Glen Canyon Dam Adaptive Management Work Group
Agenda Item Information
February 19-20, 2014

Agenda Item
Quagga Mussels – Impacts and Solutions for Hydropower Facilities

Action Requested
Information item only

Presenters
Leonard Willett, Bureau of Reclamation

Previous Action Taken
N/A

Relevant Science
N/A

Background Information

In January 2007, the quagga mussel, a thumbnail-sized invasive species from Eastern Europe, was discovered at Lake Mead.

The discovery generated instant concern, as these mussels can potentially colonize water supply systems at hydroelectric power plants and similar facilities to the point of disrupting operations.

The Bureau of Reclamation's Lower Colorado Region immediately embarked on a concerted effort to learn more about these mussels. The objectives were twofold: to ensure the mussels did not affect power generation or water delivery operations at Hoover, Davis and Parker dams, and to gather information that could be shared with other water facility owners and operators about the mussel, its potential impacts, and methods of preventing or combating those impacts.

Throughout 2007, Reclamation conducted literature searches, inspected its facilities, established partnerships with other water utilities in the Lower Colorado River Basin, conducted a sampling program to determine the density of mussel larvae in Lake Mead and Lake Mohave, and supported public outreach efforts.

Reclamation also contracted with a consulting firm experienced in mussel control for a further assessment of Hoover Dam and Davis and Parker Dams, and for recommendations of possible methods of preventing or controlling infestations on critical operating systems.

As a result of this effort, the Region has implemented specific control measures at:

Hoover Dam
Davis Dam
Parker Dam
Imperial Dam/Yuma Area
Quagga Mussels, continued

In addition, Reclamation's Research and Development Office in Denver and other agencies are conducting further research and testing new quagga mussel prevention methods at these dams and other facilities.

It may not be possible to eradicate the mussel from the Colorado River system, but, working in partnership with others, the Lower Colorado Region is taking steps necessary to ensure Reclamation hydroelectric facilities continue to provide water and power for the American Southwest.

The presentation will provide an update on quagga mussel control efforts in the lower Colorado River, and update on status of quagga mussels in Lake Powell, and implications for future management and operations of Glen Canyon Dam.
Taking No Prisoners
Beating Back Invasive Species

Leonard Willett
Lower Colorado Region
Background:

• January 2007 adult quagga mussel found in Lake Mead (assumed to be from a mussel infested house boat)

• Fall of 2007 – Reclamation’s Lower Colorado Dams (LCDO) office completed facility review
Background:

- Findings from review and updated activities of the lower Colorado river dams

- Research activities and control barriers that are environmentally friendly
Facility Assessments

Facility Vulnerability Assessment Template
Invasive Quagga and Zebra Mussels

http://www.usbr.gov/mussels/
## 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>
</tr>
<tr>
<td>Holding ponds</td>
<td>Fire protection systems</td>
<td>Area coolers</td>
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</table>
## More Impacted Systems

<table>
<thead>
<tr>
<th>Storage tanks</th>
<th>Main pumps</th>
<th>Seal water systems</th>
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</thead>
<tbody>
<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>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Environmental Requirements

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Adults do not survive long-term</th>
<th>Uncertainty of veliger survival</th>
<th>Moderate Infestation Level</th>
<th>High Infestation Level</th>
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</thead>
<tbody>
<tr>
<td>Calcium (mg/L)</td>
<td>&lt; 8 to &lt;10</td>
<td>&lt;15</td>
<td>16-24</td>
<td>≥24</td>
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<tr>
<td>Alkalinity (mg CaCO3/L)</td>
<td>&lt; 30</td>
<td>30-55</td>
<td>45-100</td>
<td>&gt;90</td>
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<tr>
<td>Total Hardness (mg CaCO3/L)</td>
<td>&lt;30</td>
<td>30-55</td>
<td>45-100</td>
<td>≥90</td>
</tr>
<tr>
<td>pH</td>
<td>&lt;7.0 or &gt;9.5</td>
<td>7.1-7.5 or 9.0-9.5</td>
<td>7.5-8.0 or 8.8-9.0</td>
<td>8.2-8.8</td>
</tr>
<tr>
<td>Mean Summer Temperature (°F)</td>
<td>&lt;64</td>
<td>64-68 or &gt;83</td>
<td>68-72 or 77-83</td>
<td>72-75</td>
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<tr>
<td>Dissolved Oxygen mg/L (% saturation)</td>
<td>&lt;3 (25%)</td>
<td>5-7 (25-50%)</td>
<td>7-8 (50-75%)</td>
<td>≥8 (&gt;75%)</td>
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<tr>
<td>Conductivity (μS/cm)</td>
<td>&lt;30</td>
<td>&lt;30-60</td>
<td>60-110</td>
<td>≥100</td>
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<tr>
<td>Salinity (mg/L) (ppt)</td>
<td>&gt;10</td>
<td>8-10 (&lt;0.01)</td>
<td>5-10 (0.005-0.01)</td>
<td>&lt;5 (&lt;0.005)</td>
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<tr>
<td>Secchi depth (m)</td>
<td>&lt;0.1 &gt;8</td>
<td>0.1-0.2 or &gt;2.5</td>
<td>0.2-0.4</td>
<td>0.4-2.5</td>
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<tr>
<td>Chlorophyll a (μ/L)</td>
<td>&lt;2.5 or &gt;25</td>
<td>2.0-2.5 or 20-25</td>
<td>8-20</td>
<td>2.5-8</td>
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<tr>
<td>Total phosphorous (μg/L)</td>
<td>&lt;5 or &gt;50</td>
<td>5-10 or 30-50</td>
<td>15-25</td>
<td>25-35</td>
</tr>
</tbody>
</table>
Control Strategies

• Proactive:
  – Preventive

• Reactive
  – “Clean” after establishing
  – Can be labor intensive

• Redesign/Retrofit
# State Criteria for a Positive Water Body

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<tr>
<th>STATE</th>
<th>Not Established</th>
<th>2 micro., independ. experts</th>
<th>1 micro. + 1 PCR</th>
<th>1 micro. + 2 PCRs</th>
<th>2 micro. + 2 PCRs</th>
<th>Adults</th>
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<tbody>
<tr>
<td>AZ</td>
<td>x</td>
<td>x (temporal)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CA</td>
<td>?</td>
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<td></td>
<td></td>
<td>x</td>
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<tr>
<td>CO</td>
<td></td>
<td></td>
<td>x</td>
<td>x (same sample)</td>
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<td>ID</td>
<td>x</td>
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<tr>
<td>KS, ND, OK</td>
<td></td>
<td></td>
<td>x</td>
<td></td>
<td></td>
<td>x</td>
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<tr>
<td>MT</td>
<td></td>
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<tr>
<td>NE</td>
<td>x</td>
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<td>x</td>
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<tr>
<td>NV</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x (+SEM)</td>
<td></td>
</tr>
<tr>
<td>NM</td>
<td>x</td>
<td></td>
<td></td>
<td></td>
<td>x (+5 experts)</td>
<td></td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td>x</td>
<td>x (+SEM)</td>
<td></td>
<td></td>
<td>x</td>
</tr>
<tr>
<td>SD, TX, WA</td>
<td>x</td>
<td></td>
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<tr>
<td>UT, WY</td>
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</table>

[RECLAMATION]
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 Havasupai – Jan. 2007
Food Web Alteration Time Line – Lake Huron Main Basin

Source - Michigan DNR, 2007
Chinook Weight at Age 3 – Lake Huron

Source - Michigan DNR, 2007
Chemical Degradation - Corrosion

Siphons

Pseudofeces
Sampling Plates at Parker Dam
November 11/07 – 6 Weeks of Settlement
Domestic Water Intake Parker Dam

Jan 2008

Feb 2008

Opening

Flange
Spillway Gates – Parker Dam

LC Dive Team 02/21/08
Aquatic Weeds – Lake Havasu, AZ
August 2008
Aquatic Weeds – Lake Havasu, AZ
August 2011

- Evaluate weeds and intake design. Retrofit of trash bar screens with racking systems (Parker Dam)

- Evaluate impacts of mussels on reservoir water quality and environmental impacts.
Parker Dam Trash Rake – Sept 2013
Davis Dam
Davis Dam Fixed Wheel Gate - Oct 07
Hoover Dam
Intake Towers - April 2009

- Fore bay: 1094 ft
- Intake: 1045 ft
- Intake: 895 ft

Upper Cylinder Gate: 11/2007
Historical Observations-Hoover Dam

Nov 2007 Penstock

Apr 2008 Gen Cooling Water Supply Line

Oct 2008 Penstock

Oct 2009 Penstock
External surfaces Inspection – Oct 2008

Penstock Lateral Shell Debris (13ft diameter)

Penstock Drain – Heavy Settling

Over 6 Inches Deep
Penstock belly drain – Oct 2010
Hoover Dam Generator Packing Area
Problematic Mussel Fouling

Small water opening to
supply packing stuffing box
Hoover Dam 1/8” Strainer prior to UV Unit – Sept 2010
## Hoover Dam’s 10-Year Budget for Mussel Control

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<td>470,000</td>
<td>490,000</td>
<td>510,000</td>
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<tr>
<td><strong>Equipment &amp; Materials</strong></td>
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<td>330,000</td>
<td>350,000</td>
<td>370,000</td>
<td>390,000</td>
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<td><strong>Hoover Labor</strong></td>
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<tr>
<td><strong>Non-Contract</strong></td>
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<td>40,000</td>
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<tr>
<td><strong>Total</strong></td>
<td>820,000</td>
<td>860,000</td>
<td>900,000</td>
<td>940,000</td>
<td>980,000</td>
<td>1,020,000</td>
<td>1,020,000</td>
<td>1,020,000</td>
<td>1,020,000</td>
<td>1,020,000</td>
<td>1,020,000</td>
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</tbody>
</table>
Fire protection and other cooling water systems need protection.
External Structures Options

Mechanical Cleaning

• de-water and use power wash

• underwater, scrape and vacuum or power wash
Oxidizing Chemical Treatment

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

Chlorine tankers used at MWD in southern CA at Gene Camp for mussel control

Cost: $10m/yr
Reclamation Lower Colorado Region Research Activities

- Monitoring substrate
- Installed bio-boxes
- Evaluating water jetting system for exterior cleaning
- Evaluating anti-foul coatings and materials to resist mussels (Dr. Allen Skaja, TSC Denver)
Reclamation Lower Colorado Region Research Activities

- Tested micro-filtration systems (40-80 micron) completed
- Evaluating ultra-violet light treatment (on-going)
- Evaluation of Zequanox treatment (completed)
- Turbulence study on cooling water (study underway)
- Copper Ion Generator (study underway)
- pH down or up evaluation (completed)
Installed Bio-Box Sampler for Monitoring

Mussels settling on plates

Cooling water inlet from reservoir
Domestic Water Lines – Davis Dam

Water Blasted

~108 ft

Ready for Pseudomonas Fluorescens Study
Water Jetting Equipment

Video
- pre inspection
- water jetting
- post inspection

multiport nozzle

before

after
Coatings Panels

3-month fouling rate
Parker Dam Trash Rake Coating Research Summer 2013
Fish Screen Material (Cu- Ni Wedge Wire)

3-month fouling
Sep – Dec 2009
Cooling Water Filter Options

Parker Dam Research Filter
2008 - $100K

40 & 80 micron filter cartridge inside of all housing

Hoover’s SCADA Filters
$200K - 2010

Hoover’s cooling water
$333K – 2010
(4 filters purchased for A2, N2, N1, & N8)
Self Cleaning Ballast Safe Filter

Pre-strainer (filter)

Filter Cartridge – 40 micron
Hoover Dam Cooling Water Mussel Control UV System (research)

Started August 2010
2 lamps

Renata Claudi (RNT Consulting)
starting 4 lamp evaluation

Upgrade to 4 lamps to increase dosage April 2011
Hoover Dam Cooling Water Mussel Control UV System – Aug 2010

Total Cost: $116K

UV Unit, Pump, & Piping: $70K

Installation: $46K

10” cooling water line 1250 gpm @ 150 psi

1/8” strainers prior to UV unit
Hoover Dam Cooling Water Mussel Control UV System (research)

4 Lamps

Cleaning Gel storage for wiper system
UV dosage response evaluation for settlement prevention of mussels

UV equipment cost $100 – 150K
1250 gpm with UVT of 85
dosage of 100 mj/cm²
Power operational cost $2500/yr
$0.035/kwh

UV equipment cost $225 – 375K
4000 gpm with UVT of 85
dosage of 100 mj/cm²
Power Plant Mussel Control System
Atlantium (HOD) UV Light System

UV Cooling Water System
installed July 2013 on a
4000 GPM system
Marrone Bio Innovations and Bureau of Reclamation work at Davis Dam, AZ
Emerging Options - Zequanox
*Pseudomonas flourescens* (PF)

Mussels’ last meal - Scientists want to add PF that are lethal to invasive mollusks to water at Hoover or Davis dams

Photo courtesy of Las Vegas Sun Newspaper
Zequanox Regulatory Status
North America

• Bacterial product (Developed at NY State Museum and commercially developed by Marrone Organic Innovations for quagga & zebra mussels)

• How does it work? The bacteria produce natural compounds that kill the mussels when they use it as food source. It destroys the mussels’ digestive system.
<table>
<thead>
<tr>
<th>Trial Week and Water Temperature (degree C)</th>
<th>Dose (mg/L)</th>
<th>Percent Mortality (%)</th>
<th>Std. dev. (+/- %)</th>
<th>Mortality Check (day)</th>
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<tbody>
<tr>
<td>March 23, 2009 14 deg. C</td>
<td>100</td>
<td>87</td>
<td>3</td>
<td>34</td>
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<tr>
<td></td>
<td>50</td>
<td>84</td>
<td>2</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>75</td>
<td>82</td>
<td>5</td>
<td>32</td>
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<tr>
<td></td>
<td>25</td>
<td>75</td>
<td>6</td>
<td>32</td>
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</table>

Information provided by Marrone Bio-Innovations
Zequanox Davis Dam June 2011
Cooling Water System
Zequanox Accomplishments at Davis Dam

- **Biobox studies**
  - Provided ability to field test formulations and provide valuable feedback to correlate with lab studies

- **Cooling water subsystem treatments**
  - 3 successful treatments
  - Achieved **77% adult mussel mortality** – both one time treatment and cumulative treatments

- **Juvenile periodic treatment program**
  - Achieved **85% biomass reduction** with monthly treatments
  - Demonstrated effective control of recently settled mussels
Zequanox Treatment – Monthly Material Price for Davis Dam (January 2013)

Costs based on average run time of 10 Months, Bi-Weekly Treatments.

- **Minimum Flow 1500 GPM**
  - $7800.00 Per Month
  - $78,000 Per Year – One Unit
  - $390,000 Per Year – Five Units

- **Normal Flow 3800 GPM**
  - $13,700.00 Per Month
  - $137,000,000 Per Year – One Unit
  - $685,000 Per Year - Five Units
Extensive Ecotox Studies Show No Impact to Other Aquatic Species

**FISH**
- Bluegill sunfish (*Lepomis macrochirus*)
- Channel catfish (*Ictalurus punctatus*)
- Chinook Salmon (*Oncorhynchus tshawytscha*)
- Coaster brook trout (*Salvelinus fontinalis*)
- Common Carp (*Cyprinus carpio*)
- Fathead Minnow (*Pimephales promelas*)
- Klamath Suckers (*Catostomus* spp.)
- Lake sturgeon (*Acipenser fulvescens*)
- Largemouth bass (*Micropterus salmoides*)
- Rainbow Trout (*Oncorhynchus mykiss*)
- Sacramento Splittail (*Pogonichthys macrolepidotus*)
- Smallmouth bass (*Micropterus dolomieu*)
- Striped Bass (*Morone saxatilis*)
- Walleye (*Sander vitreus*)
- Yellow perch (*Perca flavescens*)

**MOLLUSCS**
- Blue Mussel (*Mytilus edulis*)
- Freshwater Mussel - Duck Mussel (*Anadonta*)
- Freshwater Mussel - Black Sandshell (*Ligumia recta*)
- Freshwater Mussel - Fatmucket (*Lampsilis siliquoidea*)
- Freshwater Mussel - Pink mucket (*Lampsilis abrupta*)
- Freshwater Mussel - Hickorynut (*Obovaria olivaria*)
- Freshwater Mussel - Higgins Eye (*Lampsilis higginsii*)
- Freshwater Mussel - Mucket (*Actonaias ligamentina*)
- Freshwater Mussel - Paper Pond Shell (*Utterbackia imbecillis*)
- Freshwater Mussel - Plain Pocketbook (*Lampsilis cardium*)
- Freshwater Mussel - Washboard (*Megalonaias nervosa*)
- Freshwater Snail (*Lymnaea peregra*)

**OTHERS**
- Mallard Duck *
- Midge (*Chironomidae*)
- Mayfly (*Baetis*)
- Amphipod (*Hyalella azteca*)
- European Freshwater Crayfish (*Austropotatamobius pallipes*)
- Freshwater Crustacean (*Asellus aquaticus*)
- Freshwater Water Flea (*Daphnia magna*)

**PLANTS AND ALGAE**
- Algae *
- Bindweed (*Convolvulaceae*)
- Common Water Plantain (*Alisma subcordatum*)
- Curly Dock (*Rumex crispus*)
- Mallow (*Malvaceae*)
- Nightshade (*Solanaceae*)
- Smallflower Umbrella Sedge (*Cyperus difformis*)

* EPA required
† Final report expected by mid-2013.

Studies conducted by Institute of Technology, Sligo, Ireland; New York State Museum and USGS; U.S. Bureau of Reclamation; Certified Good Laboratory Practices (GLP) Lab; and MBI lab
Zequinox Treatment Programs

• Product applied with standard equipment
• Treatments can be completed within hours
  – ~2-6 hrs depending on program
• Mortality occurs over time, reducing damage to equipment from shell debris
• Safe for employees in the surrounding area
• Mortality typically monitored via biobox systems

Annual
Designed for facilities with tolerance for moderate to large shell sizes (larger than 4 mm in size)
Treatments occur annually; typically end of season

Bi-Weekly
Goal is to limit the number of mussels that exceed 4 mm in size (adult sized)
Ideal for sensitive systems and equipment
Treatments are performed every other week throughout the settlement season
Bi-Weekly Regimen Reduces Settlement by 90%
Native mussel restoration

• Zequanox® to aid in native freshwater mussel (unionid) restoration efforts
  – Conduct non-target studies on native unionid species and additional fish species
    • Focus on Great Lakes and Mississippi River Basin species
  – Apply product to restoration cages or unionid beds to reduce fouling by dressenids
Turbulence Study – April 2013
Proposed Copper Ion Generator Unit

Anodes are installed in cells (fresh water units). A side-stream of water is passed thru the unit and a copper-rich concentrate is formed. The treated solution is then distributed to one or more intakes to treat all the users.
pH up evaluation

RNT Consulting pH evaluation for Reclamation

Precipitate observed after 24 hours at pH 9.3
FUTURE-Pulse-pressure evaluations for invasive quagga mussel control
QUESTIONS

Leonard Willett, Quagga Mussel Coordinator
LWillett@usbr.gov (702) 494-2216