RECLAMATION
Managing Water in the West

Facility Vulnerability Assessment Template

Invasive Quagga and Zebra Mussels

U.S. Department of the Interior
Bureau of Reclamation

May 2009

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Invasive Quagga and Zebra Mussels

Prepared for Reclamation by:

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May 2009

Facility Vulnerability Evaluation Checklist

Project Name:	
Prepared by:	**Date of Preparation:**
Issue #:	**Date of This Issue:**

A facility assessment process usually requires considerable time for planning and coordination, background research, site visits, evaluation of data and preparation of a report. Several small facilities that are similar or duplicates may be grouped together. It is likely that a team approach of 2 or 3 people is most effective at carrying out the assessment with at least one of the team having operations knowledge/experience of the specific facility (as explained below). The assessment team lead should become familiar with general mussel characteristics and behavior or possibly have a support person familiar with mussels as part of the assessment team.

The specific risks and problems that a particular facility will have with the dreissenids will depend on:

1. How the raw water gets into the facility,
2. Any processes to treat or transform the water for various facility applications,
3. The routing of all piping branches and location of components and equipment, including materials of construction, and
4. The operating envelope of the various water systems (such as max and min flow rates, frequency of operation, temperature ranges).

As every facility has a number of unique features, a site person familiar with the operation of the various water uses in the plant/facility is an essential contributor to the assessment.

This assessment template can be used under most circumstances and for the most common assets to assist in carrying out a facility assessment. If your asset is a small fish hatchery or a large pumping plant, knowing what must be protected either from primary settlement by mussel larvae or from ingress of adult mussel shells, is key.

The template is best applied after an environmental assessment of the water source for susceptibility to mussel invasion is carried out. However, such an assessment is not a prerequisite of applying this template. Management may decide to proceed with a facility assessment ahead of or in parallel with the assessment of environmental suitability. As a minimum, it is strongly recommended that the calcium content of the water passing through the facility be checked to determine whether there is sufficient calcium to support mussels. As a guideline, calcium contents of 8 mg/L or less will not support long term survival of adult mussels. There are of course other parameters which may mitigate or preclude mussels thriving in your waters but all become irrelevant if sufficient calcium to support mussel survival is not present.

Water in contact with concrete and mortar can cause a steady deterioration of these materials by leaching out the calcium from the calcium silicate bonding materials. This action is most pronounced with soft or mildly acidic waters such as are found in reservoirs fed from swampy areas. Where there are concrete structures that are relatively sheltered, a local area of elevated calcium may exist that would support mussels. In reservoirs of low or marginal calcium, such sheltered areas would be good locations to monitor for mussels especially if the concrete structures show any form of deterioration due to concrete leaching.

1. Instructions for Using this Document

- For each Item No. below, complete all blank fields (see footnotes for Status and Comments columns).
- The checklist is divided into logical phases. It is best not to proceed from one phase to the following phase until that phase is completed. Within each phase, many tasks will likely proceed in parallel and the order in which they are done is at the team leader’s discretion.
- Issue this checklist with your weekly or monthly reports as appropriate. Be sure to identify the issue date so readers know they are looking at the most recent update and are able to assess progress or provide input to the program.
- This template is set up for a small size project. Appendix A contains an outline for a minor project *Project Plan*. This is provided for the guidance of the user and not intended to replace standard project methodologies that may exist within the Bureau. Appendix A also contains some helpful suggestions concerning the project team skills and roles.
- Also included in appendix A is a sample time/task chart (Gantt chart). The durations are intended to be representative of a real facility assessment but you should adjust these for your own circumstances. It may be helpful to place dates in the appropriate checklist item if it is considered unnecessary to use the Gantt chart approach.
- Instructions, comments or suggestions in this main document are provided in boxes with a yellow background.

2. Preparation (Step 1)

Item No.	*Item*	Status [1]	Comments / Plan to Resolve
1	**Planning**		
1.1	Has the project scope – including definition and objectives – been prepared?		
1.2	Has the *Project Scope Statement* been approved?		
1.3	Is there a *Project Plan* against which to measure progress?		
1.4	Does the *Project Plan* address the following areas:		
1.4.1	• Project Scope and Deliverables		
1.4.2	• Project Schedule		
1.4.3	• Project Budget		
1.4.4	• Project Organization and Resources		
1.5	Were key project stakeholders brought into the *Project Plan*?		
1.6	Were potential customers involved early in the planning process?		
1.7	If there are vendors, have they signed off on the *Project Plan*?		
1.8	If there is an independent oversight contractor, have they signed off on the *Project Plan*?		
1.9	Is the Project Sponsor function identified and defined?		
1.10	Are there alternate persons if key members of the project are not available or become reassigned?		
1.11	Other organization items (*please list*):		
2	**Tracking & Monitoring**		
2.1	Are the various types of reports, their contents, frequency, and audience defined and communicated to the Project Team?		
2.2	Are the input requirements from Project Team members clearly documented and communicated?		
3	**Meetings and Input Data**		
3.1	Have the various meetings, purpose, context, frequency, and participants been defined and communicated?		
3.2	Have the drawings and documents from the facility sites been requested?		
4	**Project Assumptions and Constraints**		
4.1	Are there any key assumptions upon which the assessment is based and have these assumptions been documented?		
4.2	Does the Project have any Constraints such as:		
4.2.1	• Facility shutdown schedules?		
4.2.2	• Facility access limitations and ventilation requirements?		
4.2.3	• Monitoring issues such as availability of reports from sampling plates set out in previous seasons?		

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[1] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **Y** (Yes), **N** (No); **NA** (Not Applicable)

2. Preparation (Step 1)

Item No.	*Item*	Status [1]	Comments / Plan to Resolve
4.2.4	- Any training needed for key project staff?		
4.2.5	- Any pre-project procurement needed for portable field equipment?		

3. In-house Review and Preparation for Field Visits (Step 2)

Item No.	*Item*	Status [2]	Comments / Plan to Resolve
1	**Reviewing**		
1.1	Have drawings and documents from the facility site been reviewed?		
1.2	Have questions arising from the document review been communicated to and discussed with the site experts?		
1.3	Did the document review identify any pre-site-visit activities that should be done such as video inspections requiring divers or shutdown of equipment that needs to be scheduled?		
1.4	Are all pre-site-visit tasks needed to be done at site completed?		
1.5	Has the deliverables list been updated based on the information from the site documents?		
1.6	Have all system checklist sheets been prepared?		

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[2] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **Y** (Yes), **N** (No); **NA** (Not Applicable)

4. Site Visits, Follow-up and Reporting (Step 3)

The general approach should be to follow the path of the water through the site facility. The water path will become more complicated each time the water branches into a specific system. Follow each system in turn and you will have covered the complete flow of water through the facility.

Item No.	*Item*	Status	*Comments / Plan to Resolve*
1	**Field Walkthroughs**		
1.1	Has the pre-meeting at site been completed?		
1.2	Were all necessary site staff available?		
1.3	Have follow-up discussions with staff not available during the site visit been scheduled and completed?		
1.4	Have all the system walkthrough checklists been completed?		
1.5	Have all actions arising from the site meeting and system walkthroughs been documented and communicated to the person responsible for the action?		
1.6	Has the draft project report been reviewed by all contributors?		
1.7	Has the final report been approved for issue?		
1.10	Has the final report been distributed?		

5. Mussel Risk Evaluation - Project Team Contact List

Project Name:

Project Lead:

Some suggestions for the roles of the various team members and the skills or knowledge that would be helpful for each team member are contained in Appendix A.

Name	*Title*	*Location*	*Office Phone & E-mail*

6. Mussel Risk Evaluation – Sample Facility Deliverables List

Facility Name:

The deliverables are internal document packages prepared for each system or major structure. Once all deliverables are completed, they are then used to prepare the overall assessment report which would be the only external deliverable. It will be helpful when preparing this list to refer to Appendix D for additional detail about typical systems and components at risk that should be considered.

Major Structure or System	***Reference drawings Used***	***Deliverables***
e.g. 1: Dam	List all General Arrangement (GA's), plan view and cross sections as well as any detail drawings	Copies of all drawings + photographs + dam walkthrough checklist.
eg2: pump station unit cooling water system	List all flow sheets, Piping and Instrumentation Diagrams (P&ID's), or GA's	Copies of all drawings, photographs + completed system walkthrough checklist.
eg3: power station fire water system	List all flow sheets, P&ID's, or GA's	Copies of all drawings + completed system walkthrough checklist.
Continue with systems or structures until all areas in contact with raw water are covered.		

Appendices

A. Project Work Plan

B. System Walkthrough Checklist

C. Typical Facility Details

Appendix A - Sample Project Plan Outline

1. Introduction

Purpose of the Plan

State the purpose of the Project Plan. Indicate in a short statement that the Plan will provide a definition of the project, including the goals and objectives.

Background Information about the Project

Describe the project history. Include information such as previous initiatives, regulation, resource availability, and the impetus and rationale for the project. Describe, in essence, how the project came about.

2. Scope

A clear and concise definition of scope is key to the success of any project. The scope should describe from a quantitative perspective what is to be accomplished. Its purpose is to aid in establishing realistic work plans, budgets, schedules, and expectations.

Scope Definition

State specifically what work will be done. If the project is part of a phased approach, it may include deliverables from the previous stage and the scope defined by which objectives, tasks or actions will be further defined and developed

Costs, Benefits and Risks

This is the financial scope of the project. Briefly state the costs and benefits associated with the project. Include a description of any known risks and how they will be dealt with. Risks may be items which could delay or impede the assessment such as conflict with other projects. The risk of not proceeding with the facility assessment should be described as well.

Project Products/Deliverables List

This is the deliverable scope. Project Products may include formal deliverables as well as informal concrete results. Include in this section a list of the deliverables and their contents (if appropriate) to be produced during the project. Remember to include project management deliverables, such as the Project Plan and Work Plan.

Milestones

This is the temporal scope of the project. List and briefly describe significant project accomplishments that will act as primary checkpoints for the project's progress. These are generally the points at which the completion of an activity or group of activities causes the project to reach a milestone by producing a highly visible or significant product or result (e.g., equipment delivery, material delivery, review meeting, approval checkpoint). Not every task completion date in the project will be a milestone, but every milestone should be tied to a deliverable.

Assumptions

Briefly describe any assumptions made about the project related to resources, scope, expectations, schedules, etc.

Project Constraints

Describe the principal constraints and limitations under which the project must be conducted, concerning the project environment or parameters (timeframes and deadlines, funding, skill levels, resource availability, etc.).

3. Project Work Plan

This is a detail of all stages, tasks and subtasks. It includes a Gantt Chart (Project Network Chart) which shows estimates of how long it will take to complete each subtask, task and stage, the resources required to complete each task, the task dependencies and interrelationships, and any special considerations that must be made.

Project Roles and Responsibilities

Identify specific resources that are required to complete the project. At a minimum, the Project Team should include:

- one technical lead to read and interpret technical drawings,
- one person very familiar with the life cycle and habits of dreissenids,
- one person very familiar with the operation of the facility to be evaluated

Describe the roles and responsibilities of each Team Member along with the communication plan to ensure that Team Members understand what is expected of them. Describe the mechanism for communicating responsibilities across the Project Team and within the organization at large (to the extent that it is required).

Project Team Contact Directory

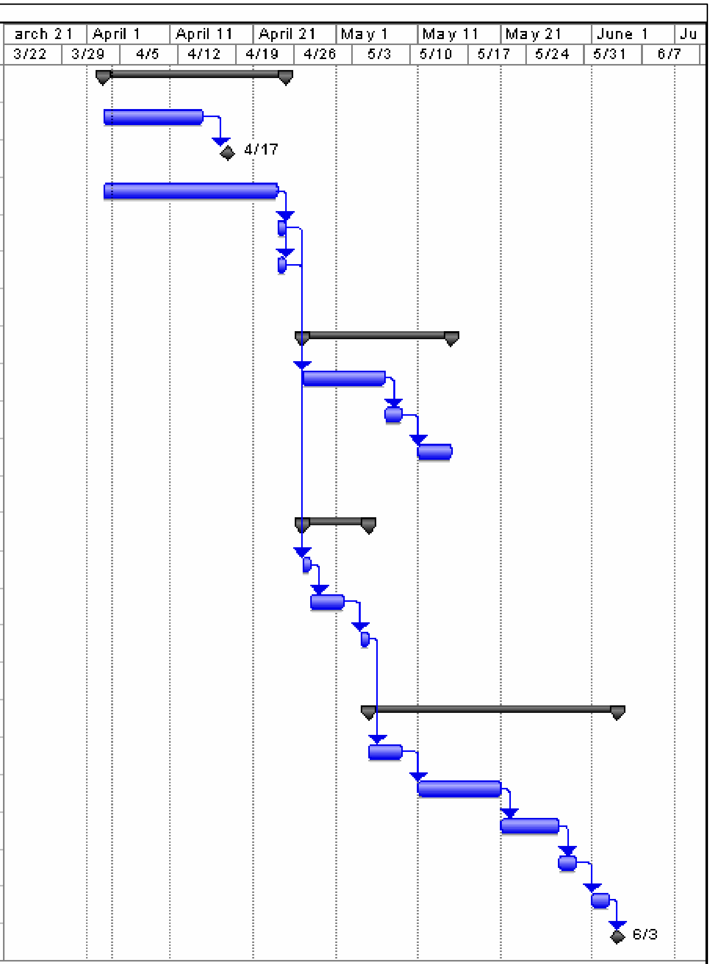
This is a list of all Team Members and other key individuals affected by the project. The list should include their names, physical locations, phone numbers, alternative contact numbers, Mail Stops, email addresses, titles, and any other pertinent information that will enable better communication between the impacted individuals.

4. Approvals

Sign-off Sheet

Include a Sign-off Sheet that must be signed by the Project Team, Project Manager, Executive Sponsor, Client, and management of the enterprise associated with the project. The Sign-off Sheet represents the contract between the project and the business area affected by the project.

ID		Task Name	Duration	Start	Finish	Predecessors
1		Planning and Preparation	16 days	Fri 4/3/09	Fri 4/24/09	
2		Prepare project plan	8 days	Fri 4/3/09	Tue 4/14/09	
3		Plan approvals	3 days	Wed 4/15/09	Fri 4/17/09	2
4		Request drawings from facility	15 days	Fri 4/3/09	Thu 4/23/09	
5		Drawings Received	1 day	Fri 4/24/09	Fri 4/24/09	4
6		Schedule field visits	1 day	Fri 4/24/09	Fri 4/24/09	4
7						
8		In-House Technical Review	14 days	Mon 4/27/09	Thu 5/14/09	
9		Review facility drawings	8 days	Mon 4/27/09	Wed 5/6/09	5
10		Prepare Deliverables list of System	2 days	Thu 5/7/09	Fri 5/8/09	9
11		Prepare checklist for each system	4 days	Mon 5/11/09	Thu 5/14/09	10
12						
13		Field Visits	6 days	Mon 4/27/09	Mon 5/4/09	
14		Site pre-meeting	1 day	Mon 4/27/09	Mon 4/27/09	6
15		System Walkthroughs	4 days	Tue 4/28/09	Fri 5/1/09	14
16		Exit meeting	1 day	Mon 5/4/09	Mon 5/4/09	15
17						
18		Analysis and Reporting	22 days	Tue 5/5/09	Wed 6/3/09	
19		Analyse Field data	4 days	Tue 5/5/09	Fri 5/8/09	16
20		Prepare draft report	8 days	Mon 5/11/09	Wed 5/20/09	19
21		Review and Comment Period	5 days	Thu 5/21/09	Wed 5/27/09	20
22		Prepare Fianl Report	2 days	Thu 5/28/09	Fri 5/29/09	21
23		Approvals	2 days	Mon 6/1/09	Tue 6/2/09	22
24		Issue Report	1 day	Wed 6/3/09	Wed 6/3/09	23



Project: TypicalEvaluationSchedule
Date: Sat 4/4/09

Task	▬	Milestone	◆	External Tasks	▬
Split	⋯⋯	Summary	▬	External Milestone	◆
Progress	▬	Project Summary	▬	Deadline	⇩

Page 1

Appendix B - System Walkthrough Checklist

System or Structure Name:

Prepared by: **Date of Preparation:**

1. Instructions for Using this Document

- Prepare one of these sheets for each system or major structure identified in the Deliverables list.
- For each *Item No.* below, complete all blank fields (see footnotes for *Status* and *At Risk of Mussels* columns).
- For some of the components such as valves and strainers there may be several in one system. If more than one component needs to be considered add an extra sheet for that particular component group.
- Refer to Appendix C for additional information and suggestions about various systems and components.
- Add additional rows as required where you identify items that need to be considered and are not covered elsewhere in the list.

2. Walkthrough Checklist

Item No.	*Item*	*Status* [3]	*At Risk (yes/no)*	*Comments*
1	**General for Dams, Reservoirs, Aqueducts**			
1.1	Are there any membranes, control joints, permeable construction media, drains, etc. that will let raw water pass?			
1.2	Are there any air vents?			
1.3	Check if the spillway and appurtenances are always wet or dry and record duration of dry period.			
1.4	How much does the water level (i.e. reservoir water surface elevation) fluctuate?			
1.5	Are all potential water seepage paths inspected on a regular basis?			
2	**Water Intake Structures**			
2.1	Types of intake structures present (more than one may be present):			
2.1.1	• Open Canal Direct into Facility (concrete)			
2.1.2	• Open Canal Direct into Facility (other material-specify)			
2.1.3	• Forebay (specify lining material)			
2.1.4	• Tower (specify construction material)			
2.1.5	• Submerged Tunnel or pipe intake (specify construction material)			
2.1.6	• Penstock intakes (specify construction material)			
2.1.7	• Fish Barriers			
2.2	Is the floor of any intake structures likely to be covered with silt or sediment?			
2.3	Are any structures duplicated to provide a back up?			
2.4	What is the flow velocity range in the structure?			
2.5	Is the structure accessible for inspection or maintenance?			

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[3] *Enter one of the following:* **C** (Complete), **P** (Partially Complete), **A** (Absent); **Y** (Yes), **N** (No); **NA** (Not Applicable)

2. Walkthrough Checklist

Item No.	*Item*	*Status* [3]	*At Risk (yes/no)*	*Comments*
2.6	Are there any shutdowns to provide easy access and what is their frequency?			
2.7	Are there scheduled maintenance cycles and what are their frequencies?			
3	**Trash Racks, Grates, Screens**			
3.1	Record spacing, size and material of trash rack bars.			
3.2	Are trash racks fixed or easily removable for maintenance?			
3.3	Is there a planned maintenance frequency for the trash racks? If so what is interval?			
3.4	Is there a trash rake or other style of cleaning system?			
3.5	Are the rake fingers sufficiently large to remove mussels from sides of trash rack bars?			
3.6	Record location, material, size and grid spacing of any small intake grates.			
3.7	Are grates fixed or removable for easy maintenance?			
3.8	Check if grates at bottom of pipes or channels get covered with silt or sediment.			
3.9	Record location, material, size and grid spacing of any screens.			
3.10	Are screens fixed or removable for easy maintenance?			
4	**Wells and Sumps**			
4.1	Location and material of constructions of wells.			
4.2	Identify level fluctuations in pump wells.			
4.3	Distance of pump suction from bottom of wells. Will pump ingest shells that are transported along the floor into the well?			
4.4	Location and material of constructions of sumps.			
4.5	Is there a float or other instrumentation in sump that could become covered with mussels?			
4.6	Frequency of sump inspection by plant staff.			
5	**Pumps and Turbines**			
5.1	Is pump motor or turbine generator water or air cooled? Water cooled motors are at risk.			
5.2	Can mussel shells get into wear ring gaps?			
5.3	Does pump have a mechanical seal?			
5.4	How is the seal flushed during start-up?			
5.5	How is the seal flushed during normal running?			
5.6	Does the turbine or pump have a stuffing box?			
5.7	Is there a stuffing box lantern ring or other cavity for cooling and flushing water?			
5.8	How is the ring flushed during start-up?			
5.9	How is the ring flushed during normal running?			
5.10	Check if the motor bearings have water cooled lubrication?			
5.11	Check if the pump has water cooled bearings?			
5.12	Can mussel shells get into the water lubricated bearing passages?			

2. Walkthrough Checklist

Item No.	Item	Status [3]	At Risk (yes/no)	Comments
5.13	Do seal or stuffing box cavities have a means of monitoring or inspection?			
5.14	Can seals or stuffing box be cleaned without removing motor?			
6	**Piping**			
6.1	Identify materials of construction for piping.			
6.2	What is flow velocity range in piping?			
6.3	How much time is velocity above 6 ft/sec?			
6.4	How much time is velocity below 6 ft/sec?			
6.5	Are there any offsets or changes in pipe diameter?			
7	**Instrument Tubing and Instruments**			
7.1	Identify any small diameter lines (2" diameter or less) including material of construction such as:			
7.1.1	• Flow measurement taps			
7.1.2	• Piezometer taps			
7.1.3	• Pressure taps			
7.1.4	• Sample lines			
7.1.5	• Pressure balance lines			
7.1.6	• Other - specify			
8	**Heat Exchangers**			
8.1	Identify material of construction of plenum.			
8.2	Identify material of construction of tubing.			
8.3	What is diameter of tubing?			
8.4	What is flow velocity range in tubing?			
9	**Valves**			
9.1	Identify all normally open (NO) valves.			
9.2	Can NO valves fail to seal properly if valve seat or valve face becomes mussel coated?			
9.3	Identify all normally closed (NC) valves			
9.4	Can NC valves fail to open if valve face becomes coated with mussels?			
9.5	What is throat diameter of valve? Is it small enough to become plugged by mussel shells?			
10	**Strainers and Filters**			
10.1	Identify the style of strainer, material of construction of strainer body and basket as well as the size of the basket pores. Typical styles are:			
10.1.1	• Fixed In-line strainer			
10.1.2	• Duplex strainer			
10.1.3	• Self-cleaning strainer			
10.1.4	• Wye (Y) strainer			
10.1.5	• Other type - specify			
10.2	Identify the style of filter, material of construction of body and filter element, as well as the size of the filter pores. Typical styles are:			

2. Walkthrough Checklist

Item No.	*Item*	*Status* [3]	*At Risk* (yes/no)	*Comments*
10.2.1	• Self-cleaning filter			
10.2.2	• Replaceable cartridge filter			
10.2.3	• Other type - specify			

Appendix C - Typical Facility Details

Steps Involved (facility and system walkthrough)

The following steps are typical:

1. Gather and Review Site Data

Obtain and examine drawings of the facility well in advance of the sight visit. This will make your sight visit more efficient and reduce the amount of time required from facility operators. Examining the drawings ahead of time will also allow you to ask questions of clarification and may identify additional systems that need to be examined.

Request drawings for all systems exposed to raw water. The types of drawings that are most useful are system schematics and layout drawings.

The drawings are variously referred to as Flowsheets, P&ID's (piping and instrument diagrams), or System Schematics. They show you what components exist and how they are arranged in relation to each other. These drawings are typically not to scale.

The layout drawings are typically referred to as general arrangement (GA) drawings. Some detailed drawings may be appropriate as well. They show you where structures and components are located and how they are built. These drawings are always to scale.

Be aware that drawings may not always be up to date. Some older facilities may have undergone changes or improvements over the years that were not deemed sufficient to justify a drawing update. When requesting drawings, you should ask for "as built" drawings if available.

Examine all the flow diagrams, understand the subsystems and where they split from the main intake line. Note the position of fixed grates, pumps, strainer, filters, coolers, heat exchangers, air-conditioning systems and any other equipment which either uses raw water for cooling or just passes it along.

2. Facility Walkthrough

Good drawings are a start but they do not tell the whole story. So as a next step, with drawings in hand, walk the facility from the point of where the water enters, to where the water leaves. Make sure that the drawings truly represent what is in the facility. Sometimes modifications are made but not recorded. Sometimes systems are abandoned and decommissioned, but still appear as functional on the drawings. This walkthrough is best done with a mechanical maintenance staff member who has been at the facility for a number of years.

During the walk through, note materials of construction and jot these on the drawings. Concrete and stainless steel are more prone to macrofouling than brass and copper.

Aside from materials of construction, the next important piece of information is the duty cycle of the various systems. How a system is used is just as important as the components in the system and the materials of construction. The duty cycle of a system can very often expose problems that may be otherwise overlooked. Similarly, the duty cycle can sometimes be used strategically to control mussel problems. Some information to gather is:

1. Which systems can never incur misoperation of shutdown for other than scheduled inspection and maintenance (e.g., fire protection, cooling water, emergency gates, air vents, other safety systems)? These represent the most critical or highest priority systems to be protected.
2. Are they always operational - If they are always flowing, what is the flow velocity in the various parts of the system.
3. Are they intermittently static and full - If they are static and full, how long do they remain static
4. Are they intermittently static and drained for what period of time.
5. If there are up front strainers on the discharge of the pumps, what kind of mesh size or gap do they have, how often are they opened and inspected or cleaned.
6. What is the diameter of the smallest pipe in the system?
7. What are the smallest heat exchangers present?
8. Has debris ever been found in any part of the system which carries raw water? Describe.
9. Is there adequate or excess cooling capacity in the heat exchangers? Perhaps the water which exits now is warmer than when designed.
10. Are there any visible signs of infestation by mollusks in exposed water areas such as drains? (Ex: Asiatic clams (*Corbicula* sp), snails or dreissenids)

3. Analysis

Once you feel you are fully familiar with the raw water systems in your facility it is time to head back to the office and combine drawings with field observations to develop a list of structures and systems likely to be impacted.

Generically, systems that contain fixed grates with small gaps, narrow intake pipes already running at capacity or small diameter pipes where raw water is chronically (or intermittently) moving at less than 6 ft/sec will be problem areas. What follows is a review of the different problems macrofoulers cause to various facilities using raw water and the impact they may have on civil structures.

Typical Facility Systems

Intake

Intake systems provide the means by which water enters a facility. Intake systems encompass large static structures such as a concrete-lined forebay, intake pipes, towers, trash racks and floating barriers. Some structures are active like gates, valves and trash rack cleaning equipment. Some facilities have the ability to take water from more than one source at different times switching between canals, wells or piping.

Raw Water

Many facilities require water usually for cooling or flushing purposes. When this water is taken from the main water stream passing through a facility, then it is referred to raw water. The raw water will be brought into the facility via piping where various branch piping taps off the raw water piping to provide for a variety of other functions.

Service Water

The terms “raw water” and “service water” are often used interchangeably. A good rule of thumb is to consider water as raw until it passes through some modifying component which is usually a strainer. Thereafter, the water could be considered service water. Service water is most commonly used for cooling but it can also be delivered in small diameter piping throughout a facility for washing stations, sanitary facilities or lawn and garden irrigating.

Unit Cooling Water

It is most common in larger facilities that have major specific functional groupings such as turbines or large pumps to duplicate these groupings so that together they to make up the overall facility. Each of these duplicated groupings is referred to as a unit. Units that have large cooling water demands will typically have a dedicated service water system referred to as unit cooling water. The unit may also use the overall facility service water system for various common needs. Unit cooling systems are often interconnected and also connected to the overall service water system for redundancy and back-up purposes. As the number of units increases and the interconnections increase, the overall water flow within the facility becomes more complex. This is why it is essential to have knowledgeable facility personnel as part of the evaluation team.

Domestic Water

Many facilities are not located where municipal water is available and therefore have to make their own domestic water for potable use in sinks, showers, eye wash stations etc. Sometimes domestic water may be used by equipment that can only function properly with clean filtered water.

Fire Protection Systems

Safety systems, such as fire protection, frequently use treated city water. In such cases they are safe from macrofoulers. If, however, they draw water directly from a raw water source, they are as vulnerable as other service water systems. Fire protection systems are designed to be filled with water and then maintained in a static pressurized state. Typically, the hose stations are often a convenient source of water for washing equipment or flushing debris from spills on floors. This means that a constant stream of water is needed to replace the volume of water used. This make-up stream is the main point of entry for dreissenids. It also provides food and oxygen necessary for their survival. Macrofoulers may enter these systems either as larvae or as adult translocators if there are no strainers present at the discharge of the pump.

Sometimes, portions of fire suppression systems such as deluge systems are kept in a partially drained state. The location of where the system becomes dry will need to be noted.

In addition to make-up water to compensate for leaks, fire systems tend to be tested on regular basis, sometimes monthly. During these tests, raw water is frequently drawn through the entire piping system. Such tests, if conducted during the breeding season may introduce larvae or adult macrofoulers into the fire protection system. Adult macrofoulers may be eliminated by up-front strainers and larvae may fail to survive if the system is truly static or if there is rapid decay of oxygen in the system.

Drainage and Sumps

Drain piping and sumps are often overlooked as being at risk from mussels. However, they can easily become colonized with mussels. Typically, the drain piping and sumps do not threaten the operability of a facility but they can be an operational nuisance if infested. Open drains and sumps can often be good places to look for the presence of mussels as well as other indicator species such as clams and snails.

HVAC

Heating, ventilating and air-conditioning systems (HVAC) employ a variety of technologies. Some systems use air as the medium to exchange heat and will not be at risk of mussel problems. Other systems use raw water to chill air or a coolant, and in very dry climates, the raw water may be used in an evaporative cooler.

HVAC systems are normally associated with personnel comfort, and therefore, impairment of the system is not usually a high priority, operational concern. However, sometimes areas of a facility contain rooms of essential control equipment, usually electrical in nature, that generate heat and require uninterrupted cooling. These areas will need to be examined to make sure that any raw water used is protected from impairment by mussels.

Compressed Air

Compressed air can be an essential operational system in a facility to operate valve actuators and maintain water level suppression for rapid-start turbines (i.e., spinning reserve). Compressed air systems commonly rely on cooling water for inter-coolers. More rarely, the compressor motors may have water cooled bearings or even water cooled motors.

Discharge

Discharging water from a facility is typically not as great a concern as other systems. The water tends to be more turbulent exiting in a power plant tail race or pumping station discharge piping and releases are usually made thru very large high capacity structures.

Instrumentation and Control

The performance and health of all systems is monitored and adjusted by facility operators using the available instrumentation and control (I&C) systems. Level gauges, sight glasses, flow meters, pressure transmitters and various types of control valves are all examples of equipment in the I&C systems. Typically, the equipment and piping are small relative to the process systems that they are associated with. Their small size makes them particularly vulnerable to mussels. The equipment may be in contact with raw water but may not have any flow such as a pressure tap. The instrument line leading from the pipe to the pressure transducer may not be at risk if there is no oxygen in the line due to no flow. The entrance to the pressure tap then becomes the area of concern. If the tap is plugged, the instrument could become unreliable.

Components and Structures within the Systems

Water Intake Structures

Deep water intakes

Intakes which draw from depth greater than 90 feet will generally experience least amount of fouling by dreissenids. This is due primarily to three factors. In most cases, depths greater than 90 feet contain water which is permanently cooler than shallower depths. This area is described as being below the thermocline. The incoming water will be much cooler than that above the thermocline during the reproductive season. Low ambient temperatures translate into slower growth of molluscs. Secondly, food available may be limited. Light at 90 foot depth will be very low in most cases, limiting the growth of green algae (the primary food source for most molluscs). The third moderating factor is that the number of viable veligers reaching the intake may be limited depending on the bottom profile of the lake or reservoir and on the circulation patterns which exist. Further, the ambient water temperature may be below the minimum temperature required by free swimming larvae to settle.

Even intakes which draw from great depth need to be evaluated individually. The withdrawal zone and the general reservoir hydrodynamics need careful consideration. For example, at the Hoover Dam the water enters the dam through four separate penstocks. Each penstock has its own cylindrical intake tower, a segmented intake opening at each of two different water depths with gates for each segment opening, and trash racks set on 3 “ centers. One of the intake towers was dewatered and the inside surfaces of the tower were inspected in late 2007. Almost the entire internal concrete surface of the intake tower was colonized by quagga mussels. There was a gradient of settlement density, with most settlement observed in the upper 60-90ft of the tower. Settlement tapered off with increasing depth, but it was only at 200ft below lake level that we saw no further settlement on the tower walls (Leonard Willett, US Bureau or Reclamation, pers.comm). However, the penstocks which were fed from these intake towers and which were at 200 feet below lake level had substantial settlement on all the walls. The main reason for this appears to be the withdrawal of relatively warm and nutrient rich water from the 60 foot depth which contains large number of dreissenid veligers.

In some southern U.S. reservoirs, where water is withdrawn from the bottom of the reservoir, dissolved oxygen may plummet at certain times of the year precluding survival of dreissenids in these intakes.

Mid-water intakes

Water intakes which are of relatively small diameter (24 to 72 in), situated in the upper 90 feet of water and very long (several hundred yards) are particularly vulnerable. The lake end of the intake usually terminates in a fixed grate or trashrack designed to exclude large debris. Water flows through the grate and into the intake, most often under gravity feed, into perhaps a pumping station. The intake grate is likely to be the most visible point of fouling. Mussels can easily close gaps in the grate and decrease the intake capacity.

In the intake itself, even before the mussels settling in the intake pipes reduce the amount of water the pipe can carry, they increase the friction and turbulence of flow by increasing the roughness of the pipe surface. During the intake design, the material roughness is incorporated into required diameter calculations (using the Hazen and Williams formula) as the "c" factor (or coefficient of friction) to determine the size of pipe required to satisfy discharge capacity requirements. When the roughness increases due to mussel settlement, flow rates drop and plants pumping water near their design capacity will have trouble meeting demand. VanCott (1993) working on the Great Lakes has shown that increased roughness and decreased capacity was recorded within four weeks from the on-set of settlement, when zebra mussel densities rose from $0/m^2$ to $6,000/m^2$.

Shallow and Surface Water Intakes

For plants which have very large diameter intakes or which utilize a surface intake, often the mussel infestation only causes problems when the raw water reaches the pump house. Before the entrance into the pump house, fixed trash racks are frequently used to trap large floating debris. Trash racks are often the first visible structure fouled when mussels arrive. At the Monroe power plant, trash bars which are set on 3-inch centers became badly fouled within one season. More than 75% of the straining surface was occluded. Anywhere below the first 6 feet, the mussel layer spanned the 3-inch gap between vertical slats, and also extended as much as 6 inches past the downstream side of the rack (Kovalak 1993). Such observations have since been reported from number of different industries in variety of geographic locations.

It is common to place floating surface barriers in the area approaching an intake. These barriers may be to prevent large floating objects from reaching the intake or they may be to prevent boaters from approaching too close to the intake. Sometimes the floats suspend nets to prevent fish from entering the facility. The floats can become weighed down with mussels and no longer able to perform their duty.

In northern or cooler climes, shallow intakes or grates on surface intakes may develop a secondary problem of frazzle ice due to the presence of macrofoulers on the intake grate. At the water works of Monroe Michigan, zebra mussel population in and around the inlet to the raw water intake contributed heavily to the frazzle ice formation, which in turn interrupted raw water flow for more than 56 hours (Lepage 1993). It is likely that the velocity changes and turbulent flows created by the zebra mussel population enhanced the development of frazzle ice.

Penstocks

Penstocks are the specialized intake structures found at many hydraulic plants. They channel the incoming water through a vertical drop towards the turbines. Although during full operating capacity, the flow velocities in the penstock are generally too large for mussels to settle, during short outages or peaking power operations, settlement is possible if the penstock is not dewatered. Typically, one penstock will feed one turbine and therefore penstock flow can be stopped depending on the grid demand. However, at Hoover each penstock supplies several units via laterals. If not all units are operating (which is typical for peaking power plants or plants that supply running reserve) then penstock velocities are considerably reduced allowing for settlement (as was observed at Hoover).

During longer outages, especially in warm waters, the drop in dissolved oxygen in the water within the penstock may be sufficient to prevent settlement from taking place.

Infestation of the penstock by mussels would result in increased hydraulic roughness which would then translate into loss of power production. In cold climates, the penstock may be subject to frazzle ice formation as described above.

Penstock air vents should be identified. The wetted portions of the vent piping can be mussel settlement locations as there is typically not high velocity flow in the vent branch. Confirmation of intended air vent operation (i.e., for what purposes including draining, filling, and/or emergency gate closure) and exploration of the possibility for reduced air vent capacity are important.

Trash Racks, Grates, Screens

Most trash racks are at risk of mussel settlement. Determining the accessibility of trash racks for cleaning is important and will affect control strategies and associated facilities protection requirements. Can they be removed easily for cleaning? Are they occasionally exposed due to water level changes at which time cleaning would become easier? How can they be inspected or monitored to verify if mussel build up is occurring or has reached a level that cleaning intervention is required. Trash racks may be good candidates for anti-fouling or foul release coatings.

There are frequently other screens designed to exclude fish and smaller floating debris for intakes or diversions. These are sometimes travelling screens which rotate at frequent intervals and the impinged debris is washed off by a screen wash system. These screens may have mesh size as fine as 1mm and as coarse as 13mm. While the screens themselves are not typically colonized due to their rotation in and out of water, the supporting structures are usually heavily infested. Severe colonization of supporting structures may interfere with the operation of the screen. Further, when the intakes, intake channels or forebays have high density of adult mussels, the mussels tend to form clusters. These clusters are subject to sloughing by current and gravity. They tend to roll along the bottom with the current and frequently impinge on the travelling screens. These clusters are either removed from the travelling screen by the screenwash system, or the may be carried over and fall from the travelling screen into the pumpwell which is being protected.

In most situations, intake grates or screens are fixed and similar to trashracks will require a means for either periodic or continuous cleaning.

Gates, Stop Logs

Isolation or emergency gates are often suspended in the water above an opening. Fouling of the gate could interfere with proper insertion of the gate. Gate or stop logs into guide which are usually carbon steel C-channel shapes. Mussel fouling in the channel could make it difficult to properly seal the gate or stop logs and in some cases has the potential for causing seal damage.

Wells and Sumps

Accumulation of mussels on the sump floats could cause unreliable level detection. The floats and sump should be inspected at regular intervals. Mussels typically settle on the external portions of submerged pump casings and on the walls of the sump at levels below the level shut off switch.

Within the pumphouse, the pump wells are generally made of concrete and subject to heavy colonization by dreissenids. The walls as well as pump bells which are immersed in water and through which water is withdrawn can be the source of adult mussel clumps and individual shells for downstream systems if those systems are not protected by up-front strainers. Fire protection pumps, frequently located in the pumphouse, are of particular concern.

The water in sumps can very often be several degrees warmer than the raw water. Mussels may grow more rapidly in the sump than in other areas in cold water areas. Conversely, when raw water is very warm, the slightly elevated temperature of the sump may prevent mussel growth.

Pumps and Turbines

At large pumping stations, the pump shaft seal water system is often supplied with filtered water only during pump start up. During normal running, the seal cavity may be exposed to small shell fragments and some increased wear may be experienced. The seal cavity may become a settlement area for mussels. Check if the seal cavity has a procedure for inspection and cleaning provided by the seal manufacturer and recommend inspections if seal cavity temperatures rise above permitted levels.

All pumps have air cooled or water cooled motors. If motors are air cooled, dreissenids should not impact on their operation. If the motors are water cooled, as is the case with many of the larger pumps, the motor windings, motor thrust and guide bearings, pump guide bearing and pump shaft seal may all require cooling water. Most cooling water for such applications is passed through strainers.

The strainers are effective at preventing adult mussels or mussel shells large enough to cause plugging problems from entering into the piping system. However, veligers will readily pass by the strainers and can settle in areas of the piping that are not made of copper or copper alloy.

The pump shaft seal water system, if not supplied with filtered water, may be exposed to small shell fragments and some increased wear may be experienced. The seal cavity in mechanical seals and the lantern ring cavity in stuffing boxes may become settlement areas for mussels and will need to be inspected and cleaned if seal cavity temperatures rise above permitted levels.

Pumps and turbines usually have wear rings on the rim of the rotating parts. These wear rings are of a sturdy material. However, there is normal wear and presence of mussel shells could increase the wear rate on the rings. The facility should be alerted to the possibility of increased wear ring rates.

Turbines will have guide bearings and, similar to large pumps, the bearings are usually oil lubricated with water-cooled oil coolers. Generator bearings will need cooling water as well. The oil coolers will be at risk of impairment from mussel shells. Turbines may have shaft seals that require some water passage for cooling. If the seal passages become blocked with mussel shells, the seal components may overheat and become damaged. The shaft seal leakage is collected and drained. Mussel veligers are small enough to pass through the gap between the shaft and seal. The drain piping would be at risk of mussel fouling.

Seals on slurry pumps used for ash disposal failed on ten occasions at the Monroe plant during 1989. Water supply to the seals was blocked by shells of small mussels causing the failure.

Piping

As water is drawn into the various systems, so are the free swimming larvae during the reproductive season. The mussels can settle in piping. Carbon steel, stainless steel, aluminum and concrete piping are all at risk of settlement. Copper piping of alloys with high copper content are at much less risk of fouling.

Most of the systems of concern are composed of small diameter, (typically 8” or less) piping where the water velocities are less than 6 ft/s. Under such conditions, larvae may settle and start to grow. This creates conditions for further settlement. The subsequent development of dense colonies in turn decreases the amount of water available to the plant system.

In some instances, areas which on paper have design flow rates high enough to preclude attachment, have been found full of juvenile mussels. This may happen during partial or short term outages when the flows are reduced for a period of time.

Embedded small diameter piping is of particular concern because in most cases, the piping may not be accessible for conventional cleanout.

Cross connection piping between systems should be identified. Where connections are normally closed, mussels can settle in the cross connect pipe and block flow when the cross connect is needed.

Surge tanks are special cases of a pipe with a large diameter. The wetted portions of the tank are at risk of mussel settlement. If the inlet to the tank becomes partially plugged, then the piping is at increased risk of water hammer. If the tank also serves as a vent, then increased risk of pipe collapse may exist unless the entrance to the tank is kept clear.

Instrument Tubing and Instrumentation

Gauging stations and float wells are used to track the water levels in the various water bodies and the movement of water between the water bodies. The gauging stations usually include a tap line, stilling well and float. The inlet pipe could become colonized with mussels and could impair the accuracy of the gauging station where there are frequent or sudden changes in flow and levels. For locations where flow rates and water levels change very slowly, there may not be a reduction in accuracy as a plugged pipe would still allow water to percolate to the stilling well. However, the floats could have sufficient mussels attached such that the level readings become unreliable.

Any instrument using raw water or in contact with raw water could attract mussel settlement. If the lines have no flow, such as pressure sensing lines, then the settlement is likely to occur near the tap end of the line where oxygen and nutrients are available for the mussels.

Any instruments in direct contact with raw water, such as level gages or acoustic flow meters, are at high risk of infestation. Some float based level sensing wells also have non-contact instrumentation as a back-up. Facility operating personnel should be advised that reading discrepancies may be due to mussels on floats.

Water sampling stations have a regular flow of water through them for analysis purposes. The intake piping is particularly at risk in this equipment.

Heat Exchangers

The largest volumes of water (up to 90% of the total) drawn into industrial and power generating plants is for cooling and heat transfer. The rest of the volume is used for plant processes other than cooling such as make-up steam systems, service systems such as cleaning, air conditioning, fire protection and human consumption. All systems are vulnerable to macrofouling infestation to greater or lesser degree.

The inlet plenum and outlet plenum of coolers is typically at risk of veliger settlement unless these portions of the components are made from copper or copper alloy. Copper alloys may build up a bio-film which is generally undesirable for heat exchanger performance. However, if a bio-film is permitted to form, mussels can attach to the bio-film. Mussels thus attached are easy to remove but if allowed to grow can release and plug tubing..

In addition, the inlet plenum of a cooler is typically a catchment area for any shells that manage to find their way along the upstream piping and shell material can gradually accumulate in the plenum ultimately blocking tubes and causing poor performance of the coolers. If poor cooler performance is detected, the maintenance personnel should be advised that mussel shell accumulation is a possible cause. Manufacturer’s recommendations or existing operating procedures should be followed to isolate the cause of the poor performance, inspect the heat exchanger for mussel fouling and clean the heat exchanger.

As a general guideline, 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 heat exchanger tubes could become settlement areas for mussels.

Valves

The development of dense colonies places proper operation of valves at risk, particularly valves which do not operate frequently. For example, at one facility, a 4 inch butterfly valve failed to close because the disc was completely covered by mussels. Even if a valve will close, there may be leakage resulting from trapped mussel shells.

Valves are often placed in series. The inter-chamber cavity may have a vent line and pressure balancing line. Either or both of these could be disabled by mussel plugging.

Strainers and Filters

Adult mussels which may be carried into the system or have detached from upstream locations will continue to move downstream until an in-line strainer prevents further movement. At such locations, large aggregates of mussels may form, even when the overall infestation is light. The strainers may limit flow to downstream system and cause unexpected system upsets.

Even self-cleaning strainers can present risks. Check the duty cycle of the strainer. If there are periodic system shut downs, mussels can begin to grow on the downstream side of the strainer and provide a source of mussel shells that one would normally have expected the strainer to remove.

When carrying out a field inspection, it is usually a good idea to inspect several strainers for presence of shells.

Materials of Construction

Mussels will attach to almost any material of construction. Typical materials such as concrete, carbon steel, and stainless steel are all good settlement substrates for mussels. Less common materials such as aluminum, wood, and plastics will also serve as settlement substrates.

When mussels are removed from steel and aluminum, the byssal threads are often left behind. The byssal thread/metal interface can serve as a site for corrosion pitting.

Copper and tin are toxic to mussels. Tin is not common as a material of construction. Mussels can occasionally be found to be covering a copper material. This typically occurs in areas of low flow where a film has accumulated on the copper. The mussels are attaching to the film not the copper. Mussels are typically easy to remove from copper surfaces where they do manage to settle due to the film. Copper needs to be kept clean by the flow so that the mussels are exposed to the copper ions.

Mussels do not like settling in areas where there is a silt covering the material. The silt can move, dislodging the mussel. Also, silt will cover settled mussels and cause mortality.

Dams, Reservoirs, and Aqueducts

There are many structures in North America which deliver water, provide inland waterways, regulating water levels, control flood flows, or provide water to industrial users.

Also included in this section would be impoundments, holding ponds, recharge ponds, siphons, dikes, turnouts, and canals.

All dams have outlet works. The outlet works will have an upstream (dam pressure) side and a downstream side. The trashracks and upstream tunnel need to be considered especially as it is usually very difficult to drain these areas. The downstream tunnel may also be at risk of mussels but usually has greater ease of access for cleaning. The pressure gates need to be considered as well as any inter-chamber piping and vent lines.

Structures which rely on movable gates to regulate flow need to be considered for impact of dreissenids. Attached mussels can colonize the outside and inside of submersed gates thereby increasing their weight. If the design parameters of the lifting equipment can not cope with much additional weight, the gates could become inoperable. Improper sealing is also a concern if the seals around the doors are colonized. Small drains associated with submersible gates can become clogged as can weep holes.

Level gauging systems usually require small diameter raw water lines which connect to sensor equipment. These could of course become plugged and impair the performance or response time of the gauges. If float type measuring systems are used, mussel accumulation on the float will generate a level reading error. If mussels are allowed to fully impact such structures, the dams may not be able to control the water levels as required.

Reservoirs often have large annual level fluctuations. The level changes can sometimes be used to assist in controlling the level of mussel infestation through desiccation during the normal level changes. Floating structures within a reservoir need to be identified as they will change level with the reservoir and can inoculate the reservoir when the levels increase.

All dams incorporate drain tubes. The drains will collect dam water that manages to pass the dam seal and percolate through the dam wall. Mussel veligers may be able to travel with the normal dam seepage into the drain tubes where they could settle and grow. The occurrence of such attachment is likely to be rare but has been documented at dam facilities.

Dams incorporate foundation uplift drain pipes. Water in these pipes is generally expected to be ground water seepage and not likely to transport mussels. In addition, reservoir seepage from the dam making its way to the pipes passes through the base material in the dam, which will normally suffocate any mussels. Nevertheless, it is important to discuss these pipes with dam staff and confirm that raw water cannot reach the drain.

Dam structures have a rigorous inspection program. In the unlikely event that sufficient mussels should accumulate to restrict the drain flow, the reduced drainage should be picked up during the frequent routine inspections by dam staff. However, it is important that dam staff be made aware of how to identify mussels and what the consequences might be of mussel presence.

Sometimes the seepage through the dam drains to a sump. The sumps could become an ideal inspection area to check for the presence of mussels. Mussels typically settle on the external portions of submerged pump casings and on the walls of the sump at levels below the level of the shut off switch.