Threat of Mussel to Reclamation Water Facilities
What Water Storage and Delivery Facilities are Vulnerable to a *Dreissena* Mussel Infestation?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Colonization Potential (Infestation Probability)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>High</td>
</tr>
<tr>
<td>Salinity, ppm</td>
<td>0-1,000</td>
</tr>
<tr>
<td>Calcium, ppm</td>
<td>25,000-125,000</td>
</tr>
<tr>
<td>pH</td>
<td>7.4-8.5</td>
</tr>
<tr>
<td></td>
<td>8.5-9.0</td>
</tr>
<tr>
<td>Water temperature °C (°F)</td>
<td>17-25 (63-77)</td>
</tr>
<tr>
<td>Turbidity, cm (Secchi disk)</td>
<td>40-200</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolved Oxygen, ppm</td>
<td>8-10</td>
</tr>
<tr>
<td>Water velocity, (ft./sec.)</td>
<td>1.6-2.3</td>
</tr>
</tbody>
</table>
Water Transfers

- Western water systems differ from eastern:
  - Long, continuously managed reaches of flowing water
  - Systems designed for water dispersal
  - Structures often lack designs and management plans to contend with quaggas and zebras
  - New problems are apparent requiring new management techniques
Water Transfer - Colorado
Assets We Manage

- 348 storage reservoirs
- 254 diversion dams
- 16,075 miles of canals
- 1,460 miles of pipelines
- 280 miles of tunnels
- 37,495 miles of laterals
- 17,040 miles of project drains
- 268 pumping plants over 1,000 horsepower
- 58 hydroelectric power plants
Forms of Problems

• Flow restriction
  – Roughening (Friction loss)
  – Blockage

• Chemical degradation

• Biological/Environmental
  – Food chain
  – Habitat
  – Water quality
  – Water resource industry
  – Toxic accumulations

Quagga mussel, Lake Havasu – Jan. 2007
Flow Restriction, cont’d

Fouled Trash Rack, Corps of Engineers

Intake screen blocked by shells
Biological/Environmental

Recreational loss - Zebra mussels on Lake Michigan Beach

Habitat loss - Catfish near zebra mussel covered substrate
What BOR has learned from the Great Lake Region
Site Visit Experience Ontario Hydro Power Facilities (reactive approach)

- Sir Adam Beck #2
- Sir Adam Beck #1
- DeCew #2
- Pump Generating Station
Nanticoke Coal Fired Facility Ontario (proactive approach)
Over time if left untreated

- Transformer cooling water piping plugged at Ontario Hydro Power
Ontario Hydro Plant Unit Coolers

Dead Mussels Found in Unit Coolers
Quagga Mussel Infestation at LCD Dams (Parker & Davis)
Sampling Plates at Parker Dam
November 11/07 – 6 Weeks of Settlement
Underwater Photo – Domestic Water Intake
Parker Dam

Jan 2008

Feb 2008

Opening

Flange
SPILLWAY GATES – PARKER DAM

LC Dive Team 02/21/08
Quagga Mussel Findings and Recommendations for Hoover Dam
Elevation 1045, (66’ below water)
Observations from inspection of external surfaces

- Mussels present in the intake towers at upper gate opening
- Decreasing settlement as depth increases
- Virtually no settlement at lower gate opening
- Inspection of the intake tower provided population vs. depth of settlement profile
HOOVER DAM PENSTOCK – NOV 2007

30’
Observations from inspection of external surfaces

- Mussels were found in the lower penstock at depth of 217’
Observations from inspection of external surfaces

Uncertainty about the ultimate size of the mussel population, if in doubt, expect the worse scenario

Penstock drains may be plugged by shell debris and live shells in the future
Observations from inspection of external surfaces

- Several size classes of mussels observed in the sample collected from the penstock, indicative of multiple spawning events
- Apparent new settlement present at the penstock, breeding is still on-going
Observations from inspection of external surfaces

Mussels are present in the tailrace area, apparently in much lower numbers
Tail bay cooling water overflow

Mussel Confirmed Present
Inside the Power House
What have we observed in the power house

- Some evidence of mussel presence inside plant raw water systems
- Potential for fouling by primary settling and from incoming shells
Cooling Water Take-Off

- All cooling water enters the plant through; penstock take-offs (four take offs / penstock)
- There is no barrier to ingress of shells from penstock take offs

And through tail bay suction via eductors
HOOVER DAM COOLING WATER SUPPLY – APRIL 11, 2008
Generator Air Cooler
Inlet of generator air cooler
What have we observed in the plant

- The smallest diameter of cooling water piping 2”

- Equipment most likely to get plugged by live mussels; oil coolers (5/16 inch diameter tubes) and supply leading to local air conditioners

- Equipment most susceptible to plugging by dead shells from upstream, generator coolers. Unlikely live mussels will settle in generator coolers as they are made of copper
## Other Impacted Systems

(Source ACOE – ZMIS)

<table>
<thead>
<tr>
<th>Piping</th>
<th>Circulating water systems</th>
<th>Service water systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traveling screens</td>
<td>Once through</td>
<td>Pumps</td>
</tr>
<tr>
<td>Water towers</td>
<td>Pumps</td>
<td>Piping</td>
</tr>
<tr>
<td>Trash racks</td>
<td>Piping</td>
<td>Raw water makeup</td>
</tr>
<tr>
<td>Trash bars</td>
<td>Condenser water boxes</td>
<td>Heat exchangers</td>
</tr>
<tr>
<td>Forebays</td>
<td>Condenser tubes</td>
<td>Emergency systems</td>
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<tr>
<td>Holding ponds</td>
<td>Fire protection systems</td>
<td>Area coolers</td>
</tr>
<tr>
<td>Storage tanks</td>
<td>Main pumps</td>
<td>Seal water systems</td>
</tr>
<tr>
<td>Wet wells</td>
<td>Jockey pumps</td>
<td>Strainers</td>
</tr>
<tr>
<td>Pump wells</td>
<td>Submerged pumps</td>
<td>Drag valves</td>
</tr>
<tr>
<td>Pump suction chambers</td>
<td>Intake structures</td>
<td>Makeup demineralizers</td>
</tr>
<tr>
<td>Lift pumps</td>
<td>Intake screens</td>
<td>Circulation systems</td>
</tr>
<tr>
<td>Pump bell housings</td>
<td>Intake tunnels</td>
<td>Emergency water systems</td>
</tr>
<tr>
<td>Screen wash systems</td>
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</tbody>
</table>
Components of Facilities

- Storage Reservoirs (Hydroelectric Power)
- Diversion Structures (Gravity or Pump)
- Conveyance Channels (Canals, Laterals)
- Fields
- Drains - Return to Waterway
- Sites Needing Special

Bouse Hills Pumping Plant, CAP
Central Arizona Project

Feature

- Pumping Plants 15
- Tunnels 3
- Siphons 19
- Pipelines 3
- Aqueduct 340 miles
Storage Reservoirs (Hydroelectric Power)
Diversion Structures (Gravity and Pumped)
Conveyance Channels (Canals, Laterals)

Central Arizona Project – Hayden-Rhodes Aqueduct

Confluence of CAP and SRP Eastern Canal at Granite Reef Diversion Dam
Conveyance Channels (Canals, Laterals), cont’d

Turnouts and Trash racks

Radial Gates
Fields

Ditch with furrow siphons

Pipelines
Drains - Return to Waterway

Main Drain, Palo Verde Irrigation District

Drain, Yuma Valley Irrigation District
Sites Needing Special Consideration

Inverted Siphons – Salt River Siphon (CAP)
Special Consideration, cont’d

Instrumentation

Fish Protection Facilities, PNR
What is recommended

Know thy enemy – monitor

Regular inspect and clean external structures as required

Set up monitoring plan

Implement control of incoming veligers and of mussel shell debris in critical areas

Develop rapid response plan should mussel infestation start to impact critical areas
Monitoring, why and how

- Second year for Quagga mussels in the Colorado River system

- Great Lake experience useful but not necessarily accurate

- May see huge seasonal variations in population density, larval production, settling patterns in the West vs. East

- Bureau of Reclamation can’t make good decisions without better local data
Monitoring – why

• Outside of the facilities
  - To determine when the breeding cycle starts, when settlement begins and ends
  - How many mussels will settle and grow in one year/cycle
  - How deep can mussels settle and grow
Monitoring – why

- Within the facility
  To determine the level of infestation and if required, effectiveness of treatment
  - side stream samplers (Bio-Boxes)
  - temperature sensors on critical coolers in power plants
  - ROV inspections
• Monitoring – How?
Plankton Tows
Plankton tows

- Quick and easy way to establish presence or absence of veligers at the beginning and end of the breeding season. Take large samples, process by “density separation” using sugar solution method.

- Can be used to do actual veliger counts in the incoming water, tedious and offers limited information for the plant.
CONTINUE MONITORING USING SETTLING PLATES
Recommendation

- Use the same settlement substrate material at all facilities
- Same dimensions
- At the same depth (10ft, 20....down to maximum depth)
- Examine the plates at the same time interval and in the same manner
- Multiple strings of sampling plates upstream and down
Recommendation

- Install at least one side stream sampler, two if possible
- One at the front of the system, one near the end would be ideal
- Recommended flow-through 5 gpm (20L/min)
- Settlement plates within the sampler should be the same material as outside settling plates

Davis Dam Bio-Box
Bio-Box Spiked with Live Mussels
Mussel Control

- Develop rapid response plan to immediate threat
- Decide on long term strategy
- Implement
Control Options Myth

- All facilities can use the same control options in the same way

- Engineering staff has all the knowledge required to design a perfect control system

- Technology vendors and Service providers do not have their own agenda

So......Buyer beware
Fact – Every Facility is unique
Evaluate before you decide on a strategy

• Strategy may be:
  
  – Do nothing, react only when disaster is imminent
  
  – Implement planned treatments at regular intervals
  
  – Prevent as many mussels as possible from entering the plant, alive or dead
Facility Evaluations

- As a team decide what level of infestation is tolerable in the various parts of your system

- If there is a danger of blockage by primary settlement or shell debris, what are the consequences of such a blockage (safety and economic)

- What will your customer/regulator/insurer/fire marshall say about mussel presence in various systems and the risks they may pose?

- What will your regulator say about your treatment of choice? Can permits be obtained in time?

- What is your operational preference?
Control Strategies

- Proactive
  - Preventive measures
  - Does not allow growth of mussels in the system or on the surface protected

- Reactive
  - “Clean” after establishing
  - Can be labor intensive
  - Does allow mussels to grow in the system or on the surface. Established populations have to be eliminated periodically

- Redesign
  - Retrofit
Options for External Structures*

*Structures That Are in Direct Contact With the External Environment; No Isolation Is Possible
Reactive Options for External Structures

Mechanical Cleaning

- de-water and use powerwash (104 F preferred)
- underwater, scrape and vacuum or powerwash
Proactive Options for External Structures

Antifouling Coating - for both steel and concrete

- Toxic, copper based coatings

Foul Release Coating

- Non-toxic, silicone based

Life-span 5-7 years before topcoat needs to be refreshed
Substrate Preference
(Decreasing from Top to Bottom)

- Copper
- Galvanized Iron
- Aluminum
- Acrylic
- PVC
- Teflon
- Vinyl
- Pressure Treated Wood
- Black Steel
- Polypropylene
- Asbestos
- Stainless Steel

Kerr Lock and Dam (COE), Tulsa OK

Source - Kilgour and Mackie, 1993
Options for Internal Piping Systems
Reactive Options for Internal Piping Systems

- **Thermal Wash** - 32°C for 48 hours (90°F)  
  40°C for 1 hour (104°F)

- **Mechanical Cleaning** such as
  - scrape large diameter pipes
  - use expanding air bubbles ?? or remote vehicle tools on difficult areas

- **Flushing with weak acids**

- **Oxygen Deprivation**
Reactive Options for Internal Piping Systems (Cont)

• Periodic (once or twice/year) application of
  - Non-oxidizing chemicals
  - Oxidizing chemical
Oxidizing Chemical Treatment

- Chlorine
- Bromine
- Chlorine dioxide
- Chloramines
- Ozone
- Potassium permanganate
Emerging Options

- Bacterial product (Marrone Organic Innovations), zebra mussel specific chemical….being tested on Quagga now

How does it work?

The bacteria produce natural compounds that kill the mussels when ingested. It destroys the mussels’ digestive system.
Proactive Options for Internal Piping Systems

- **Sand/media filtration** - has to remove all particles greater than 40 micron

- **Mechanical filtration** - has to remove all particles greater than 40 micron
Example of Self Cleaning Filters

Figure 7: Automatic Self-cleaning Filter
25 to 50 MICRON SELF CLEANING FILTER

- Strainer Discharge
- Course Strainer Chamber
- Strainer and Filter Vent
- Fine Filter Chamber
- Filter Silt Discharge
- Pad Eye
- Pad Eye
- Drive Unit with 1/2 HP Motor
- Fine Filter Drain
- Direction of Flow
- Main Access Hatch
- Strainer Drain
- Influent Raw Water
- Access Hatches
- Filtered Water Discharge
Mesh Requirements

Figure 2: Square Weave

Figure 4: Patented Four-layer Screen
Additional Proactive Options for Internal Piping Systems

- Strainers with 1/8” screens followed by UV systems
- Closed Loop Cooling
- Oxidizing chemicals
- Non-Oxidizing chemicals
Duplex Strainer

Closed-pipe UV system
In Line Pipeline UV Installation

- UV Monitor
- Access Hatch
- Air Release
- Wiper Motor Housing
- Upstream Isolation Valve (Not visible)
- Downstream Isolation Valve
- Access to Lamps (Both ends of chamber)
- Electrical Junction Box (wiring from cabinets)
- Direction of Flow
UV Light Bank for Open Channel
Proactive Use of Oxidizing Chemicals for Protection of Internal Piping Systems

Low levels of the chemical are added continuously or semi-continuously throughout the mussel breeding season to prevent settling by creating a hostile environment.
Other Options for Effective Control

- Oxygen Deprivation
- Temperature Treatments
- Exposure and Dry up
- Manual Scraping
- High-pressure Jetting
- Passive and Barrier Filtration
- Removable Substrates
- Chemicals or Molluscicides
- Electric Currents
- Sonic Vibration
- Natural Predators or Biological Controls
Initial Suggestions for Control

• Rapid Response Option (if settlement and shell transport increases dramatically and suddenly):
  – Install portable chlorine skids to protect critical areas
  – Use thermal treatment where possible
  – Use weak acids to dissolve shells and corrosion products
  – Mechanical cleaning as system performance deteriorates
Control and Mitigation Ideas

Use 50 micron self cleaning filters instead of strainers.

– Protects all downstream equipment

– Coarse pre-straining may still be required

– Does not require NPDES Permitting

– Environmental Friendly
Control and Mitigation Ideas

Chemical Injection

– Periodic or Continuous approach

– Requires approval of Regulator

– Multiple injection points required

– May require detoxification before discharge

• Risk – Shell material can still enter, strainers may still be required
Path Forward

• Implement monitoring immediately ie; settling plates, bio-boxes, and develop contingency plan

• Team made up of stakeholders does a detailed engineering evaluation of systems at risk vs. mitigation options

• Team agrees on the acceptable risks and selects mitigation options best suited to achieve control within the risk criteria
Summary

• Current Situation –
  – Still learning characteristics of the mussel in this environment

• Monitor and measure to: detect presence, understand the mussel breeding and growth cycle, determine risk areas in plant and develop response

• Engineering evaluation of possible control options to establish feasibility vs. operational preference vs. risk

• The actual choice of treatment will be based on a combination of regulatory, economic and operational considerations
CONCLUSION

• There is no silver bullet!

• The mussels are adaptive and continue to surprise…..No one has a crystal ball!

• Site specific integration of control strategies and continuous vigilance is required.
Cost for Mussel Control

• Ontario Hydro Experience

Average cost per MW = $1020/MW (Capital Costs)

Average Annual Operating Cost = $50/MW
Quagga Mussel Point of Contact and Consultant

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QUESTIONS