >9.5	7.1-7.5 or 9.0-9.5	7.5-8.0 or 8.8-9.0	8.2-8.8
Mean Summer Temperature (°F)	<64	64-68 or >83	68-72 or 77-83	72-75
Dissolved Oxygen mg/L (% saturation)	<3 (25%)	5-7 (25-50%)	7-8 (50-75%)	≥8 (>75%)
Conductivity (µS/cm)	<30	<30-60	60-110	≥100
Salinity (mg/L) (ppt)	>10	8-10 (<0.01)	5-10 (0.005-0.01)	<5 (<0.005)
Secchi depth (m)	<0.1or >8	0.1-0.2 or >2.5	0.2-0.4	0.4-2.5
Chlorophyll "a" (µ/L)	<2.5 or >25	2.0-2.5 or 20-25	8-20	2.5-8
Total phosphorous (µg/L)	<5 or >50	5-10 or 30-50	15-25	25-35

3.1.1 Terminology for Densities

The assignment of the qualitative descriptors of low, moderate and high potential dreissenid settlement is intended to indicate broad ranges of mussel density. Ramcharan et al. (1992) consider low densities between 1,000-3000 m^2 and high densities >~4,800 m^2, but no rationale was given. More often, a high density is considered one in which a square meter of surface is completely covered by at least one layer of mussels in one season. A typical adult mussel has a ventral surface area of approximately 2 cm^2; therefore it would take 5,000 mussels to cover 10,000 cm^2 (i.e. 1 m^2) annually to meet the criterion for high density as defined by Ramcharan et al (1992). Ramcharan et al (1992) considered 3,000 m^2 as the upper threshold of low densities because their data “appeared to represent a natural break in the density frequency distribution”. However, 3,000 m^2 represents 60% coverage of a square meter of surface. A 30% coverage seems more appropriate, so we consider a low infestation level as one in which the annual settlement density is less than 1,500 individuals/m^2 and moderate infestation as annual settlement of between 1,500 and 5,000 m^2.

3.2 Olivenhain Reservoir

From the 2010 data available, Olivenhain Reservoir has surface pH in the range likely to support massive infestation. In deeper water, both at 30m and 60m, the pH is much lower. Recently, the pH recorded at these depths is below what would be required for successful veliger development and long term survival of adult dreissenids (Fig.1). This was noted in the 2010 Quagga Mussel Response and Control Plan prepared by SDCWA. As this reservoir is the point of withdrawal for transfer to Lake Hodges, pH at this depth may limit the number of quagga mussels transferred.

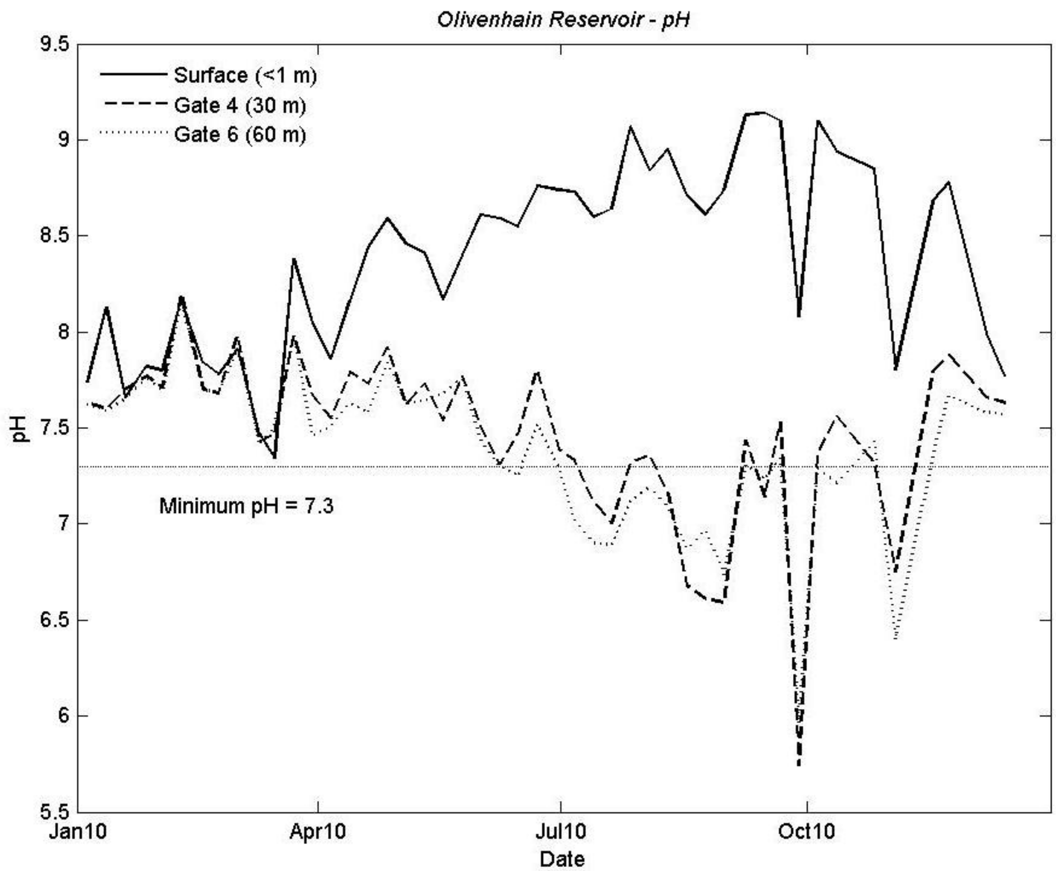

Fig.1 pH profile of the Olivenhain Reservoir.

Adult dreissenid mussels feed on a variety of single celled green algae, usually in the 40 micron size range. Green algae contain chlorophyll "a". Therefore, measurements of chlorophyll "a" indicate how much green algae is present in the water sampled. Very low levels of chlorophyll "a" could be interpreted as insufficient food available for adults.

The chlorophyll "a" levels recorded in the Olivenhain Reservoir (Fig.2) are well below optimum for development of mussel infestation.

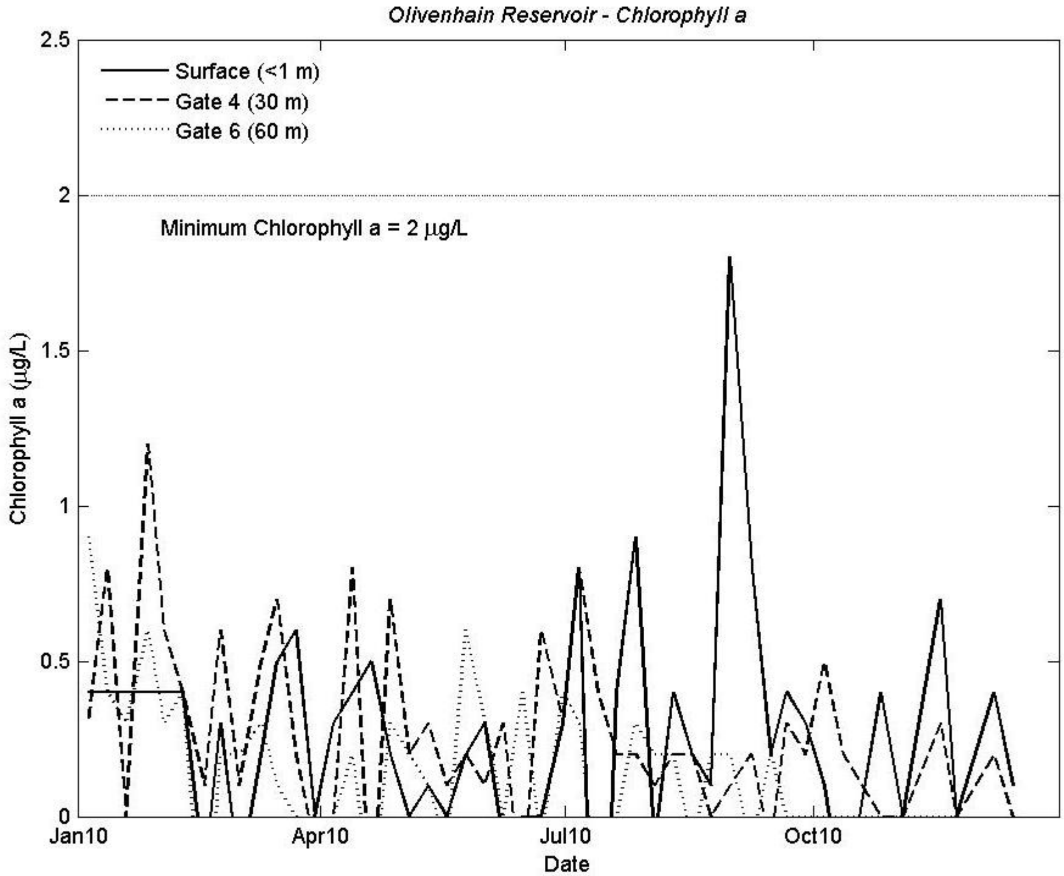

Fig.2 2010 Chlorophyll "a" levels recorded in the Olivenhain Reservoir.

These low levels of available food may limit the population of quagga mussels that could develop in Olivenhain Reservoir.

Adequate dissolved oxygen level is another requirement for dreissenid mussels. Although adults can withstand short periods of almost complete absence of oxygen, sustained periods where oxygen is below 3mg/L tend to induce high adult mortality. The dissolved oxygen in Olivenhain Reservoir (Fig.3) appears to decline in the deeper water starting in June. The observed minimum in 2010 was 3mg/L at 60m depth. Low dissolved oxygen, particularly in combination with the low pH, may severely limit the development of a substantial quagga mussel population in the deeper water of Olivenhain Reservoir under current conditions.

The temperature profile for Olivenhain Reservoir appears to be in the range likely to support massive infestation if pH, dissolved oxygen, and low chlorophyll "a" were not limiting factors.

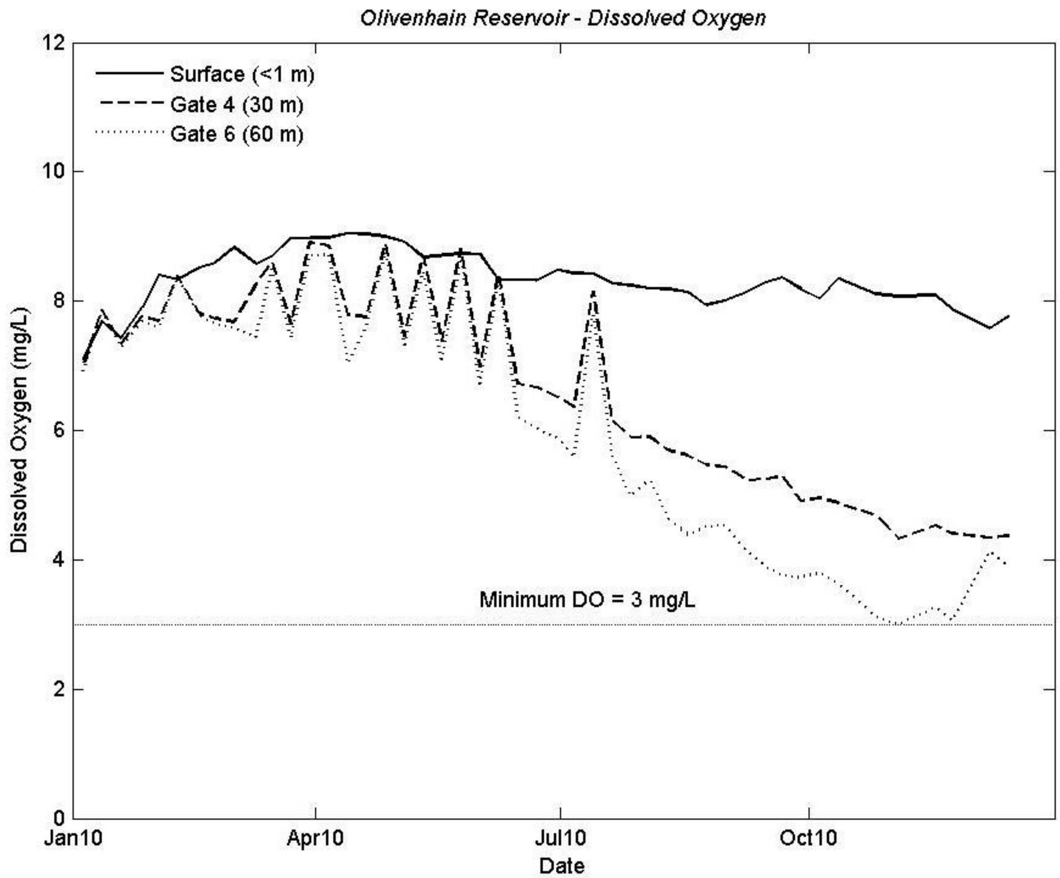

Fig.3 2010 Dissolved oxygen levels recorded in the Olivenhain Reservoir.

The above parameters recorded for Olivenhain reservoir are going to undergo changes once water starts to be pumped up from Lake Hodges. The temperature and oxygen levels of the hypolimnion will change and the nutrient levels are likely to increase. Thus, the factors potentially limiting the dreissenid population in Olivenhain reservoir at this time are likely to disappear, leading to potentially much heavier infestation in the future. Continued monitoring of the environmental factors in the reservoir is recommended.

3.2.1 Lake Hodges

Lake Hodges also has more than adequate calcium to support massive infestation by quagga mussels, but at present several environmental variables may prevent high level of infestation.

Manganese, which is present in very high levels in Lake Hodges may impact dreissenid mussels. Dreissenids are able to cope with heavy metals to some degree. Bioaccumulation of various heavy metals has been documented in both quagga and zebra mussels. However, the effect of very high levels of manganese on adult quagga mussels is not known and should be tested.

The 2010 pH levels at 12m depth are below what would be required for successful veliger development and possibly even for long term survival of adult dreissenids (Fig.4).

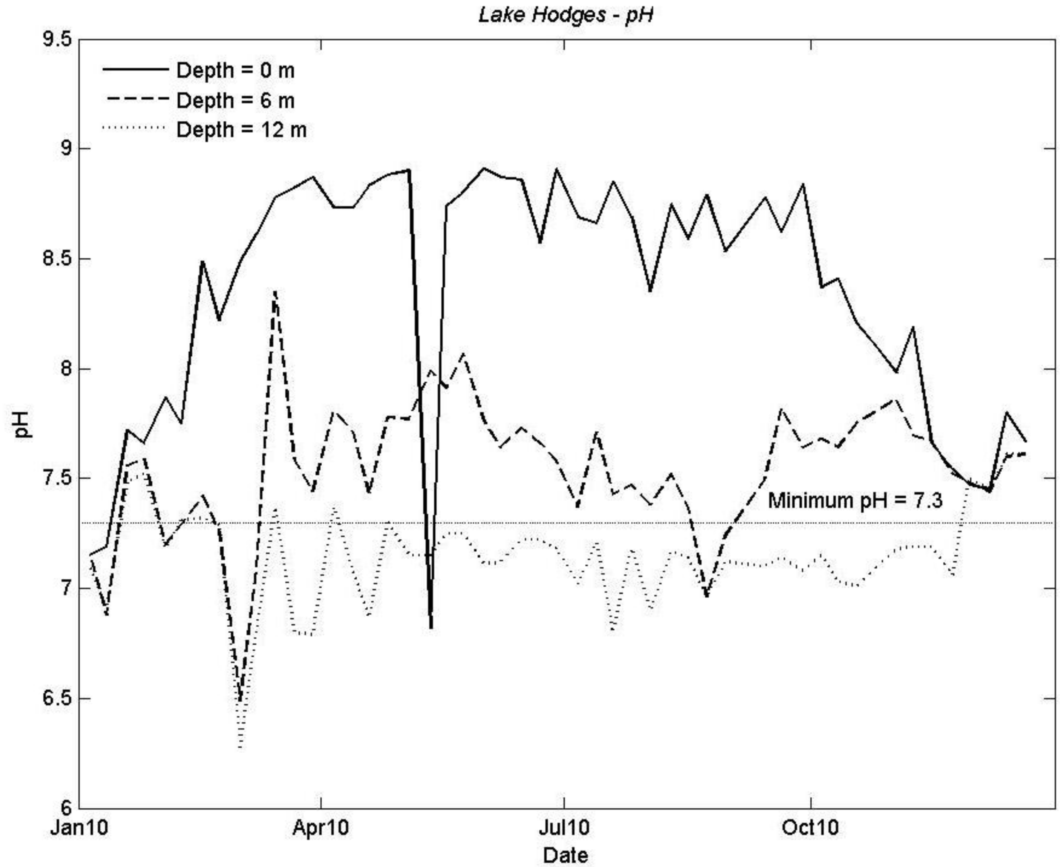

Fig.4 Lake Hodges pH levels during 2010.

Dissolved oxygen follows the same pattern as pH in Lake Hodges. For most of the year, DO is below the minimum required level for dreissenid veliger or even long term adult survival starting at the depth of 6m (Fig.5).

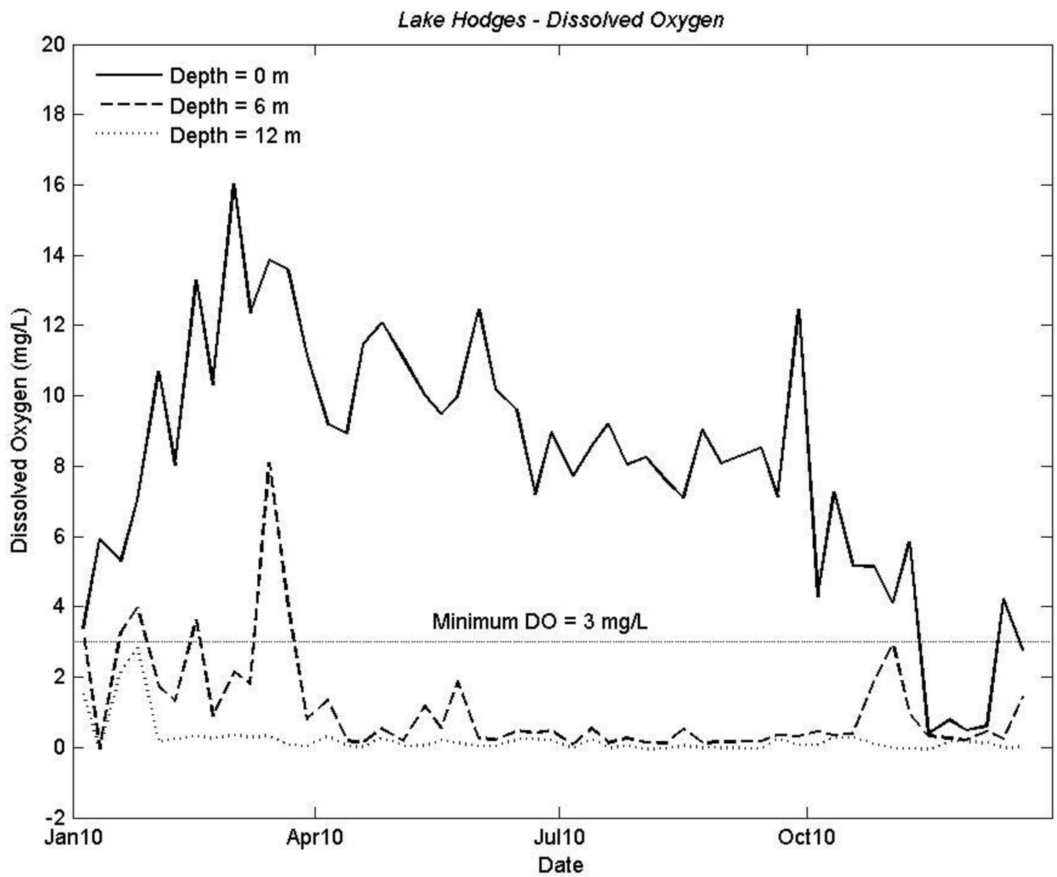

Fig.5 Lake Hodges dissolved oxygen levels during 2010.

The high surface values of dissolved oxygen suggest strong algal blooms are taking place at the surface of Lake Hodges. This observation is supported by the chlorophyll "a" measurements taken in 2010 (Fig.6). The surface levels of chlorophyll "a" exceed the upper threshold for a sustainable dreissenid population. This finding is based on various European and North American studies which document that strong algal blooms may interfere with dreissenid veliger survival (Stanczykowska & Lewandowski 1993, Mackie and Claudi 2009). The exact process is not well documented and there may be more than one mechanism that limits veliger survival, such as difficulty for veligers to swim through dense algal colonies, veligers becoming trapped in the filamentous algae and so on.

A secondary effect of strong algal blooms is that once the algae begin to die off and drift to the bottom they begin to decompose, creating a high biological oxygen demand in the lower layers of the water body. This may result in loss of oxygen in this region to the point of anoxia. For adult mussels located in this region, increased mortality will occur if this lack of oxygen persists for more than two or three weeks.

Heavy algal blooms are generally not continuous events but they may limit veliger development during some part of the year.

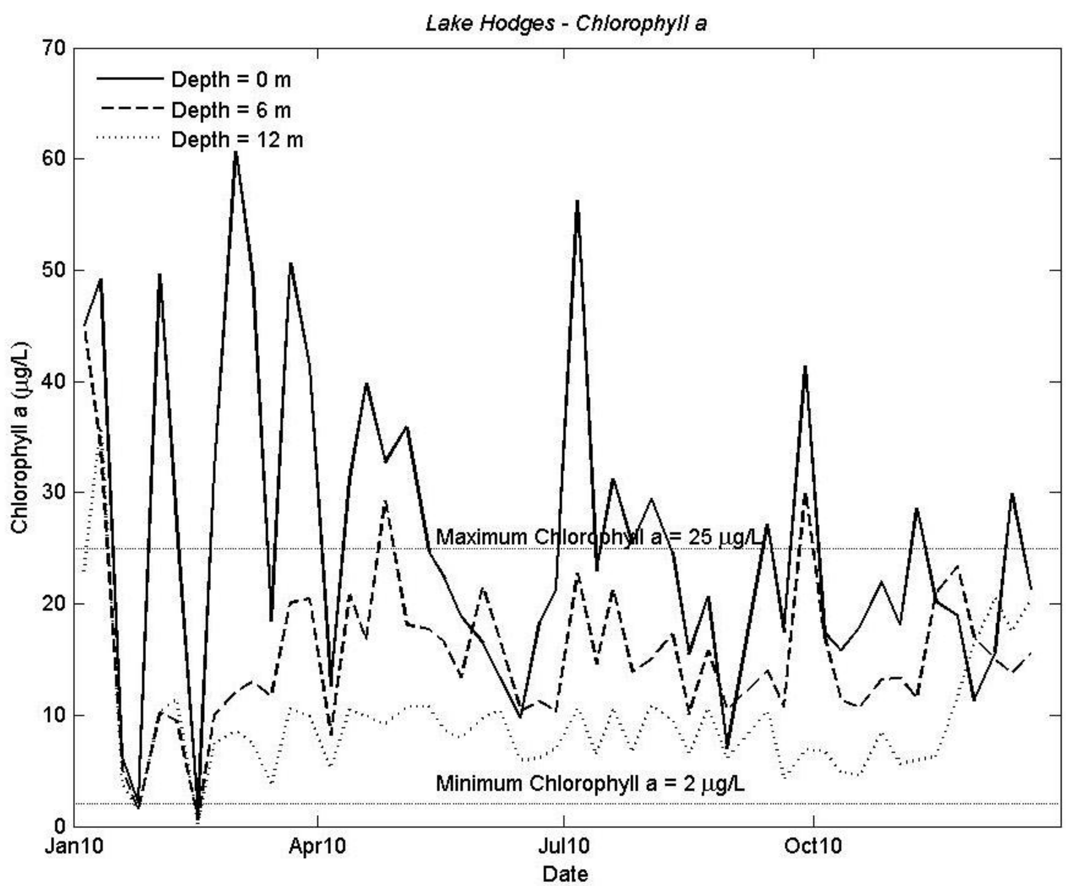

Fig.6 2010 data for chlorophyll "a" at Lake Hodges.

The temperature data for Lake Hodges suggest that this parameter is well within the optimum range for mussel development.

Once again, the environmental parameters of Lake Hodges will change when water exchange with Olivenhain Reservoir begins. This may result in improved water quality in most of Lake Hodges and perhaps result in a greater population of dreissenid mussels than would be anticipated from the current state of the reservoir. Continued monitoring of the environmental factors in the reservoir is recommended.

3.2.2 San Dieguito Reservoir

This reservoir shares the high calcium level of the other two reservoirs already described. However, the pH data available (Fig.7) suggest absence of the very low pH levels observed in Lake Hodges and Olivenhain Reservoir.

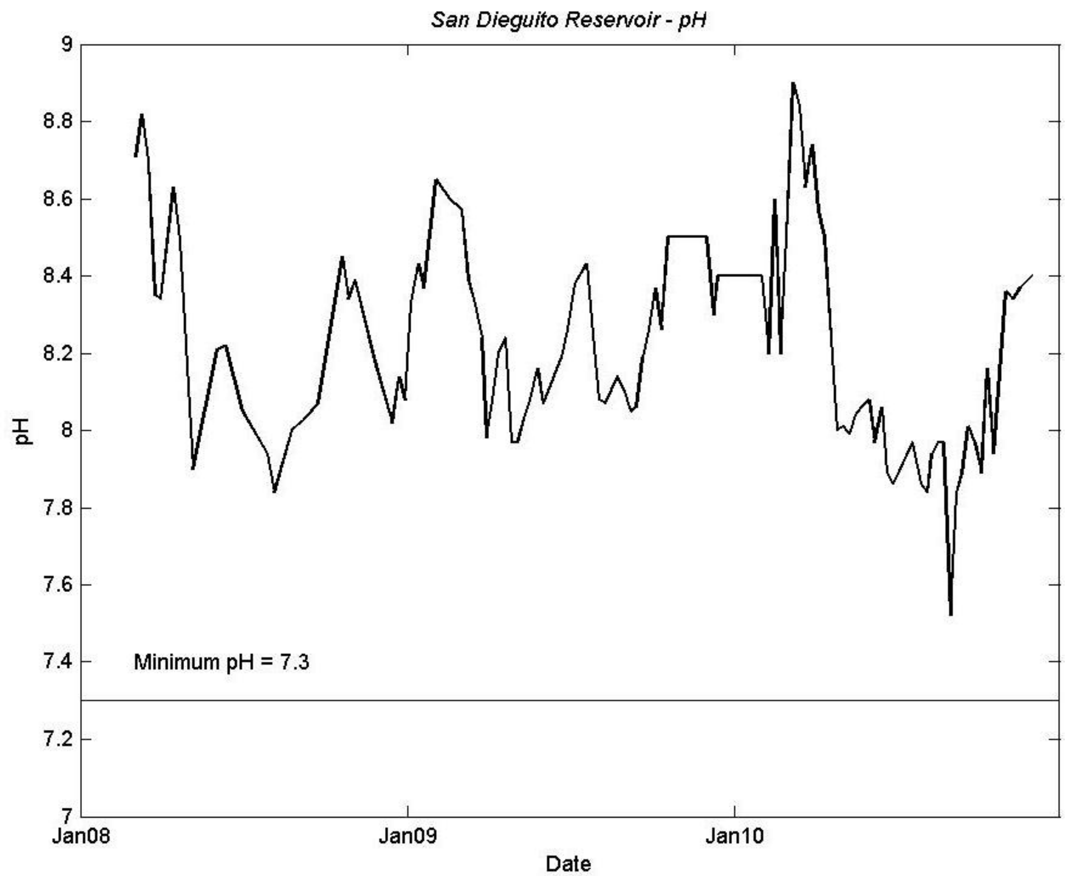

Fig.7 San Dieguito Reservoir pH levels from 2008 to 2010.

The same is true of dissolved oxygen levels (Fig.8). Dissolved oxygen appears to be significantly higher than in the other two reservoirs. Chlorophyll "a" levels (Fig.9) periodically fall outside of the optimum range for dreissenid mussels, during what is presumed to be the spring algal bloom, but they return to the optimum range relatively swiftly.

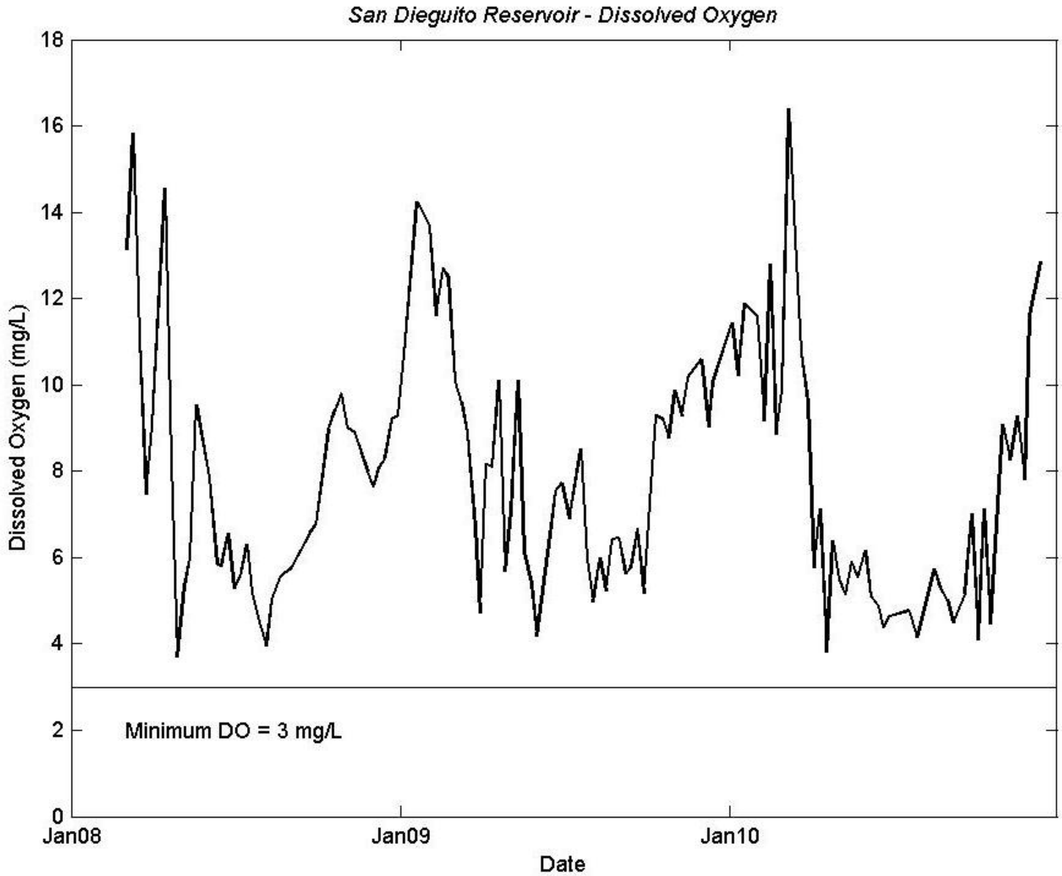

Fig.8 San Dieguito Reservoir dissolved oxygen levels from 2008 to 2010.

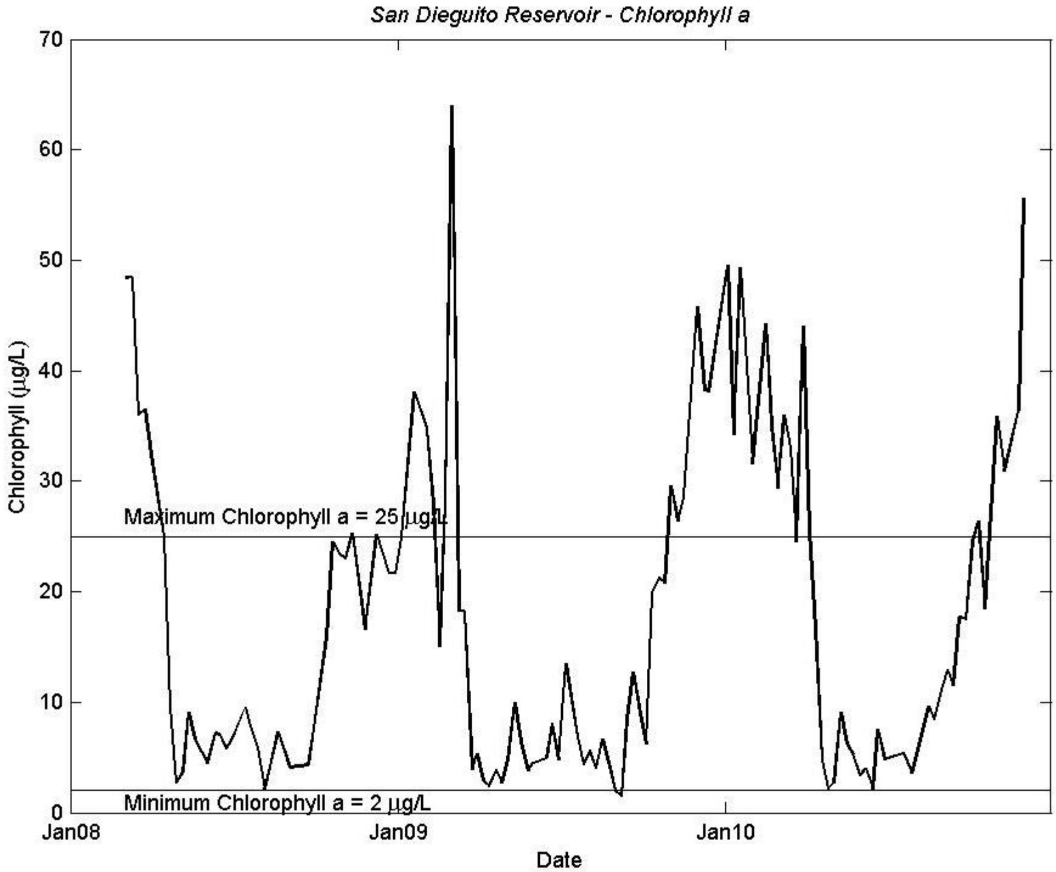

Fig.9 San Dieguito Reservoir chlorophyll "a" levels from 2008 to 2010.

This reservoir is likely to support high population of dreissenid mussels should they be introduced.

3.3 Summary of Environmental Factors Assessment

Possible relief from high dreissenid population levels due to pH, dissolved oxygen and chlorophyll ‘a’ levels at this moment.

Mixing Olivenhain Reservoir and Lake Hodges once the pumped storage process begins suggests that changes to pH, dissolved oxygen, and chlorophyll ‘a’ are likely.

Multi-year monitoring of environmental parameters, as set out in the Lake Hodges Projects Reservoir Regulation Manual is desirable and should be done, particularly as the historic limnology of Olivenhain Reservoir and Lake Hodges is about to change.

3.4 Review of the Facilities

3.4.1 Olivenhain Dam and Reservoir

The Olivenhain Dam and Reservoir were constructed as part of SDCWA's Emergency Storage Project (ESP).

The 318 foot dam is constructed of roller compacted concrete. The reservoir formed by the dam has a capacity of 24,332-acre-feet. Other elements of this portion of the SDCWA ESP include the Olivenhain Pump Station and an emergency generation system.

This reservoir is closed to the public.

3.4.1.1 The Dam Inlet/Outlet Tower

The Inlet/Outlet (I/O) tower has 6 hydraulically operated gates, 2 on each face of the tower. Each gate is 4'X6' and at a different elevation to allow for maximum flexibility in quality of withdrawn water. The normal operating regime is to draw water from below the hypolimnion. Depending on the oxygen level below the thermocline, mussel densities in the intake water should be low relative to areas above the thermocline. However, as indicated earlier, the nature of the hypolimnion will change once the Olivenhain-Hodges interconnect pipeline goes into operation.

Normal cycling of the gates will keep the gate tracks free of mussels so that a buildup of mussels will be unlikely; therefore, mussels should not pose an operational problem for the gates. Gates that do not cycle frequently in the normal course of operations should be cycled 2 to 3 times during the mussel breeding season to keep the gate tracks clear of any mussel attachment.

Fish screens on the face of the intake tower are raised out of the water when the particular gate is not in use. The screens will dry and any settled mussel veligers will die from desiccation.

3.4.1.2 The Dam Adit

All drains in the dam terminate at a common weir. The leakage is measured once per month. Any deviations from the normal leakage pattern would be checked to determine the reason for the deviation. This check should include determining if mussels are plugging any drains. Mussels in any of the drains could be eliminated by a steam lance or drain auger.

The adit has a water quality station and a full length raw water line for wash down. These are inspected once per month. Presence of mussels in either of these areas could be eliminated with a thermal flush.

The dam foundation drain system should not be affected by mussels. However, the drain system is flushed once per year and any abnormalities should be investigated to determine if they are related to mussels.

3.4.1.3 Olivenhain-Hodges Headworks

The headworks on the crest of the Olivenhain Dam house the control gates on the pipeline between Olivenhain and Hodges. There is a tapered concrete intake in the reservoir which narrows and transitions to the horizontal intake tunnel leading to the gate house.

There are trash racks oriented vertically located on the intake structure. The trash racks and tunnel leading to the gate house will be vulnerable to mussel settlement. Some mussel settlement in these areas has already been reported.

The trash racks have been recently modified to reduce the bar spacing by welding on additional bars. The purpose of this modification was to exclude smaller size trash from the pipeline. The narrower bar spacing gap will provide more surface area on which mussels can settle and will increase the rate at which mussels can form an obstruction to the flow.

The trash racks are always submerged, even at the reservoir minimum pool level. Typically, the most effective way to clean continuously submerged trash racks is by divers. A scrape and vacuum method is recommended in order to minimize the shell debris coming into the plant. If scraping only is done, the timing should be just before the pipe/tunnel is operated in pump mode. The pump flow will disperse the loosened mussels into the reservoir and reduce the chance that the debris will pass through the pump/generation plant.

Anti fouling or foul release coatings on the trash racks can reduce the time between required cleaning if the cleaning process becomes an operational nuisance.

The control gates incorporate a small slide gate that is used to balance the pressure on each side of the gate. The small slide gate is actuated by the weight of the main gate lifting bar. The weight of the lifting bar is unknown but upon inspection, it appears that mussel accumulation around the slide could hinder its operation. The main gates will cycle infrequently. If they are completely withdrawn from the water column when not in use, the small slide gate will dry out and any mussels will die. If the gates remain submerged when pumping or generating, fouling may occur. It may be prudent to periodically raise the gates completely into the operating building and pressure wash the area of the small slide gate to remove any mussel attachment.

It would be helpful to periodically cycle the gates completely, at least to the area of the gate chamber just above the tunnel, to keep the main gate guides free of mussel shells.

The tunnel and pipe line are large diameter and it is not possible that mussels could cause a flow blockage of the pipe or tunnel. However, there could be some flow reduction due to the increased roughness caused by even a small layer of mussels accumulating on the pipe walls. This would cause some minor reduction in power output during generation mode and some minor increased electricity consumption during pumping mode. If the economic penalty due to this friction increase becomes significant, then the mussel accumulation that can be tolerated needs to be assessed and the tunnel/pipe cleaned as required.

Any vent lines that are continuously wetted should be inspected periodically and cleaned of mussels. Otherwise mussel accumulation may slow the drain/fill process or cause unacceptable negative pressure conditions.

3.4.1.4 Emergency Generator Station

A 7 MW emergency generator is located near the crest of the dam. The equipment is located in a separate building and yard. The diesel generators have self contained cooling systems and do not use raw water. The emergency generators are not at risk of mussel infestation.

3.4.2 Olivenhain Pump Station

The Olivenhain Pump Station is located at the base of the Olivenhain Dam. The main purpose of the pump station is to move water from the Olivenhain Reservoir through SDCWA's Olivenhain Pipeline to the Second Aqueduct.

Water enters the pump station from the Olivenhain Dam via a 102" diameter pipe manifold. At present, system pumping is required for only a one month period, two times per year. The pumping occurs in May and again in October/November. During the remaining time of the year much of the system is either drained or chlorinated. Any water in piping that remains flooded has low oxygen levels (measured at or below 1 mg/L). At such low levels of oxygen, mussels will not survive.

The pumping portion of the pump station is unlikely to be affected by mussels in the present operating configuration. However, the main components of the system were examined in the event the operating regime should change sufficiently to allow mussels to survive in the pump station.

There are 3 horizontal double suction pumps that take water from the manifold and discharge to the Olivenhain pipeline. A fourth pipe from the manifold is a pump by-pass line, and a fifth line is for addition of another pump in the future. The sixth pipe can deliver untreated water from the reservoir to the Olivenhain WTP, but is currently not in use.

The pump motors are air cooled and will not be affected by mussels.

The pump bearings are cooled with raw water and the cooling lines are at risk of plugging from settled mussels or shell transport.

The shaft seal cooling and flush lines have Y-strainers which should minimize passage of shell material larger than the strainer pore size. Some smaller shell material could pass to the seal faces and cause some increased abrasion of the seal faces. In addition, mussel veligers could pass through the strainers, attach, and grow in the seal flush lines starving the seals of flushing and cooling flow. Mussels have also been known to colonize cavities in the seal such as the lantern ring, reducing cooling performance and requiring shutdown of the pump to clean the cavity. The addition of small pore filters (< 100 microns) will eliminate settling age veligers from the seal water.

The fire protection system inside the station and the external hydrant are provided with water from the adjacent Olivenhain Water Treatment Plant. It is understood that this water is treated water and will therefore be free of both mussel shells and mussel veligers.

The ventilation system incorporates air chillers that use raw water for cooling. The water provided to the coolers is untreated water. The water enters the air cooling system through Kinney self cleaning strainers with automatic backwash. There are also older model Hayward strainers on the cooling water piping for the chilled air system that are used for backup. These strainers are kept flooded. Both types of strainers will remove shell material and any translocating adults. The downstream portion of the strainer bodies will be settlement areas for mussels. This includes the Hayward strainers if there is any seepage flow past the isolation valves.

The piping in the chilled air cooling water is mostly copper. Copper is toxic to mussels and prevents mussel settlement. In areas of very low flow, copper can have a bio film form to which mussels attach. The attachment is weak and usually easy to clean.

The coolers are the component in the chilled air system most at risk from mussel fouling. The flow velocities are lower in the cooler and the cooler pipes are small, making them more prone to plugging. The inlet and outlet headers are typically the areas where mussel accumulation is most frequent and troublesome.

If the coolers can be taken off line for a few days, flushing of the system with hot water will be an environmentally benign way of controlling mussels. Depending on the growth rate of the mussels, one or two flushes per year done during the height of the mussel breeding season (April to November) should be sufficient. A chemical flush would also be successful if regulatory permitting can be obtained.

All air release valves in the station are flushed and checked once per year. This normal process should keep these valves operating properly.

The station air compressors are air cooled and do not use any cooling water.

There is little continuous leakage so drain lines should not be impaired with mussels. Seepage and wash down water is collected in a common sump. If the sump remains wet and is occasionally refreshed with wash down water, mussels can survive. The sump should be inspected yearly and cleaned if mussels accumulate.

There are venturi-style flow meters which may have their accuracy reduced by mussel settlement in the pressure differential lines. The pressure taps on these venturi meters have an integral cleaning plunger which is manually cycled frequently to keep the pressure taps free of debris, including mussels. These meters are calibrated twice per year and any deterioration in performance will be corrected during the calibration process.

3.4.3 Lake Hodges Dam and Reservoir

Lake Hodges Dam is a multiple-arch dam that was built in 1918 to hold back the San Dieguito River in the Del Dios Gorge. The 115 ft tall dam created Lake Hodges. This water body has many recreational users and is considered a fishing hot spot. All boats coming during daylight hours are inspected by city staff for mussels. The launching ramp is closed when staff is not present. The City has put up signage that instructs the boaters to drain/dry their boats upon leaving the reservoir.

Lake Hodges water can be directly supplied to the R. E. Badger Filtration Plant through the Cielo Pump Station or gravity fed to San Dieguito Reservoir through a recently constructed pipeline.

The spillway is on the right abutment of the dam, and is an uncontrolled concrete lip. Water passing over the spillway during the rainy season enters the San Dieguito River and currently is unrecoverable for SDCWA use. It is expected that the potential for water spills over Lake Hodges Dam will be significantly reduced once the Hodges Pumped Storage facility is in operation. Existing freshwater ponds downstream from Lake Hodges are sustained by leakage from the dam. The environmental conditions of these ponds has not been examined. However, seepage from the reservoir will have a low risk of transporting mussels and even if mussels could survive in these ponds to reach adult maturity, successful reproduction is unlikely due to potentially extreme environmental conditions and limited water volume for veliger development.

The dam outlet works consists of two vertical pipes in the wall of the dam with metal intake grates. The flow is controlled by valves within the body of the dam.

A hydrodynamic model of the lake mixing once operation of the pump/generation plant begins predicts that the Lake Hodges reservoir will become fully mixed within 6 months. Should mussels be able to move successfully from Olivenhain to Hodges then the outlet grating at the dam and downstream piping could become a settlement area for mussels. The grates are not removable and would require cleaning by divers.

3.4.4 Hodges Pumped Storage and Power Plant

Lake Hodges Pumped Storage and Power Plant connects Lake Hodges with the Olivenhain Reservoir. The connection increases the ability to store water at Lake Hodges for emergency use and also allows water from Hodges to be made available throughout the region. Additionally, the pumping ability enables water to be captured before it spills over the Hodges Dam during rainy seasons. During the transfer of water from Olivenhain Reservoir downhill to Lake Hodges, the plant will generate 40 megawatts of peak hydro electric energy.

3.4.4.1 Inlet/Outlet Structure at Lake Hodges

The I/O structure is similar to the Olivenhain/Hodges headworks. There is a tapered rectangular concrete intake in the reservoir which narrows and transitions to an intake tunnel with a downward grade leading to the draft tubes in the pump/turbine house.

There are trash racks oriented vertically on the intake structure. The trash racks and tunnel leading to the draft tubes will be vulnerable to mussel settlement.

The trash racks are completely submerged at all times. Cleaning will have to be done by divers. A scrape and vacuum method is recommended to minimize the shell debris coming into the plant. If scraping only is done, the timing should be just before the pipe/tunnel is operated in generation mode. The flow through the draft tube will disperse the loosened mussels into the reservoir and reduce the chance that the debris will pass through the pump/generation plant.

Water is delivered to the pump intake through a U-shaped draft tube. Mussel accumulation in the draft tube is unlikely as the velocities in the draft tube are expected to be above 6 ft/sec.

3.4.4.2 Raw Water

The raw water supply enters the plant from the pump draft tubes or tail water area via several intake pipes that are 3", 8" or 10" diameter. All in intakes are covered with metal grating. The intake grates typically attract mussel settlement and are at risk of partial or complete blockage by mussels.

3.4.4.3 Unit Cooling Water

The unit cooling water intakes are two 10" pipes that intersect with a common 10" raw water header.

This water then passes through two self-cleaning, auto-backwash strainers. The basket screens are 3200 micron (approximately ⅛th inch) diameter mesh. All strainers, whether automatic or manual, within the plant are equipped with 3200 micron mesh baskets.

Beyond the raw water strainers, the piping forms a common 8" header that branches into the fire water piping and the unit cooling water piping. Unit cooling water is taken from the 8" raw water header by one of three pumps. The pumps all have air cooled motors and bearings. The shaft seal is self lubricating packing requiring no water.

The unit cooling water serves the pump/turbine guide bearings, generator/motor guide and thrust bearings, and the generator/motor air coolers.

The seal flush water to the pump/turbine mechanical seal and labyrinth ring on the shaft is filtered to 100 microns. This will provide protection from both mussel shells and mussel veligers.

The strainers are effective at preventing entrance of adult mussels or mussel shells into the piping system. However, veligers will readily pass through the strainers and can settle in the downstream piping and components.

The inlet plenum and outlet plenum of air coolers and oil coolers are typically vulnerable to veliger settlement unless these portions of the components are made from copper or copper alloy. In addition, the inlet plenum of a cooler is typically a catchment area for any shells or shell fragments that manage to find their way along the upstream piping. Shell material can gradually accumulate in the plenum, ultimately blocking tubes and causing poor performance of the coolers. If poor cooler performance is detected by either flow or temperature monitoring, maintenance personnel should be advised that mussel shell accumulation is a possible cause and take appropriate investigation steps.

Cooling lines are likely to have flow velocities greater than 6 ft/sec and would not be vulnerable to mussel settlement. However, the flow velocity should be confirmed, especially if the flow to the coolers is variable and can drop below design flow. Cooling lines are frequently made from alloys that do not contain high concentrations of copper. If temperatures in the cooling water are below 90°F, water flow is less than 6 ft/sec and the tubes are non-copper, then the tubes could become settlement areas for mussels. If cooler performance deteriorates and mussels are determined to be the cause, then piping can be cleaned by flushing with a weak organic acid. Hot water and compressed air are alternative methods of cleaning. In the event mussel growth in the cooling lines becomes a frequent problem, piping may be replaced by copper tubes. Even with copper tubes, cooling water piping may be clogged if mussel settlement occurs downstream of the strainers.

3.4.4.4 Fire Protection Water

The fire protection system water comes from the tail water area via a 10" line that is covered with a grate. This line directs raw water through a self cleaning strainer and then on to the fire water pumps. The grate will be at risk of flow restriction from mussel settlement. The fire water piping will also be at risk of mussel settlement unless the water in the pipe lines is tested and shown to be anoxic between fire system tests.

There is also an interconnection between the fire protection system piping and the cooling water piping downstream of the cooling water strainers. This section of piping between the raw water strainers and the fire protection system piping branch is susceptible to mussel fouling. Resultant shell debris may affect fire protection system performance during a fire test or fire event. The length of this section of piping is small and hence the risk of fire protection system impairment is also small. If more complete risk elimination is considered necessary, a separate strainer could be considered or the fire protection system could be connected to local municipal fire water if this opportunity exists.

The fire protection system is tested every 6 months and activated once per year. The existing strainers should keep out any shell material or adult mussel translocators during fire system testing. Veligers will be able to enter the fire protection piping during system testing or during use of the fire water system. In portions of the fire protection system piping that are normally stagnant, veligers should not be able to survive as the water will become low in dissolved oxygen during the periods between system uses or testing. The 6 month period between testing should be sufficient to eliminate mussels in the fire protection piping unless there is seepage in the system.

The main fire protection pumps have air cooled motors and bearings. The shaft seal is self-lubricating packing requiring no water.

A jockey pump keeps the fire water piping pressurized to 20 psi and makes up for any seepage. It is unknown at this time how often the jockey pump will be required to operate. If relying on anoxia as a mussel control measure in the fire protection system piping, the oxygen level should be checked periodically. The rate of oxygen decay should be measured as the decay can be variable depending on the particular water conditions. It may be prudent to connect the jockey pump to a system of treated water. Provided the overall fire system seepage is small, the treated water demand should be small. By using treated water as make–up for the fire protection, the introduction of veligers and adults into the system is limited to periodic fire protection system testing.

The electrical transformers are provided with a deluge system connected to the fire protection system piping. The deluge piping is usually kept drained so no settlement will occur. The deluge nozzles are at risk of plugging if shell debris exists in the fire protection piping upstream of the deluge isolation valve.

3.4.4.5 Service Water and Instrumentation

Service water in the station is raw water. The service water comes from the tailwater area via a 3" line that is covered with a grate. This line directs raw water through a self cleaning strainer and then on to the single service water pump which pressurizes a hydro-pneumatic tank. The grate will be at risk of flow restriction from mussel settlement. The service water piping will also be at risk of mussel settlement.

As service water generally does not place the pump/generation operation at risk, an operational decision to leave this system unprotected and deal with mussel problems as they arise in a reactionary mode may be practical. The overall layout of the station appeared tight for maintenance access and this may make introducing mussel mitigation measures for the service water desirable as opposed to adopting a reactionary approach. Some methods suggested would be: periodic flushing with hot water, periodic draining and drying/heating with hot air or steam, coating the intake grate with anti-fouling paint, and continuous or periodic treatment with an oxidizing chemical.

A number of valve operators, ball valve seals, flow switches, level measuring tubes, and pressure taps were observed to use raw service water. The performance of this equipment is vulnerable to impairment from mussel shells or settlement, particularly since the piping and tubing is small diameter. Check valves and air release valves can leak if mussels or their shells become lodged in the valve seats. All of these components could become an operational nuisance if significant mussel settlement occurs in the small diameter piping.

Most of the service water piping materials were observed to be stainless steel. Stainless steel provides a good settlement substrate for mussel attachment.

Station air compressors are air cooled and require no service water.

The air ventilation and cooling system operates without any requirement for raw water for cooling and will not be at risk of impairment from presence of mussels in raw water.

3.4.4.6 Dewatering System and Sump Pumps

Dewatering occurs twice per day. Mussel veligers or shell material present in the draft tube water at the time of draining will enter into the drain piping. The dewatering piping from each unit is connected to two 450 gpm pumps. The pumps cease operation automatically based on the signal from a pressure switch. Plugging of the pressure switch line by shells or settled mussels could delay the proper pressure signal and cause the pumps to continue operating momentarily. Some brief pump cavitation could result.

The dewatering piping is normally flooded up to the drain line isolation valve and thereafter is normally drained but since it is wetted twice per day, any water pockets could develop local populations of attached mussels.

The drain piping is also connected to a 2" diameter sump line that directs any seepage that bypasses the gate valve into the sump where it is removed by two float operated pumps. There will be standing water in the line up to the point of the interlocked isolation valve that is closed when the pump/turbine is operating. This line may become blocked or partially blocked by mussel shells or settled adults. Seepage may remain in the draft tube possibly at unacceptable levels.

Some drain piping cleaning may become necessary if mussel accumulation builds up in a drain line. This cleaning is usually with an auger style of mechanical cleaner.

The dewatering pumps and the sump pumps all have air cooled motors and bearings. The shaft seals are self lubricating packing requiring no water. The pumps will not be affected by mussels.

Accumulation of mussels on the sump floats could cause unreliable level detection. The floats should be inspected at regular intervals and cleaned as necessary.

The fill line takes water from the tail race via a 4" line that is covered with a grate. The grate and line are both at risk of flow restriction due to mussel settlement. The filling process would be delayed due to any flow restriction caused by mussels. An existing ¾" line is connected to the main fill line in the area of the turbine shaft coupling. This line could be used to inject hot water or some other approved chemical to kill mussels periodically before they grow to a size that would affect performance of the fill line.

3.4.5 Rancho Cielo Raw Water Pump Station

The Cielo Pump Station was constructed on Del Dios Highway to pump raw water from Lake Hodges directly to the R. E. Badger Filtration Plant.

The Lake Hodges Dam Flume provided all the water to the District until 1964 when Colorado River water augmented the area's supply. The flume was taken out of service and replaced with a new 36" water line in 2004. Local water is still able to enter the San Dieguito Reservoir through a new 18" waterline that was installed in the old flume west of Del Dios Highway.

The Cielo Pump Station has 4 vertical pumps. There are three 500 HP pumps and one 250 HP pump. The pumps have air cooled motors and air cooled oil for the bearings. The pump motors and bearings will not be affected by mussels. Pump seals and shaft sleeves could experience increased abrasion from mussel shell fragments.

Raw water also supplies motive power to some valve actuators. The supply lines are at risk of flow restriction if mussels arrive at the pump station in substantial numbers. Consideration could be given to replacing the valve operators with air or electric powered units.

In the current operating mode, the pumps sit idle for extended periods of time. Any mussels settling in the system would likely die from anoxia during the idle periods.

At present, the low dissolved oxygen is corrosive to the bronze pump impellers. As the water quality in Lake Hodges changes due to mixing with the Olivenhain water, the corrosion may lessen but mussel survival and attachment may be possible.

The pump discharge lines have air release valves to vent air in the water lines. These vent valves could be prone to leakage from mussel shell entrapment.

At Cielo, copper sulfate is added to the pumped water via a venturi mixing system as part of a pilot test to evaluate if it can be used to control the spread of algae from Lake Hodges to San Dieguito Reservoir Copper sulfate is toxic to mussels although the minimum lethal concentration level has not been established. Incidental observations of mussel mortality have been reported from various sources when algal treatments were taking place. If the duration and frequency of copper sulfate addition used at Cielo overlaps with the mussel season, then there are obvious permitting and cost benefits to extending an existing treatment method to control mussels. The minimum concentration to cause mussel mortality should be determined to confirm if the present dose used for algal control is sufficient.

At present, copper sulfate injection is only operational when operating in pump mode. The main flow piping portion of the plant would be at risk of mussel colonization when the plant is operating in gravity mode. Modifying the copper sulfate injection to include gravity mode would be necessary for complete protection. .

3.4.6 San Dieguito Dam, Reservoir and Pump House

The San Dieguito Dam is a multiple arch structure which created the San Dieguito Reservoir. The reservoir serves as a regulating water body which receives its water from Lake Hodges. The reservoir also holds emergency water in case the district is cut off from imported water supplies. The San Dieguito Reservoir is closed to the public.

The water quality in the reservoir is being improved through an active program of aeration and aquatic plant growth. The current water quality and future improved water quality are likely to support a sizable population of dreissenid mussels.

The pump house has 5 vertical multi-stage pumps of varying flow capacities. All pumps have air cooled motors and bearings. The motors will be immune to the effects of mussels.

The pump bearings are flushed and lubricated with pressurized water from the pump discharge. Increased bearing wear is possible from entrained mussel shell fragments. Mussels may reduce flow by settling in the bearing flush lines and cause bearing overheating problems.

Small diameter pressure balancing lines in isolation valves, air release valves and a venturi style flow meter were noted as possible locations for mussel shells and settlement to cause problems if the mussels arrive.

3.4.7 R. E. Badger Water Treatment Plant

The San Dieguito Water District and Santa Fe Irrigation District jointly own and operate the R. E. Badger Filtration Plant. The plant receives imported water from SDCWA through the San Dieguito Santa Fe 3,4,5 Flow Control Facility and local water from Lake Hodges and the San Dieguito Reservoir.

Veligers are present in imported untreated water supplies. If mussels arrive in Hodges and/or San Dieguito reservoirs, the R. E. Badger Filtration Plant will have mussels in all of its source water.

The flow control piping from SDCWA incorporates venturi flow meters. All these meters have pressure taps that include clean out plungers to remove any debris that may affect operation. This would include any affects from mussels.

Each pipe entering the plant is equipped with an energy dissipating Bailey valve. The orifices in the valve spool are approximately ⅜" diameter. The velocities in the valve will be too high for mussels to settle but the orifices could be plugged by adults or adult shells creating increased maintenance effort to maintain the valves. This is typical for all treatment plants receiving imported water supplies.

A small energy recovery turbine was noted but not inspected. This device would likely be minimally affected by mussels unless there are raw water cooling lines to the generator. If present, shell debris may cause increased wear on the shaft seal.

4 Mussel Protection/Mitigation Strategies and Alternatives

In Section 3 of this report, we suggested mitigation options for the various items as opportunities arose. This section provides a description of strategies and control options available. We have found that any strategy is typically evolutionary and should be updated as more experience is gained with the effect of the mussels in any particular area. In addition, each facility is unique and may adopt different control methods within the same overall control strategy. As some facility components were found to be at risk where mussels are already present, implementation of interim inspection and control actions may be considered prudent in advance of developing an overall strategy. An overall summary table (albeit brief in detail) can be found in section 4.3 that identifies affected components and suggests control actions that are likely to be successful or appropriate for the facilities reviewed, even if these actions are interim in nature. This is to serve as a quick reference for SDCWA.

We have divided various approaches for invasive mussel prevention and control strategies into the following three generic categories:

- Full barrier – complete protection of all systems and prevention of mussel introduction into new reservoirs
- System protection – Treatment as far upstream as practical to protect entire systems
- Spot treatment of vulnerable components

The description of general control strategies is followed by list of common treatment or mitigation options for typical facilities (power plants, pumping plants and water treatment plants).

4.1 Full Barrier

Tests have been conducted to determine if a single technology can serve as an absolute barrier to mussel establishment in a water body or system of water bodies. To date, no single technology is capable of achieving complete mussel exclusion. A combination of technologies is believed to have the greatest potential of successful exclusion.

A full barrier strategy would have to employ mechanical filtration followed by chemical addition or UV irradiation for a multi-barrier approach. It must be implemented prior to the arrival of the mussels unless eradication of already infested water bodies can be achieved. The mechanical filtration component physically controls adult and juvenile mussels, while chemicals or UV irradiation are intended to kill or damage mussel larvae to prevent establishment of mussel populations downstream.

To date, 100% protection of the downstream system and receiving waters has not been attempted by a large water utility. Mussel control methods have traditionally been implemented by utilities in response to infestations of mussels in their source water or system, and have been designed to minimize the growth of mussels and/or mitigate the effects of mussels once they enter their system. We did not observe any practical opportunities for mussel eradication or complete exclusion in the facilities reviewed.

4.2 System Protection

This mitigation strategy is generally used to protect entire facilities or specific systems within facilities. The chosen control method is installed as close to the source of mussels as possible to protect all components downstream of this location. This strategy can be implemented after mussel arrival as it will eliminate settled adults using such options as injection of oxidizing or non-oxidizing chemicals, use of hot water, or pH adjustment. Once the settled adults are eliminated by one of the above strategies, the system protection can revert to small pore, self-cleaning filters or carry on with periodic or continuous application of previously used mitigation strategy. This strategy will likely have a prominent role in the facilities reviewed.

4.3 Spot Treatment of Vulnerable Components

Our review of the documents, site inspection and discussions with site experts has identified a number of vulnerable components. As mussels are already present in Olivenhain Reservoir, some of these vulnerable components may have to be treated prior to an overall strategy being formulated. In these instances, immediately available options such as periodic mechanical cleaning, spot application of hot water or steam, or desiccation may have to be employed.

A table of vulnerable components and most often employed control strategies is presented below.

Table 2. **Summary Component Vulnerability and Control Strategies**

Component/Structure	Vulnerability/Comment	Prevention	Mitigation
Trash racks, grates, fish screens	Partial plugging	Coatings will help extend the period between cleaning	Manual cleaning as required;
Penstock, intake tunnels	Increased hydraulic friction losses	Inspect and clean during routine planned outages	Manual cleaning when friction creates unacceptable losses of power or flow
Small pipes/tubes for pressure/level sensing	Can plug quickly resulting in inaccurate readings	Use copper tubing to minimize fouling	Manual cleaning or hot water flush
Air vents in penstock , long pipes and tanks	Pipe wall collapse, slow draining or pressure balancing	Same as for mitigation	Check if pipe wall collapse is possible; check operation when vents are needed and clean as necessary
Service Water and Unit Cooling Water	Impaired performance of equipment	Filters to keep out shells combined with oxidizing chemicals or UV	Keep mussels out of system or deal with individual equipment as described below
System piping	Flow reduction, source of shells to plug other equipment	Use of copper piping will limit settlement	Periodic kill, flush or clean when reduced performance or shell sloughing is not acceptable.
Strainers (Wye, duplex), Filters	Increased plugging	Install strainers with self-cleaning backwash capability	Manual cleaning
Valves	Increased leakage esp. air vent valves	Cycle valves periodically to flush seats	Manual cleaning
Cooler manifolds	Plugged with shells, cooler overheating	Filters upstream of cooler	Manual cleaning
Cooler tubes	Plugged with shells	Filters upstream of cooler	Isolate cooler and lance tubes or dissolve shells with organic acid
Turbine shaft seals (glands)	Reduced water flow, increased sleeve wear	Filter gland water to < 25 µm	Manual Cleaning
Sumps	Floats measure incorrect level	Same as for mitigation	Manual cleaning
Fire protection system	Plugged nozzles/sprinklers	Filters to keep out shells combined with oxidizing chemicals or UV; switch from raw water to treated water	Treat system (kill and flush) periodically

4.4 Common Treatment Options used by Hydroelectric Power or Pump Plants

External structures in hydroelectric plants or pump plants are most commonly protected by manual cleaning. Trash racks or travelling screens are usually the most critical structures. This includes small grates that cover the raw water entrance into smaller piping systems. If the racks can be removed, then cleaning is easier. Racks that cannot be removed require the forebay to be isolated and drained, or the use of divers to scrape the racks underwater.

The second most vulnerable area of external structures is the concrete boundary in the area of inlets, mainly forebay, inlet channels, and pump wells. The usual concern for these areas is the amount of shell material that builds up and the impact of that shell material when it sloughs and forms drifts or mounds that can be mobilized by normal water movement or sudden changes in the water movement. The most common way of dealing with shell mass is by manual removal and to coordinate the removal as far as practical with normal maintenance activities to reduce the impact of shell cleaning on station operations.

Internal components can be protected by a number of means:

1. Use of filters and strainers to keep out shells, combined with low level of oxidant to prevent settlement of veligers.
2. Use of filters and strainers to keep out shells, combined with ultraviolet light to prevent settlement of veligers.
3. Two stage strainer/filter arrangement to remove adults and veligers.
4. Use of filters and strainers to keep out shells, combined with continuous adjustment of cooling water pH to prevent settlement of veligers. The pH may be adjusted up (above 9.5 with sodium hydroxide provided calcium levels are not in excess of 25mg/L) or down (below 7.1 with acid such as phosphoric or hydrochloric). These two pH levels represent the two thresholds for dreissenid mussel survival.
5. Periodic flushing with hot water, steam or hot air.
6. Periodic draining and manual cleaning of cooling water systems.
7. End of season treatment with high doses of oxidant, usually chlorine

8. Use of an approved molluscicide.
9. Switch to treated water or well water in cooling and fire protection systems.

4.4.1 Path Forward Options for Hodges Pump/Generation Plant

Although the current water quality in the reservoirs is likely to limit or moderate the growth of mussel populations in the raw water, the water quality will change due to the mixing effect of the water moved back and forth by the plant. Hodges is expected to be a fully mixed reservoir within 6 months following the start of the plant operation. The resulting more favorable environment for mussel growth will likely mean the plant will have approximately 8 to 10 months from first operation until problems from mussels become a significant nuisance. This time period is the window available for preparing and implementing mussel control measures. Options for a path forward are suggested as follows:

1. Explore possibility of using thermal treatment as either spot treatment for problem areas or periodic treatment for entire system. This would include evaluation of setting up of a closed recirculation loop and verifying that pipe expansion would be within acceptable limits.

2. Initiate permitting for interim use of chemical control methods that would apply until more permanent methods can be designed, procured and installed. Chemical methods may include oxidizing chemicals, molluscicides, or pH adjustment.

3. Install injection taps in selected locations for the systems to be protected (cooling water, service water, dewatering, and fire protection). Installation of these taps can be coordinated with normal maintenance outages to minimize operations impact.

4. Arrange for lease or purchase of small, portable chemical injection units with integral control systems. These units take more labor to operate but are quick to install and remove when no longer needed.

5. Decide on the long-term control method to be used. If non-chemical methods are desired, explore the space availability to install small-pore self cleaning filters or UV/filter combinations. Initiate procurement of long lead time components.

6. Evaluate if service water and fire water systems can be switched to municipal water, if a well can be drilled, or if a treated water storage tank is practical.

7. Develop and test operational procedures for cleaning trash racks and grates.

8. If any major outages are planned within the near future consider replacing grates with easily removable designs or applying coatings to trash racks or grates.

4.5 Common Treatment Options used by Drinking Water Treatment Plants

Most drinking water treatment plants in North America use chlorine in the form of sodium hypochlorite (NaOCl) or chlorine gas to treat the drinking water. For most of these facilities, the control of mussels is as simple as moving the chlorine addition as close to the point of withdrawal (intake) as possible. This is usually accomplished by installing the chlorine delivery line inside the intake itself. If this is not possible, a separate line may be installed on top of the intake pipeline. The delivery of chlorine to the intake point is interconnected to the pumps which draw in raw water. Therefore, if the raw water pumps stop, so will the pumps delivering chlorine to the intake. This arrangement prevents release of chlorine to the natural environment.

Chlorine has been used as a disinfectant for potable water for over one hundred years. It is also effectively utilized for the control of macrofouling. Its mechanism of action occurs through direct toxic effects on adult organisms and inhibition of the settlement and growth during the larval stage.

If chlorine is added to the raw water at a level of 0.3 to 0.5 ppm of Total Residual Chlorine (TRC), all settlement within the intake pipe will be prevented. If there are any adults present in this pipe, they will either detach or die in place over a period of two to three weeks. Any grates at the point of intake may be cleaned manually by divers or removed and coated with antifouling coatings.

Pre-chlorination of raw water is used extensively by many drinking water plants. The only time it is not used is when there is excessive formation of Tri Halo Methanes (THMs). Most drinking water plants have stringent limits on the level of THMs which may be present in the finished drinking water. This level varies depending on the state or province.

If pre-chlorination of the drinking water would result in excessive THM formation, drinking water plants can choose from several different options:

- Mechanical cleaning of the supply line. This may be done annually or semi-annually as necessary.
- Use of other oxidizing chemicals such as ozone, chlorine dioxide, chloramines or potassium permanganate.
- Lowering the pH of incoming water.
- Adding flocculent at the pre-treatment location will cause most if not all of the incoming mussel veligers to become part of the floc, thus preventing settlement.

Direct filtration plants would benefit from pre-filtration strainers to keep adult mussels and dead mussel shells from imposing an excessive burden on the filtration equipment. Membrane filtration plants need pre-filtration to protect the membrane surface from being cut or damaged by sharp fragments of shell material. This applies equally to mussels, snails, and clams that may enter the plant.

4.6 Coatings

Coatings are applicable to all uses of raw water. Coatings can assist in reducing the impact of mussels on grates, screens, and trash racks where blockage would be a problem and on areas where sloughing of large shell clumps would be a problem, such as pump wells. The most successful coatings appear to be silicon based. Their weakness tends to be mechanical damage to the coating by floating or submerged objects. Reclamation has a strong coatings research program underway which may identify alternative coatings in the near future. Continuing monitoring of this program is recommended.

4.7 Inspecting for Mussel Accumulation

SDCWA has a number of locations which can be periodically inspected as part of the normal maintenance cycle and could be simultaneously inspected for mussel accumulations. Maintenance staff has been educated on what dreissenid mussels look like and whom to call when suspicious material is found.

4.8 Monitoring

Monitoring is an effective mitigation tool. Delaying implementation actions until the need is clearly established and the magnitude of the effect is more fully understood can save large sums of both capital and operations funds. Monitoring can also assist in making selected control options more targeted thereby increasing effectiveness and controlling costs.

SDCWA has a proactive monitoring program for early detection. Plate samplers have been set up at several locations and these plates are inspected on a regular basis for mussel settlement. Bio-boxes can be installed in critical locations to further assist with settlement detection. In addition to settlement samples, SDCWA also takes plankton samples to look for free swimming dreissenid veligers.

5 Findings and Recommendations

5.1 Findings

Based on RNT's review of the facilities visited, the following findings are offered:

1. The calcium and temperature in Olivenhain Reservoir and Lake Hodges are suitable for significant mussel populations to develop.
2. The current levels of chlorophyll "a", dissolved oxygen, and pH will likely serve to limit the size of the populations in Olivenhain Reservoir and Lake Hodges.
3. The hydrodynamic mixing effects that will take place once the pump/generation plant goes into regular operation will change the above three moderating factors and will likely trend towards increasing the potential for large populations in both Olivenhain Reservoir and Lake Hodges.
4. San Dieguito Reservoir has a suitable environment for high levels of mussel infestation should the mussels be introduced into the reservoir.
5. Multiyear monitoring is desirable and should continue particularly as the limnological regime of Olivenhain Reservoir and Lake Hodges is about to change.
6. Raising or lowering the pH of raw water used for cooling water and station services water may be an effective means of mussel control.
7. Copper sulfate is in use in some areas for algae control and this chemical may also serve as a means to control mussels.
8. Accumulation of mussels on the submerged intake grates throughout the system should be expected and grates will require periodic manual cleaning.

9. The Olivenhain Dam I/O tower should not experience any increased maintenance in addition to what is already being done due to mussel presence in the water. The existing operating protocol for the screens and gates is sufficient to avoid problems from mussels. Typically large structures such as the tower that are oversized for the flow expected are allowed to accumulate mussels. However, the tower will serve as a source of mussel shells passing both live and dead mussels downstream.
10. Increased vigilance when inspecting the adit area would be prudent.
11. The present operating mode for the Olivenhain Pump Station will result in no mussel survival in the pumping portion of the station. The most significant concern is increased maintenance for the ventilation air chillers. If the operating mode of the station changes, the risks to the pump station should be reviewed.
12. The Olivenhain-Hodges headworks will experience mussel accumulation on the trash racks. Some flow restriction can be expected.
13. A large mussel infestation may result in a layer of mussels on the walls of the Olivenhain-Hodges intake tunnel and pipeline. There may be increased hydraulic friction losses. As the ultimate mussel density is not known, a watch, measure, and evaluate approach is probably most practical at this time.
14. All systems and structures at the Hodges pump/generation plant are at risk of some degree of impairment from either mussel settlement or shells. Access for maintenance to many of the components and piping is limited by the compact building layout.
15. The present operating mode for the Cielo Pump Station will result in no mussel survival in the pumping portion of the station. A copper

sulfate injection system is in use for algae control and its set up appeared suitable for mussel control as well. The main flow piping portion of the plant would be at risk of mussel colonization when the plant is operating in gravity mode.

16. At the San Dieguito pumping station, the pump bearings and small diameter lines may have minor problems associated with mussels.
17. The main concern for the R. E. Badger Filtration Plant would be an increased maintenance for the Bailey pressure reducing valves. The source of the increased maintenance is expected to be mussel shells plugging the valve orifices. Depending on the size of the mussel infestation in the filtration plant source waters, there may be an increased debris load from the filter beds.

5.2 Recommendations

Based on RNT's review of the facilities visited, the following recommendations are offered:

1. The feasibility and cost of lowering raw water pH should be evaluated as a means of protecting all systems that use raw water for cooling.
2. The frequency and concentration of current copper sulfate addition for algae control needs to be evaluated in view of the potential control effect it may have on dreissenid mussels. If the use of copper sulfate appears practical for mussel control within any particular affected system, then the concentration of copper sulfate required to eliminate freshly-settled mussels (two to three weeks old) should be determined through testing.
3. Consider, as a minimum, the use of small pore filters for pumps that have mechanical seals.

4. Protection of the unit cooling water system at Hodges pump/generation station is strongly recommended. Suitable options include small-pore self cleaning filters, UV irradiation, or chemical injection. UV will kill veligers but may require filters to keep out shell fragments.
5. Service water and dewatering systems at Hodges pump/generation station are at risk of flow restrictions from mussel settlement and shells. As these two systems are not operationally critical, implementation of a control strategy can be delayed until the magnitude of the increased maintenance can be assessed through analysis or operational experience.
6. Some improvements or modifications to the fire suppression systems are needed to ensure that a flush of shell material does not occur during a fire use or testing, thereby impairing fire nozzle or sprinkler performance.
7. At Hodges pump/generation station, connection of the fire pressurizing pump (jockey pump) to local treated water or well water would help to assure the fire water piping is exposed to the least possible number of veligers or adult mussels.
8. Obtaining chemical treatment permits from the appropriate regulatory agencies should be initiated in order to begin mitigation when required. Discussions with the regulatory agencies should include Zequanox, pH adjustment, oxidizing chemicals, and possibly copper sulfate.
9. The progress of the Zequanox product should be monitored, as this product has the potential to replace oxidizing chemicals for mussel control.

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