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

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.

RECLAMATION

Managing Water in the West

Taking No Prisoners
Beating Back Invasive Species

Leonard Willett
Lower Colorado Region

U.S. Department of the Interior
Bureau of Reclamation

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

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Background:

- Findings from review and updated activities of the lower Colorado river dams
- Research activities and control barriers that are environmentally friendly

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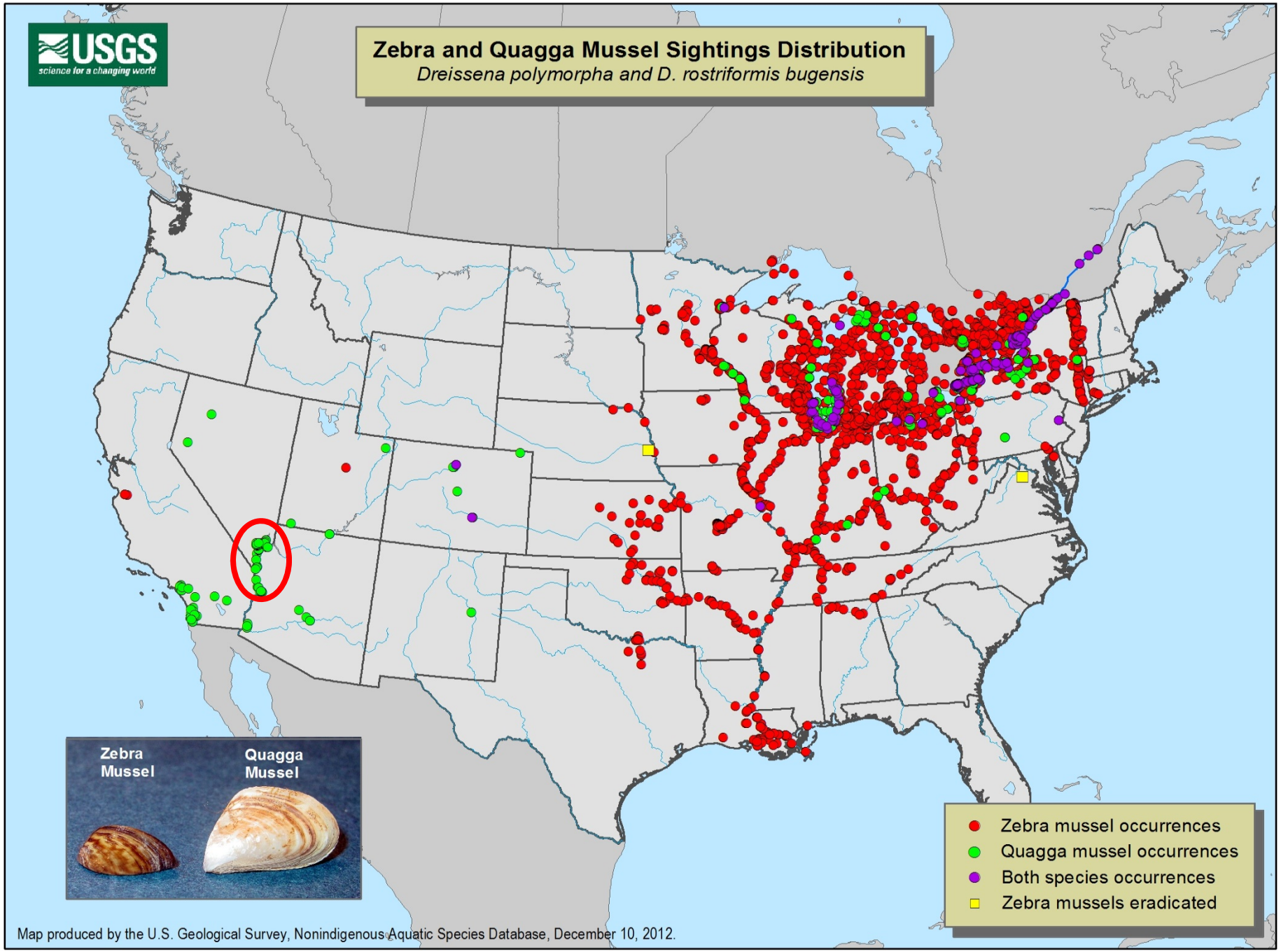
USGS
science for a changing world
Zebra and Quagga Mussel Sightings Distribution
Dreissena polymorpha and D. rostriformis bugensis
Zebra Mussel
Quagga Mussel
Zebra mussel occurrences
Quagga mussel occurrences
Both species occurrences
Zebra mussels eradicated
Map produced by the U.S. Geological Survey, Nonindigenous Aquatic Species Database, December 10, 2012.

Facility Assessments

RECLAMATION
Managing Water in the West

Facility Vulnerability Assessment Template

Invasive Quagga and Zebra Mussels

http://www.usbr.gov/mussels/

U.S. Department of the Interior
Bureau of Reclamation

May 2009

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Impacted Systems (Source ACOE – ZMIS)

Piping	Circulating water systems	Service water systems
Traveling screens	Once through	Pumps
Water towers	Pumps	Piping
Trash racks	Piping	Raw water makeup
Trash bars	Condenser water boxes	Heat exchangers
Forebays	Condenser tubes	Emergency systems
Holding ponds	Fire protection systems	Area coolers

More Impacted Systems

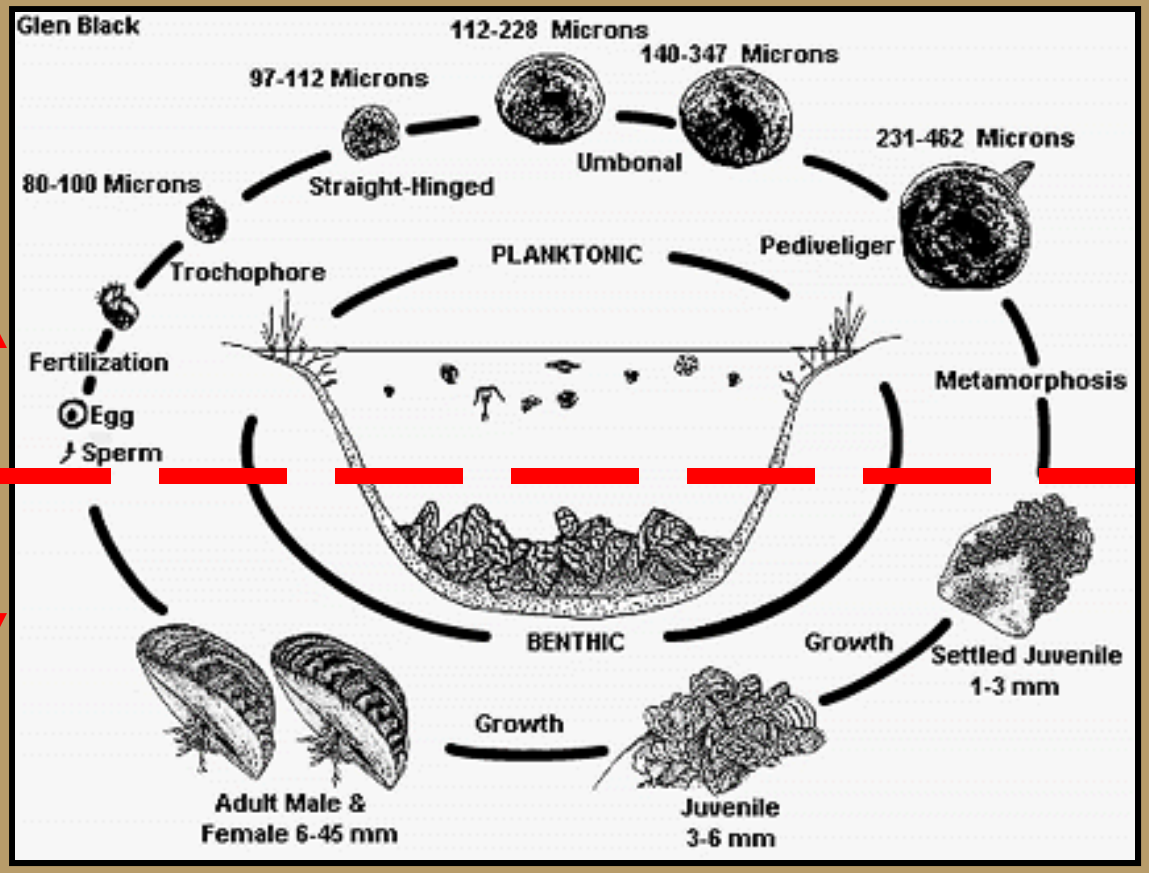
Storage tanks	Main pumps	Seal water systems
Wet wells	Jockey pumps	Strainers
Pump wells	Submerged pumps	Drag valves
Pump suction chambers	Intake structures	Makeup demineralizers
Lift pumps	Intake screens	Circulation systems
Pump bell housings	Intake tunnels	Emergency water systems
Screen wash systems		

Environmental Requirements

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

Control Strategies

- **Proactive:**
  - **Preventive**
- **Reactive**
  - **"Clean" after establishing**
  - **Can be labor intensive**
- **Redesign/Retrofit**



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State Criteria for a Positive Water Body

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

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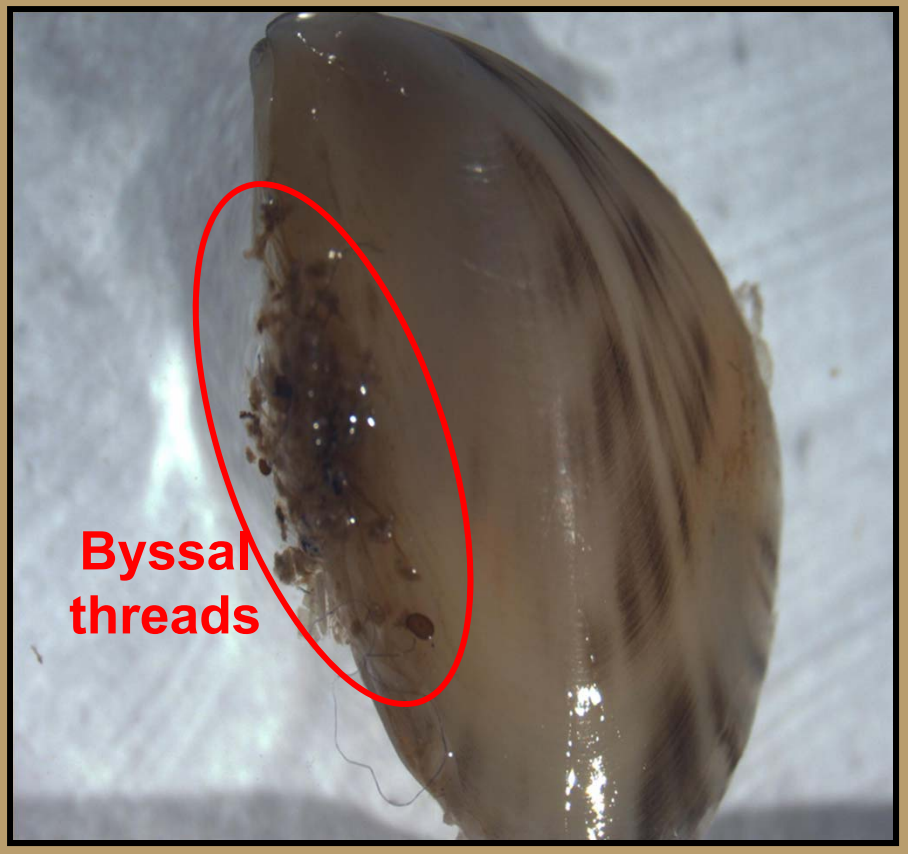
Forms of Problems

- 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

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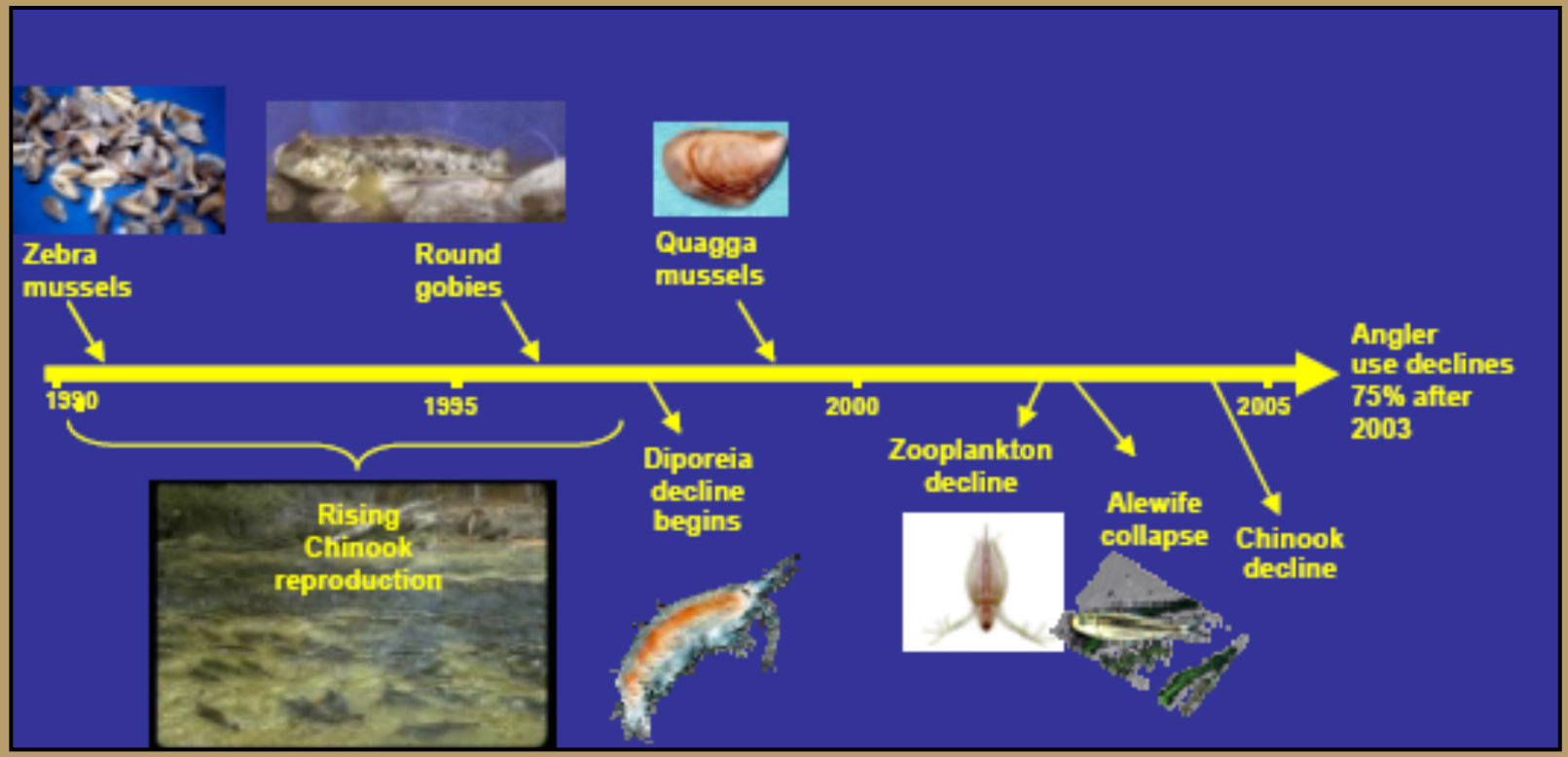
Food Web Alteration Time Line – Lake Huron Main Basin



Source - Michigan DNR, 2007

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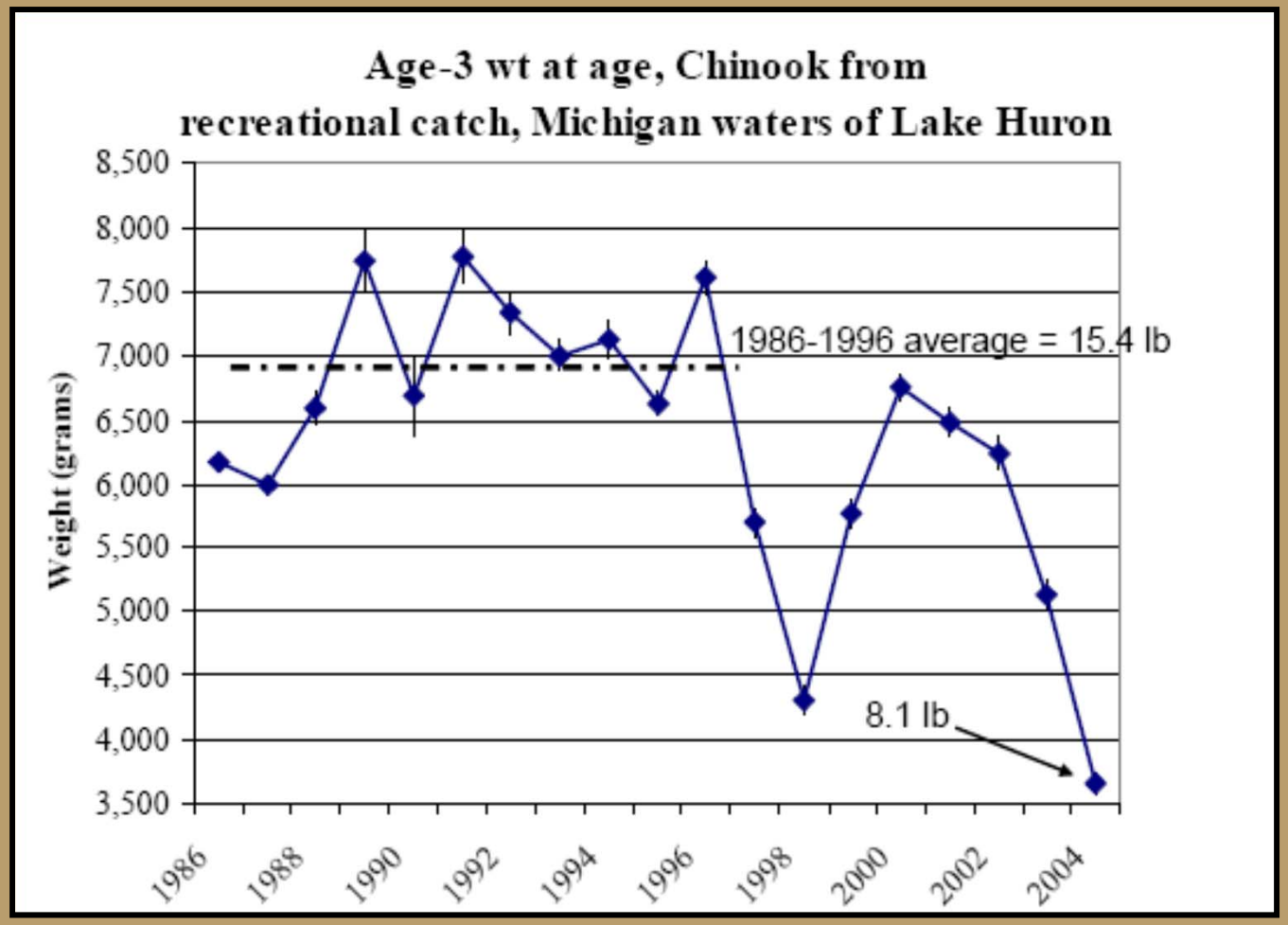
Chinook Weight at Age 3 – Lake Huron



Source - Michigan DNR, 2007

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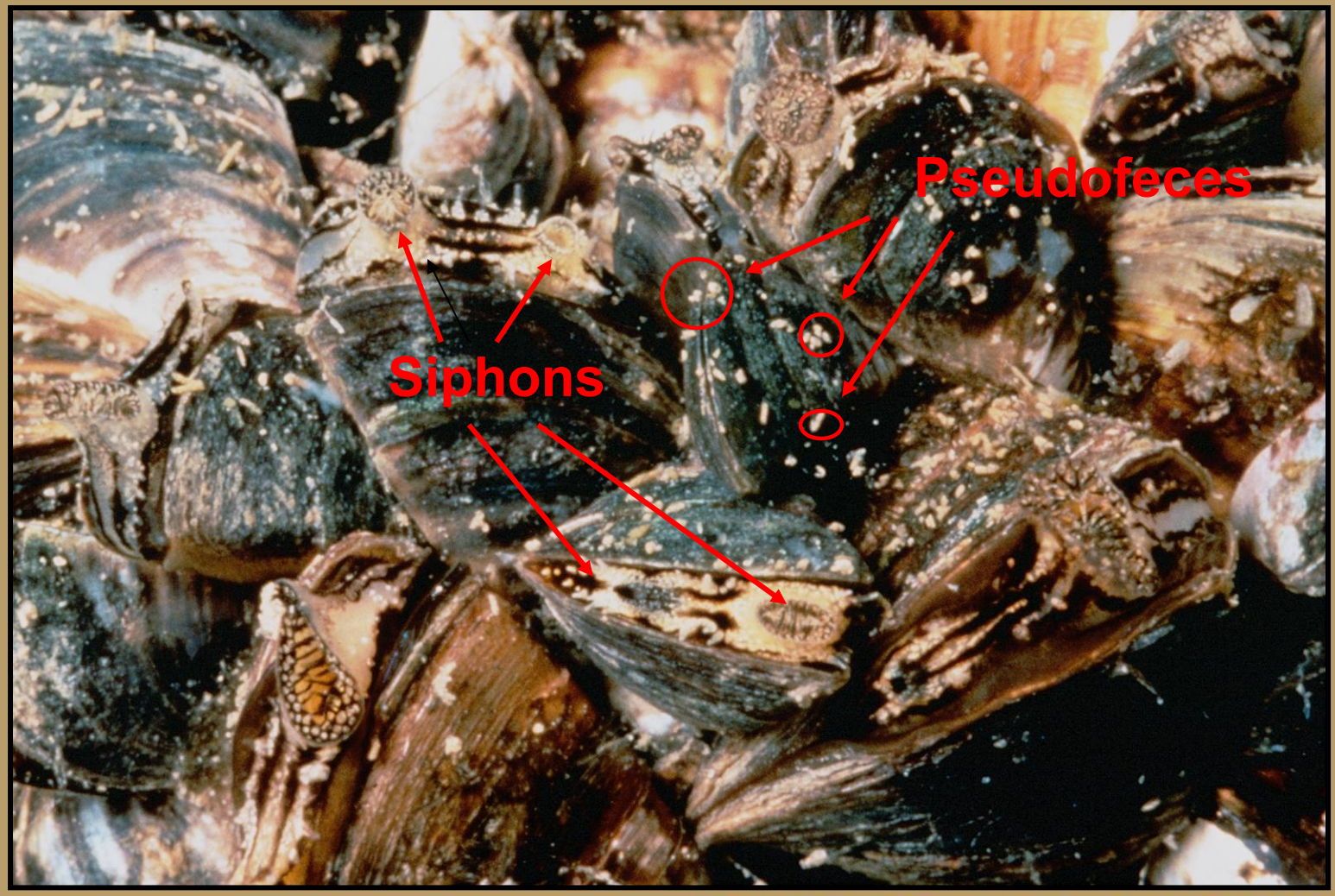
Chemical Degradation - Corrosion



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Hoover Dam Pressure Relief Valve Shaft Corrosion – April 2013

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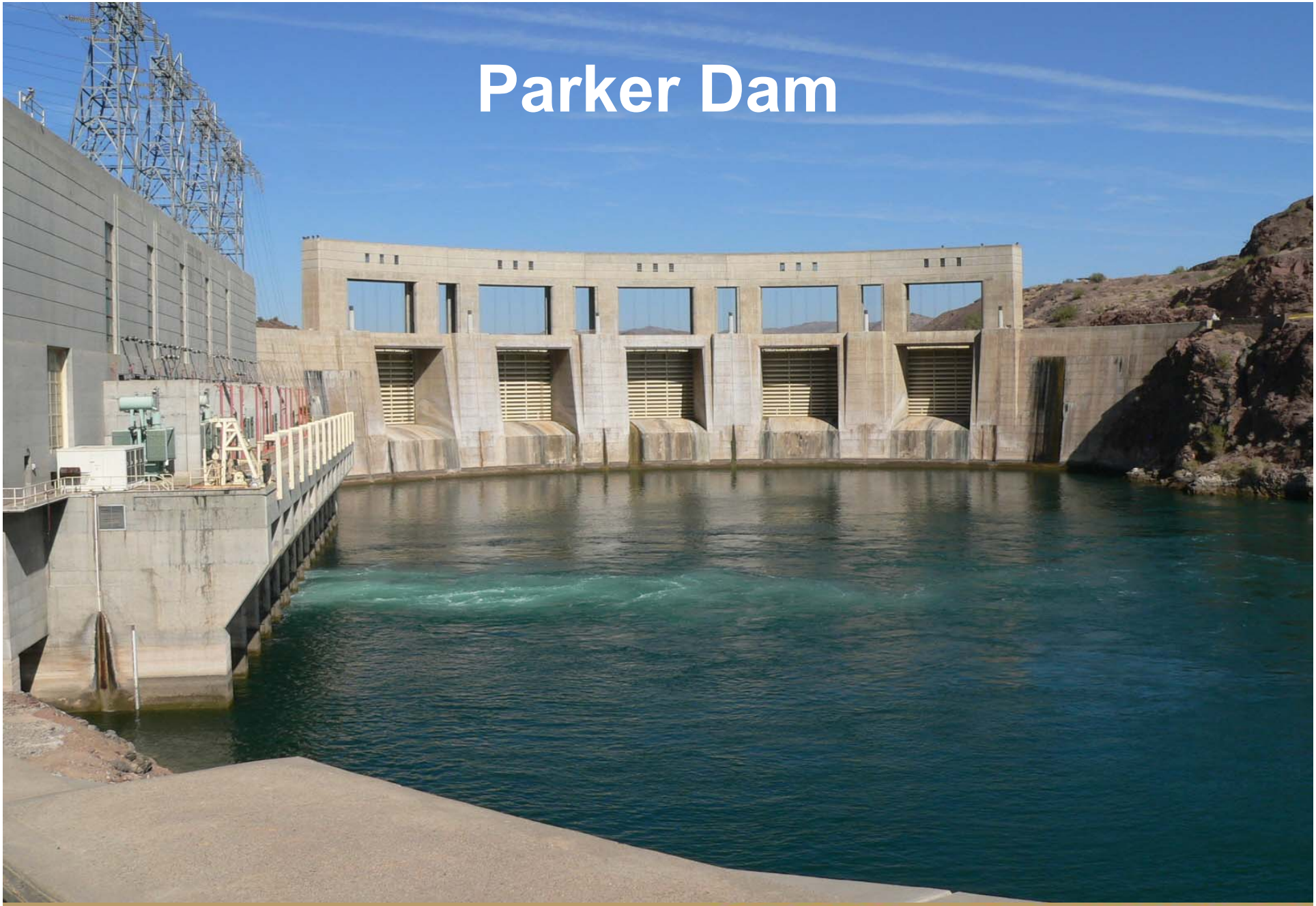
Parker Dam



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Sampling Plates at Parker Dam
November 11/07 – 6 Weeks of Settlement

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Trash Rack- Parker Dam - Jan 2013

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Domestic Water Intake Parker Dam

RECLAMATION

Spillway Gates – Parker Dam

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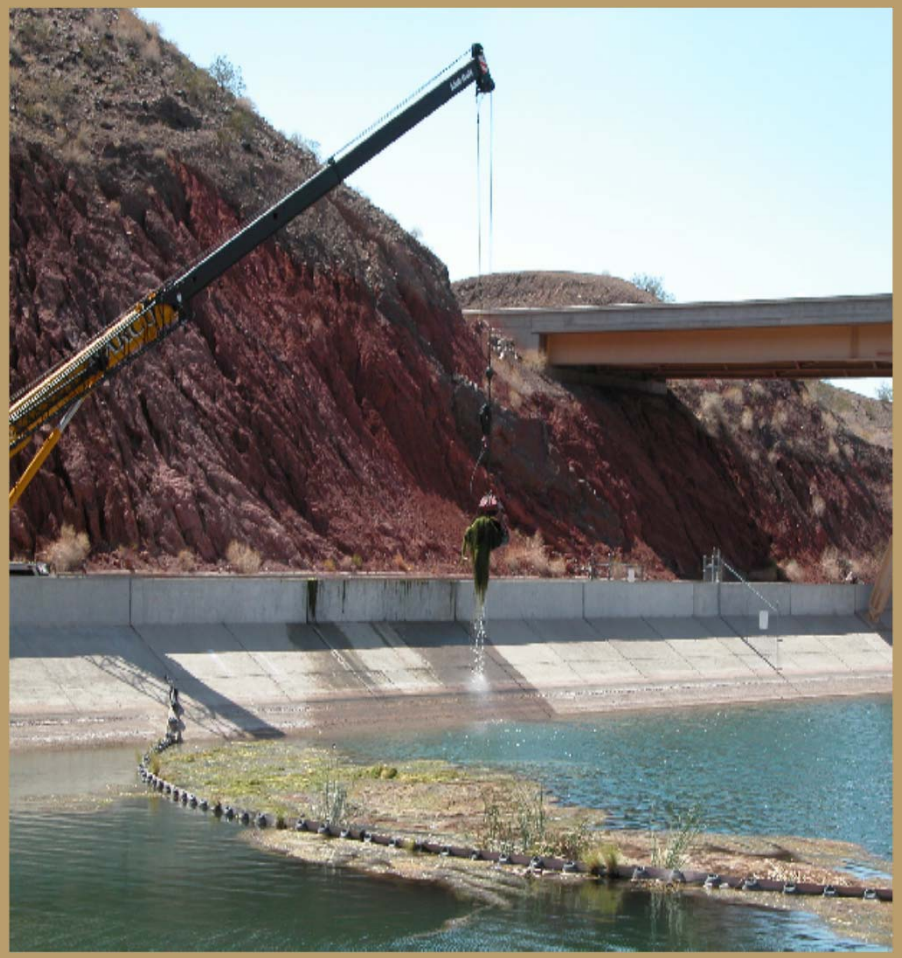
Aquatic Weeds – Lake Havasu, AZ
August 2008



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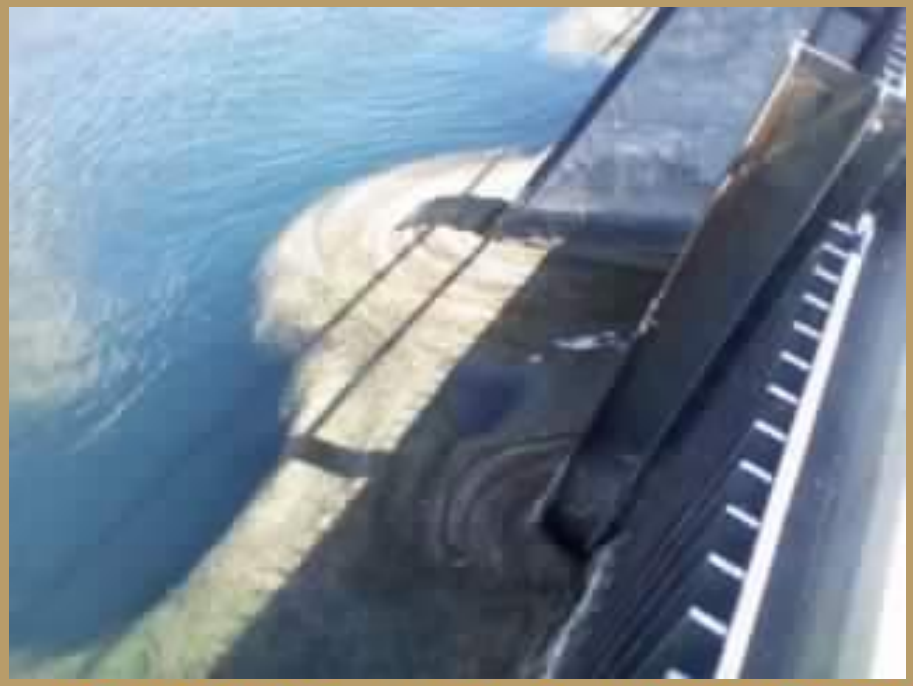
Aquatic Weeds – Lake Havasu, AZ
August 2011

- 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.



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Parker Dam Trash Rake – Sept 2013

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Davis Dam

RECLAMATION

Davis Dam Fixed Wheel Gate - Oct 07

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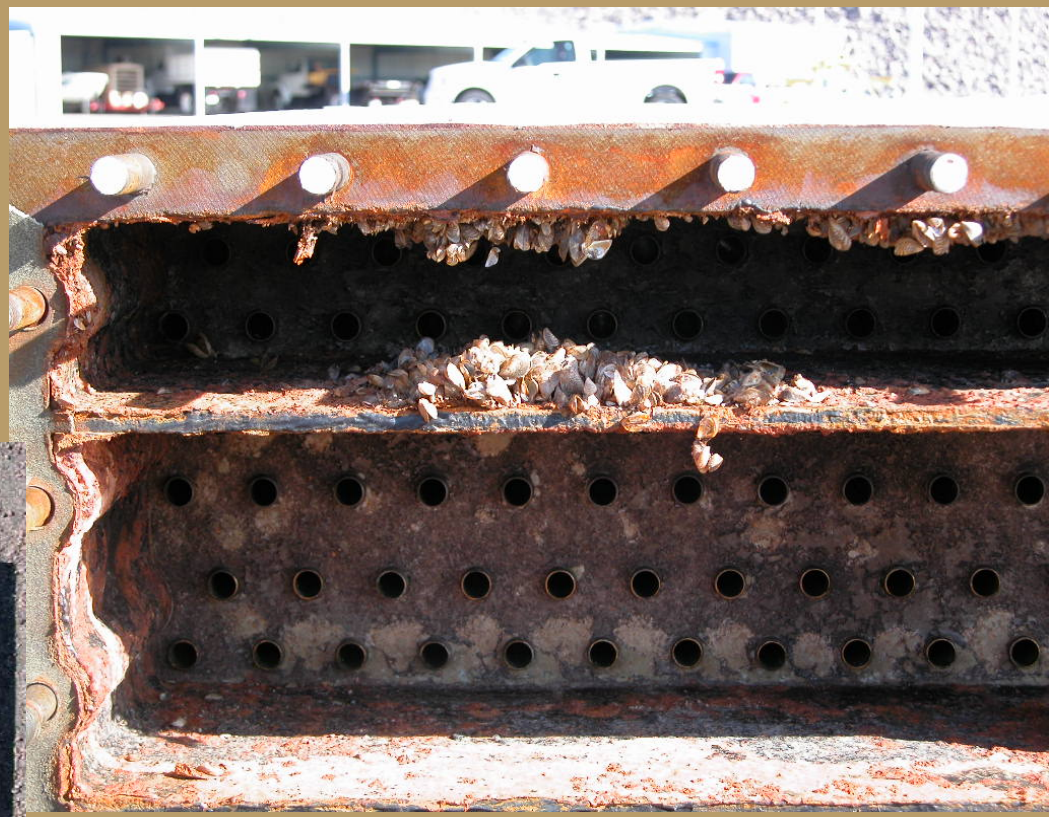
Generator Cooling Water Heat Exchanger Davis Dam - Dec 2009



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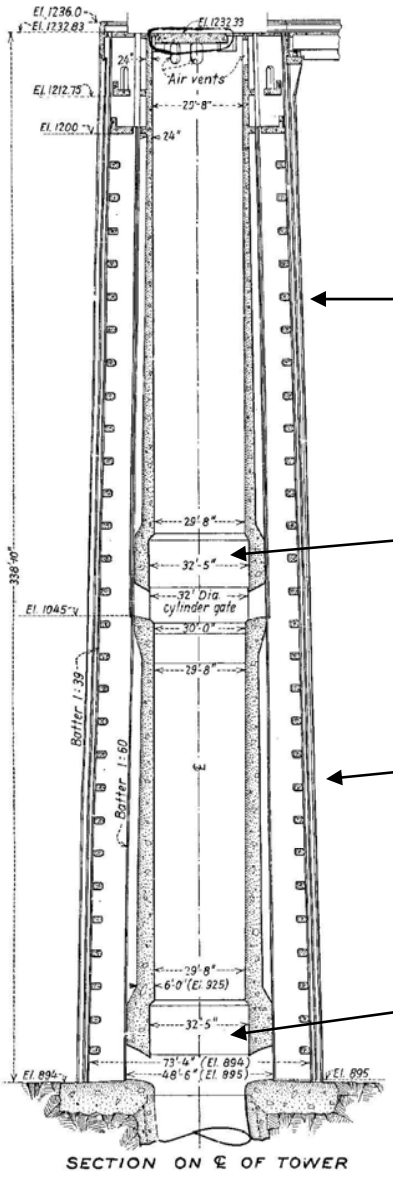
Hoover Dam

RECLAMATION



SECTION ON ℄ OF TOWER

Elev 1111
Dec 2007 Lake
Mead Level

Elev 1045
66’

Elev 970
141’

Elev 894
217’

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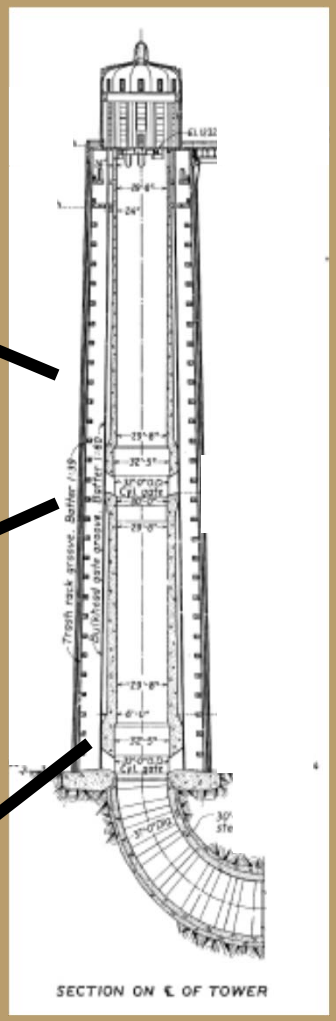
Intake Towers - April 2009

Fore bay
1094 ft

Intake -
1045 ft

Intake -
895 ft



Trash Racks
6/2009

Upper
Cylinder Gate
11/2007

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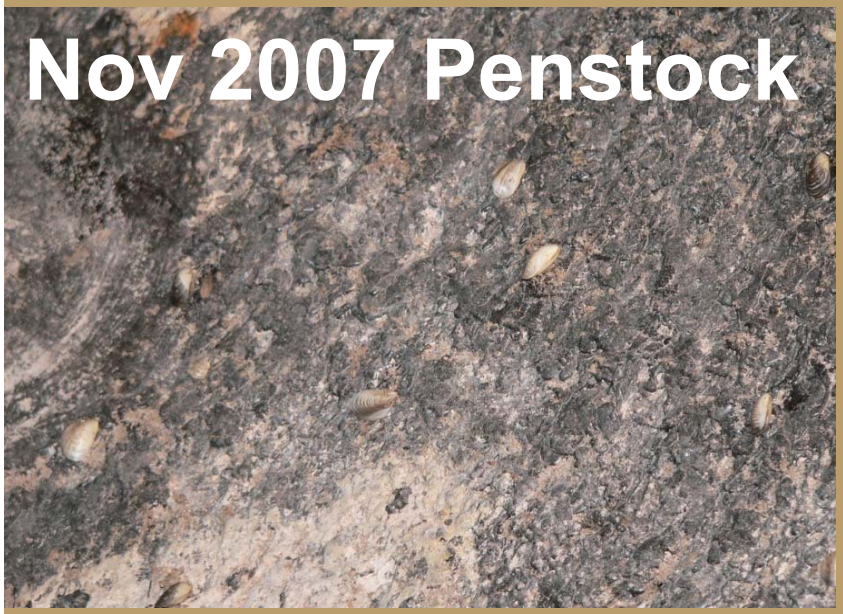
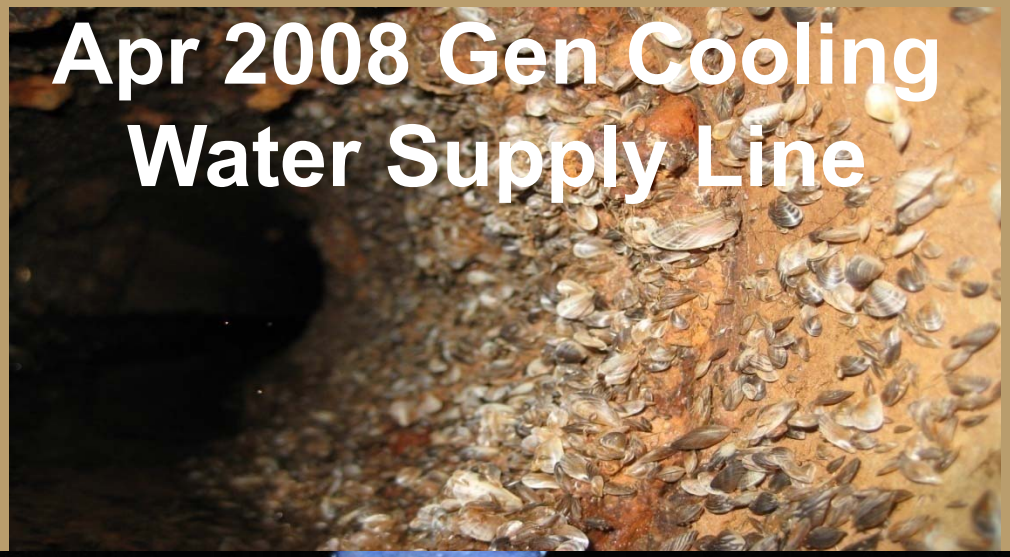
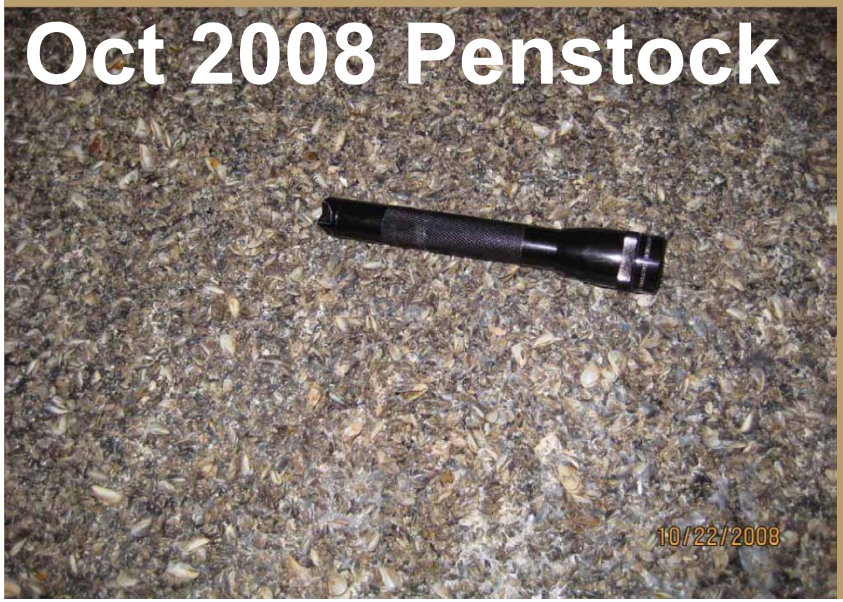
Historical Observations-Hoover Dam







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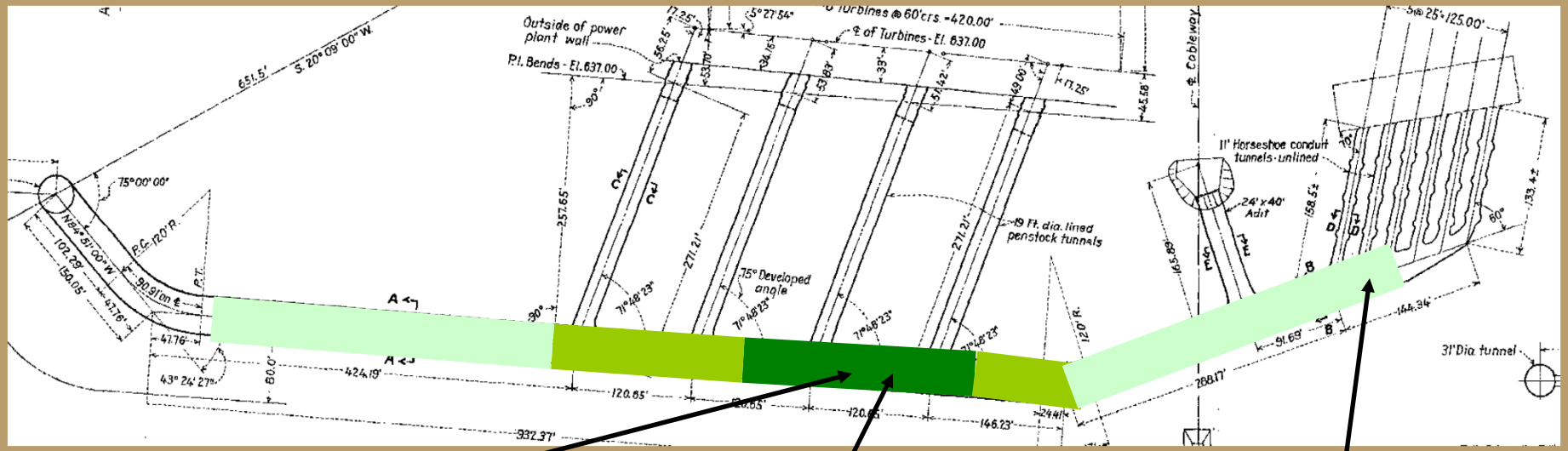
Upper Nevada Penstock Oct 2008



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External surfaces Inspection – Oct 2008

Penstock Lateral Shell Debris (13ft diameter)

Penstock Drain – Heavy Settling

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Penstock belly drain – Oct 2010

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Hoover Dam A2 Air Cooler 10/05/11

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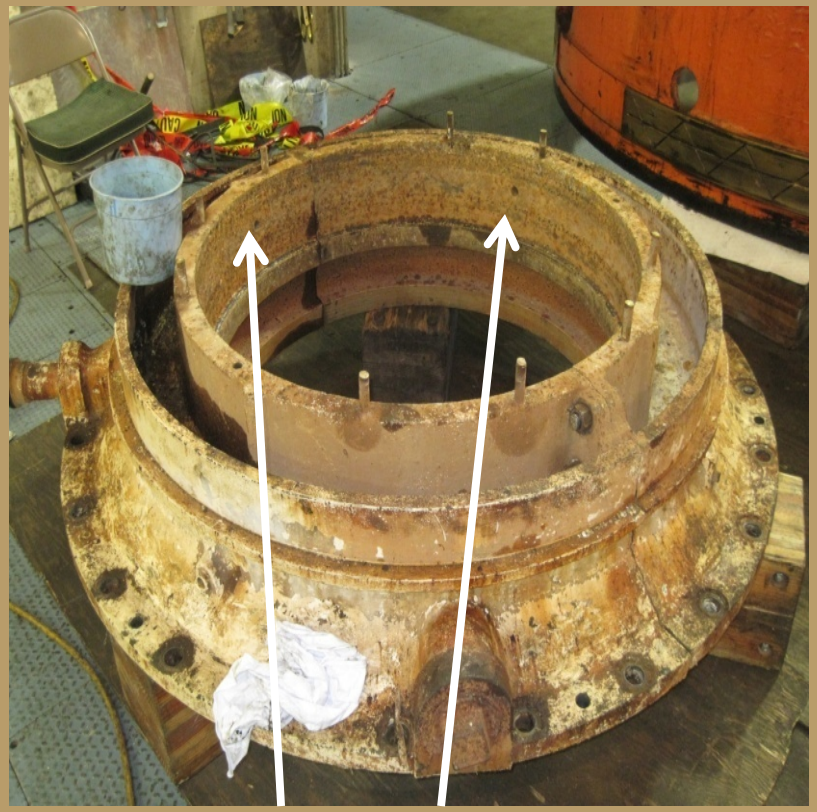
Hoover Dam Generator Packing Area Problematic Mussel Fouling



Small water opening to supply packing stuffing box

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Hoover Dam Oil Cooler Sept 2010

RECLAMATION

Hoover Dam 1/8” Strainer prior to UV Unit – Sept 2010

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Hoover Dam's 10-Year Budget for Mussel Control

	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023	FY 2023
Contract	450,000	470,000	490,000	510,000	530,000	550,000	550,000	550,000	550,000	550,000	550,000
Equipment & Materials	310,000	330,000	350,000	370,000	390,000	410,000	410,000	410,000	410,000	410,000	410,000
Hoover Labor	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000	20,000
Non-Contract	40,000	40,000	40,000	40,000	40,000	40,000	30,000	40,000	40,000	40,000	40,000
Total	**820,000**	**860,000**	**900,000**	**940,000**	**980,000**	**1,020,000**	**1,020,000**	**1,020,000**	**1,020,000**	**1,020,000**	**1,020,000**

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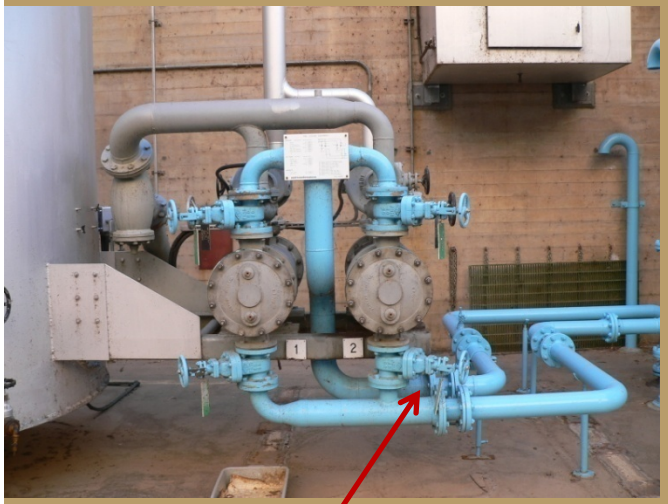
Fire protection and other cooling water systems need protection



Transformer cooling water

Fire nozzles

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External Structures Options

Mechanical Cleaning

- de-water and use power wash
- underwater, scrape and vacuum or power wash

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Oxidizing Chemical Treatment

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

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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)

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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)

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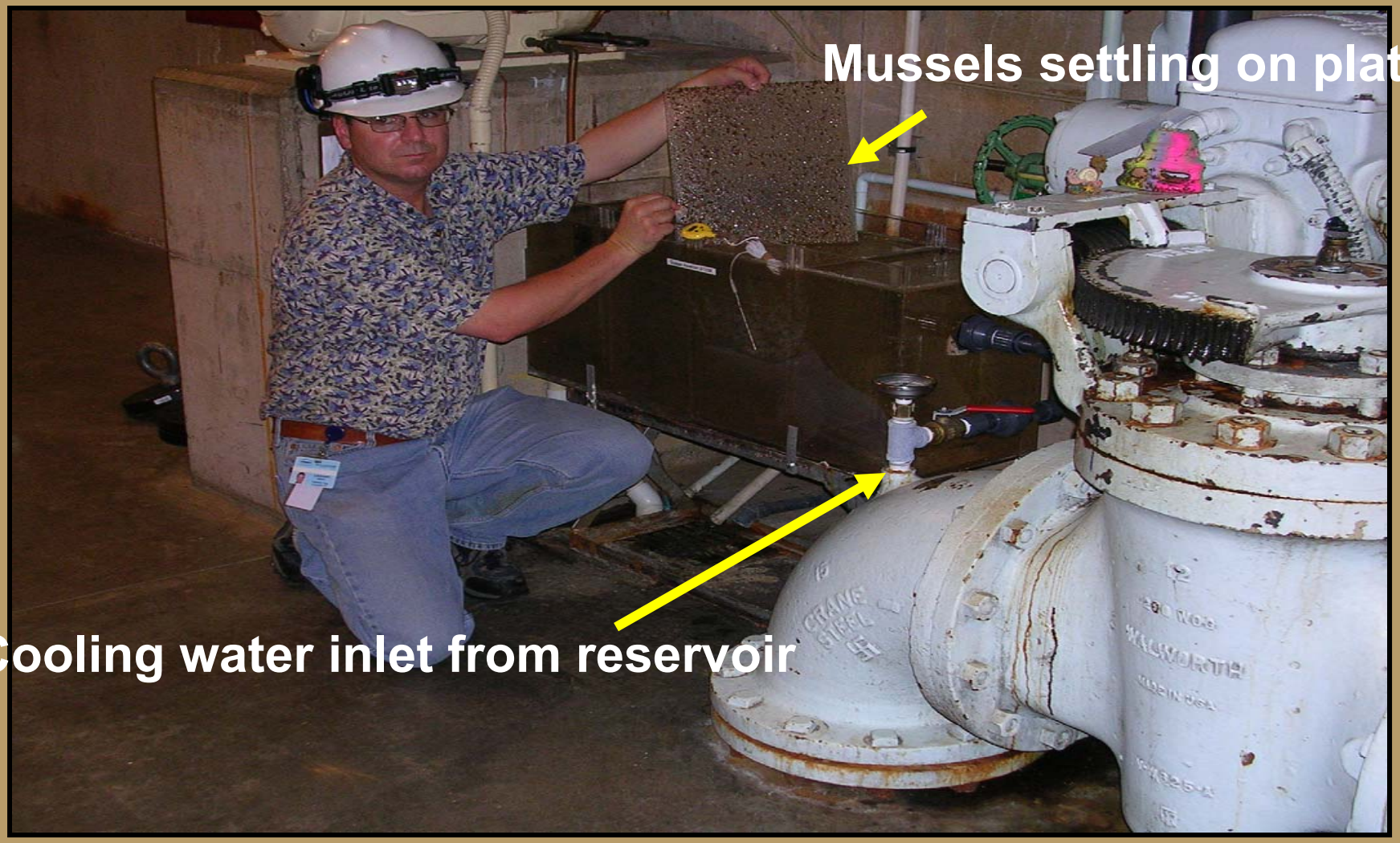
Installed Bio-Box Sampler for Monitoring



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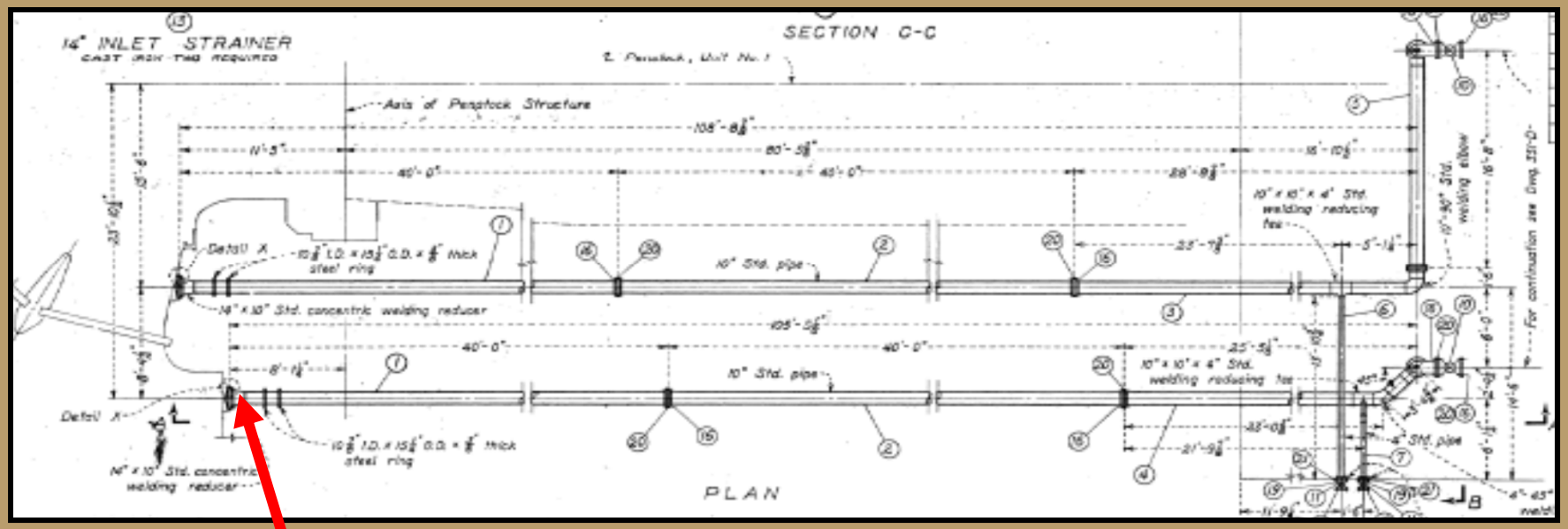
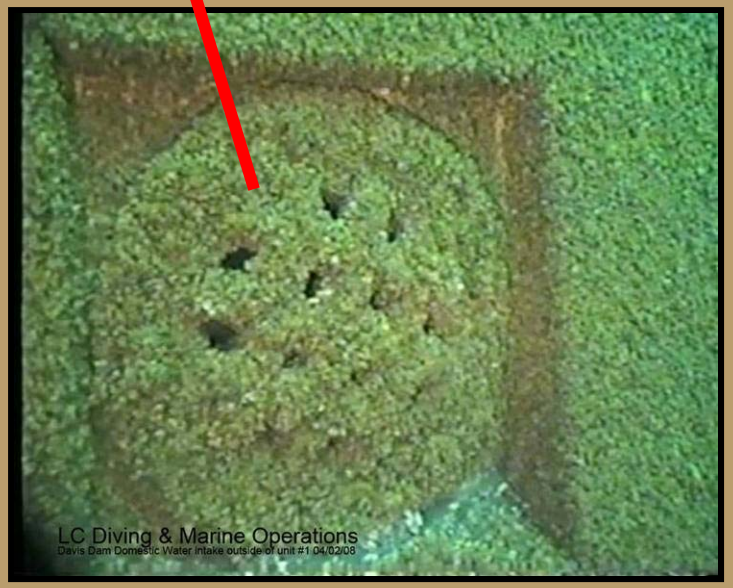
Domestic Water Intake – Davis Dam





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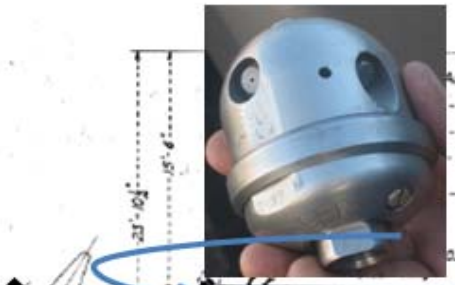
Domestic Water Lines – Davis Dam



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Water Jetting Equipment

Video

- **pre inspection**
- **water jetting**
- **post inspection**

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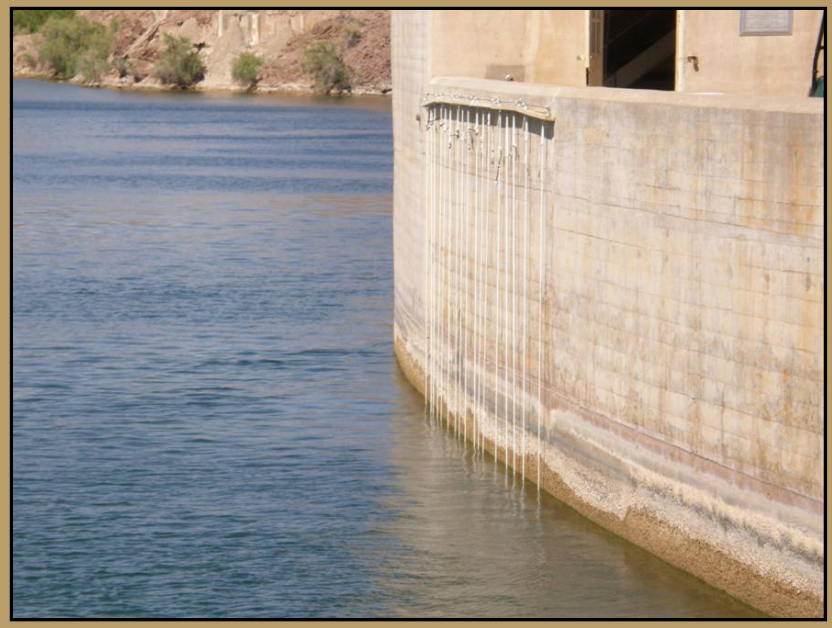
Coatings Panels Locations

RECLAMATION

Coatings Panels



3-month fouling rate

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International

Amercoat Sigmaglide

Silicone – 6 months

Silicone – 18 mo.

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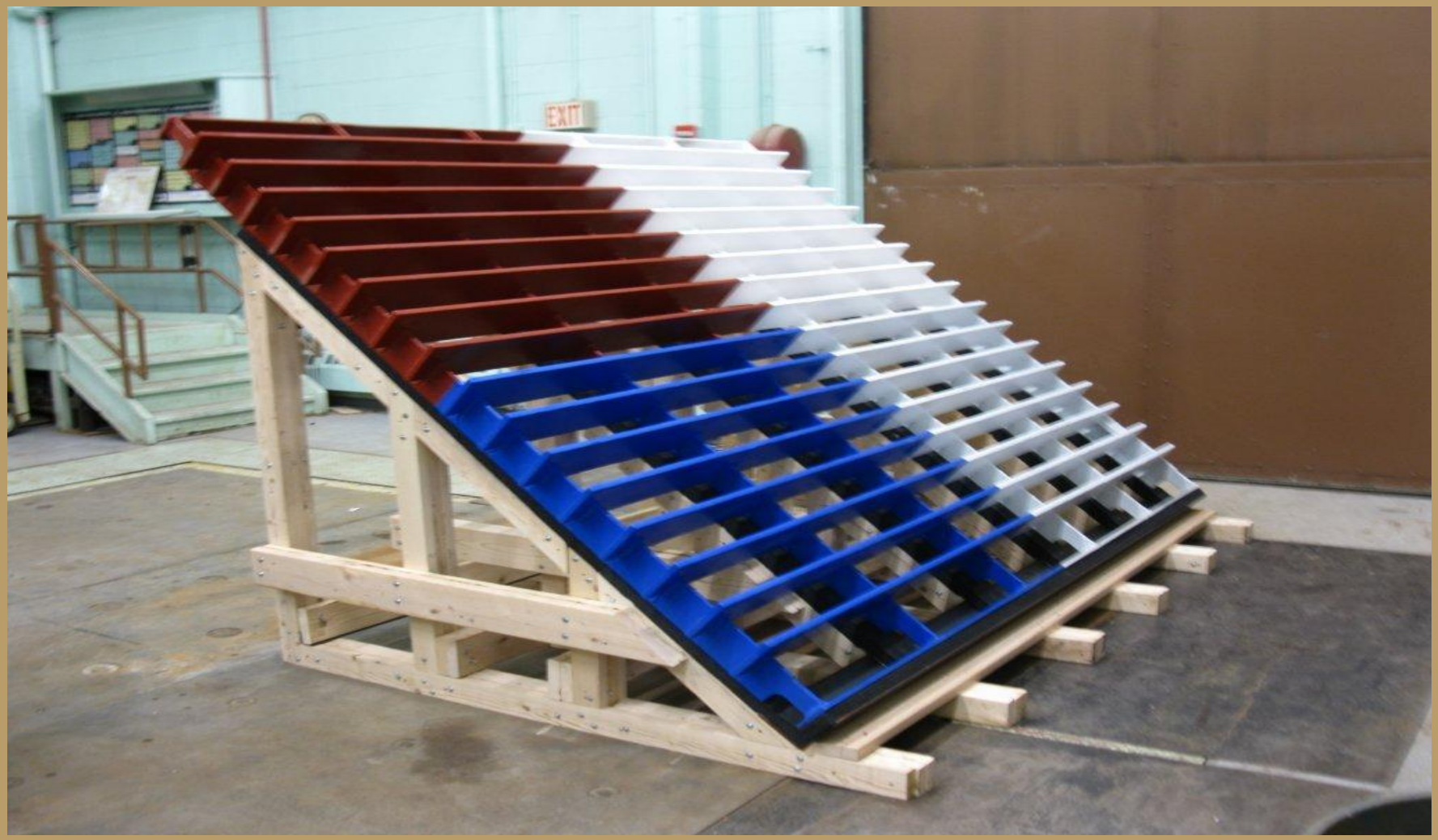
Parker Dam Trash Rake Coating Research Summer 2013



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Fish Screen Material (Cu- Ni Wedge Wire)

3-month fouling
Sep – Dec 2009

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Cooling Water Filter Options

40 & 80 micron filter cartridge inside of all housing

Parker Dam
Research Filter
2008 - $100K

Hoover's cooling water
$333K – 2010
(4 filters purchased for A2, N2, N1, & N8)

Hoover's SCADA Filters
$200K - 2010

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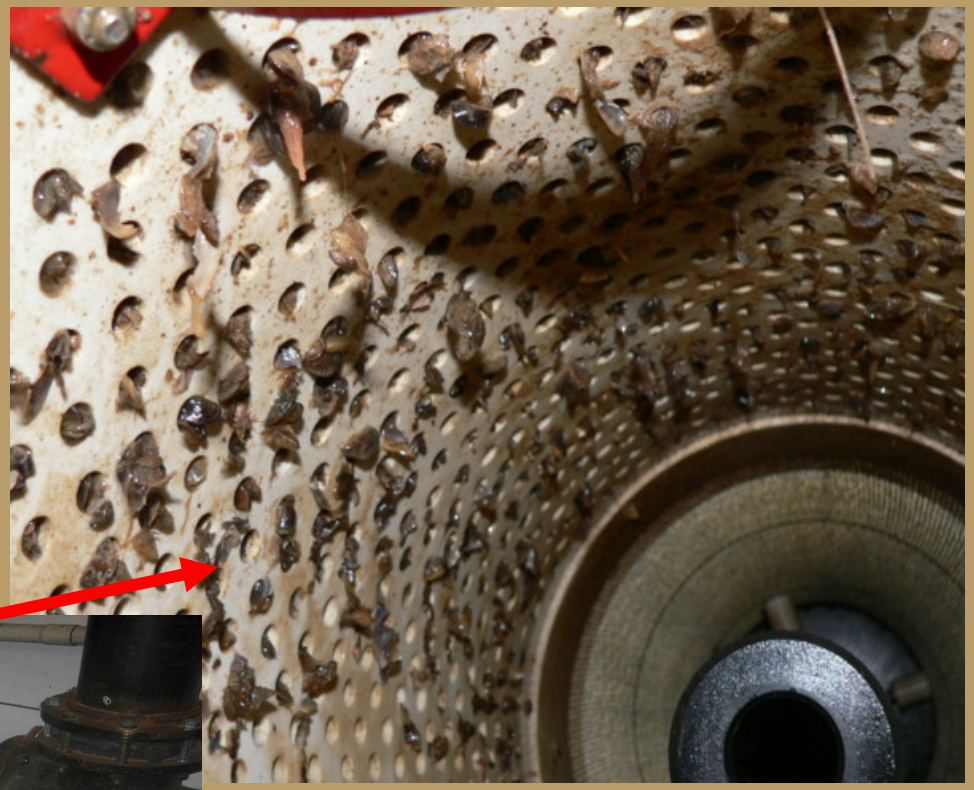
Self Cleaning Ballast Safe Filter



Pre-strainer (filter)

Filter Cartridge – 40 micron

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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

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Hoover Dam Cooling Water Mussel Control UV System – Aug 2010

1/8” strainers prior to UV unit

Total Cost: $116K

UV Unit, Pump, & Piping: $70K

Installation: $46K

10” cooling water line 1250 gpm @ 150 psi

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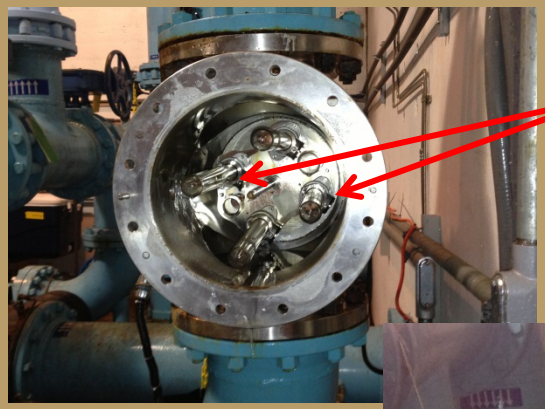
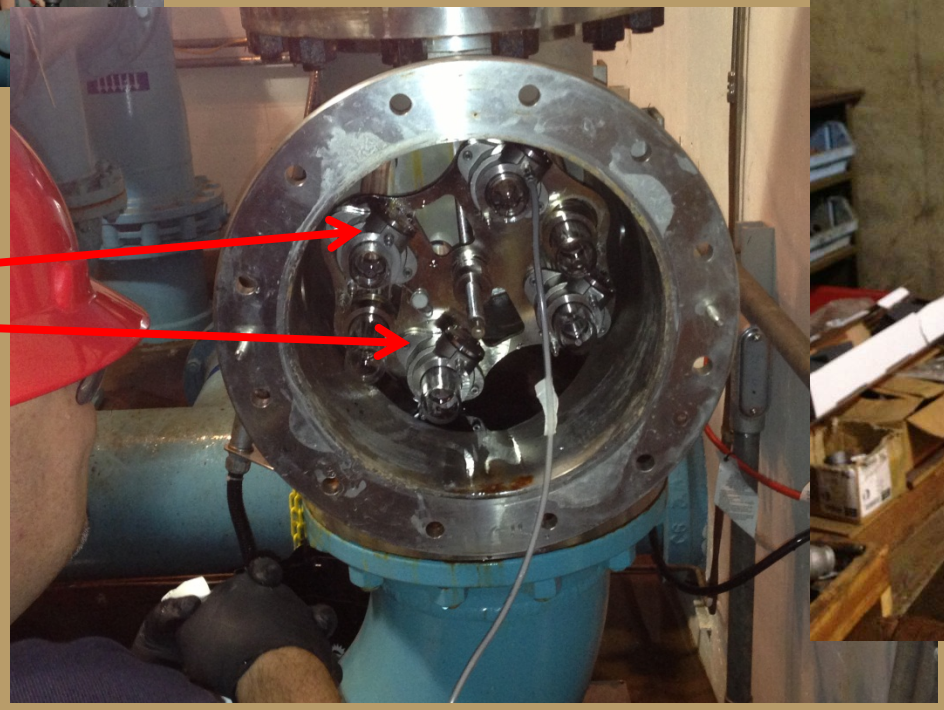
Hoover Dam Cooling Water Mussel Control UV System (research)



4 Lamps

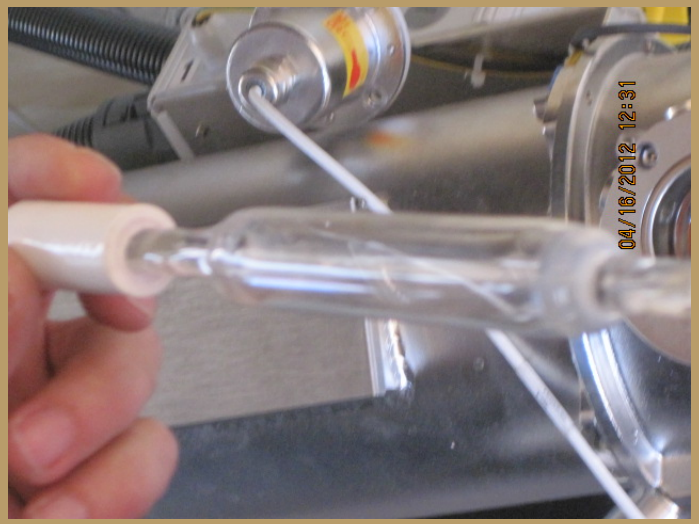


Cleaning Gel storage for wiper system

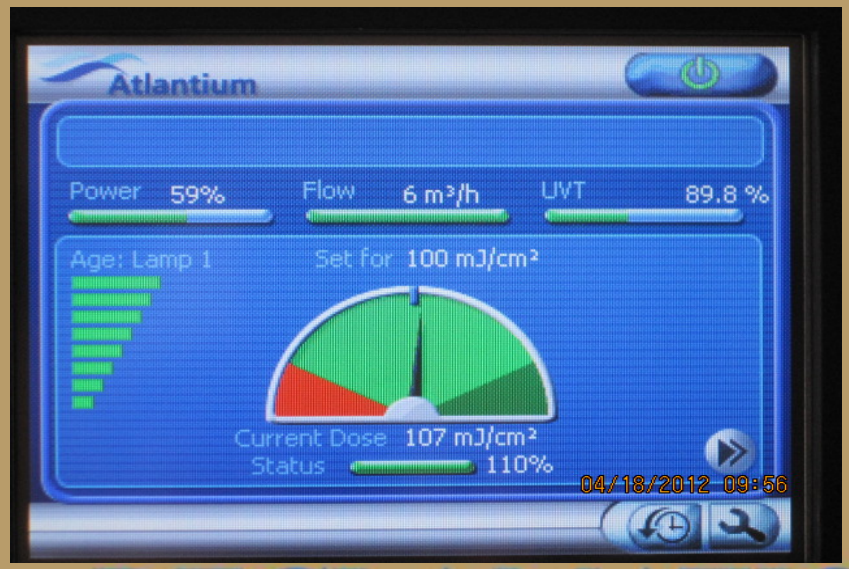
RECLAMATION

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



Renata Claudi (RNT Consulting)

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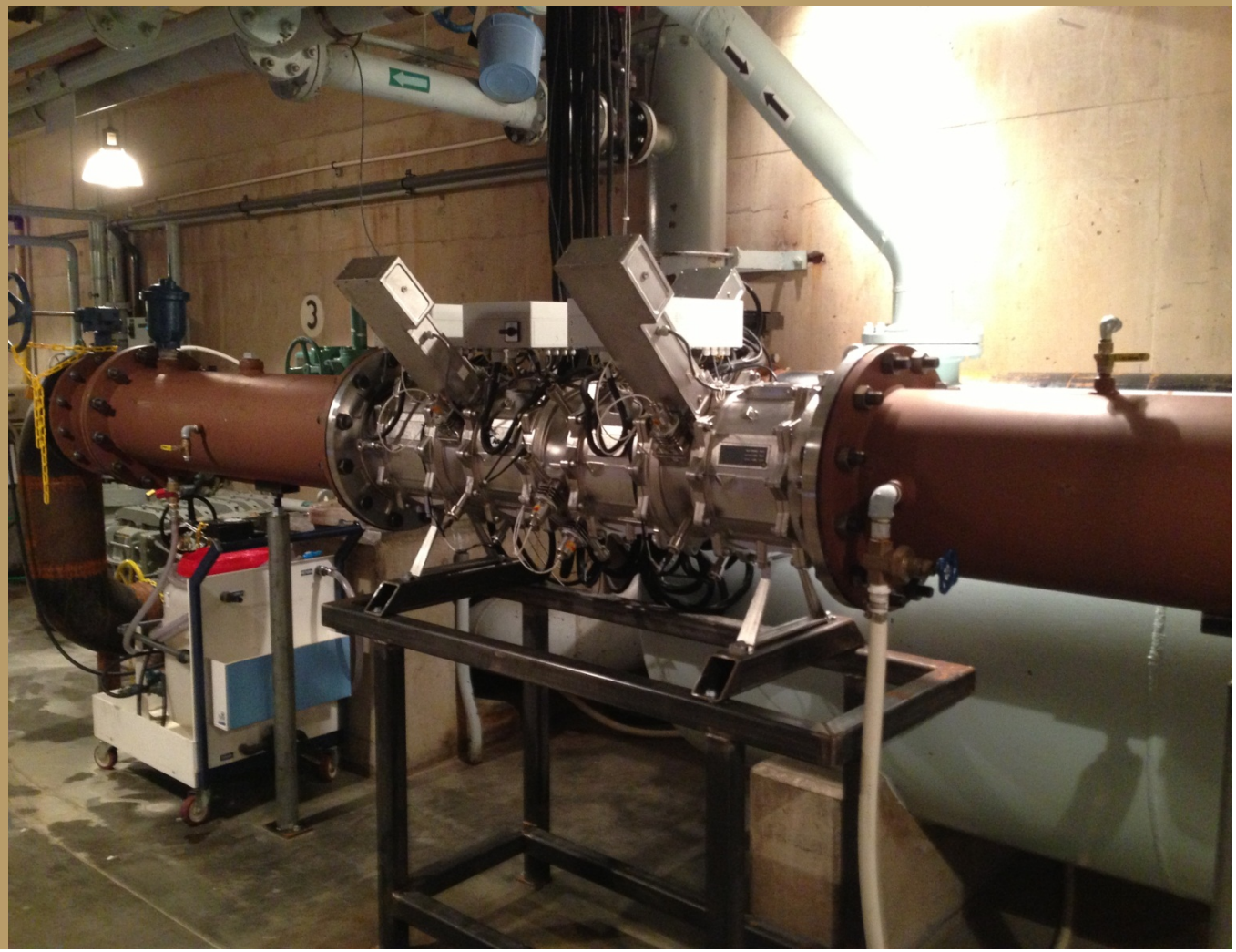
Power Plant Mussel Control System
Atlantium (HOD) UV Light System

UV Cooling Water System installed July 2013 on a 4000 GPM system



ZEQUANOX™

Invasive Mussel Control

Marrone Bio Innovations and Bureau of Reclamation work at Davis Dam, AZ

By Marrone Bio Innovations

Emerging Options - Zequanox
Pseudomonas flourescens (PF)

Photo courtesy of Las Vegas Sun Newspaper

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

RECLAMATION

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.

Healthy gut

Treated gut

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Zequanox Trials Davis Dam – Mar 2009

RECLAMATION

Zequanox Results for Adult Treatment Bio-Box Trials Davis Dam - Mar 2009

Trial Week and Water Temperature (degree C)	Dose (mg/L)	Percent Mortality (%)	Std. dev. (+/- %)	Mortality Check (day)
March 23, 2009 14 deg. C	100	**87**	3	34
	50	**84**	2	33
	75	**82**	5	32
	25	**75**	6	32

Information provided by Marrone Bio-Innovations

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Zequanox Davis Dam June 2011 Cooling Water System

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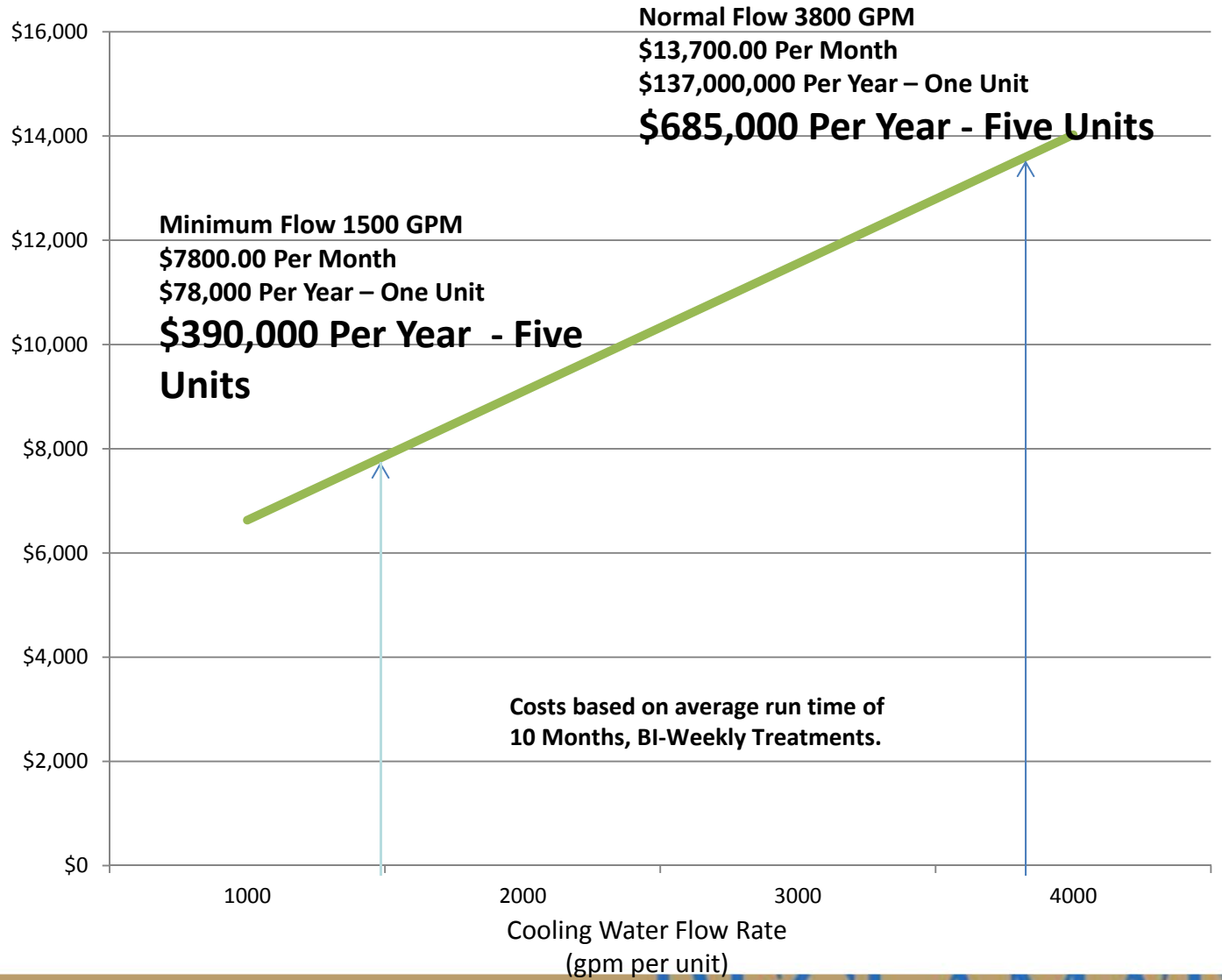
Zequanox Accomplishments at Davis Dam

- 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)



RECLAMATION

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 sucker 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*) †

OTHERS

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

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 (*Actinonaias ligamentina*) †
Freshwater Mussel - Paper Pond Shell (*Utterbackia imbecillis*) †
Freshwater Mussel - Plain Pocketbook (*Lampsilis cardium*) †
Freshwater Mussel - Washboard (*Megalonaias nervosa*)
Freshwater Snail (*Lymnaea peregra*)

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

RECLAMATION

Zequanox 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

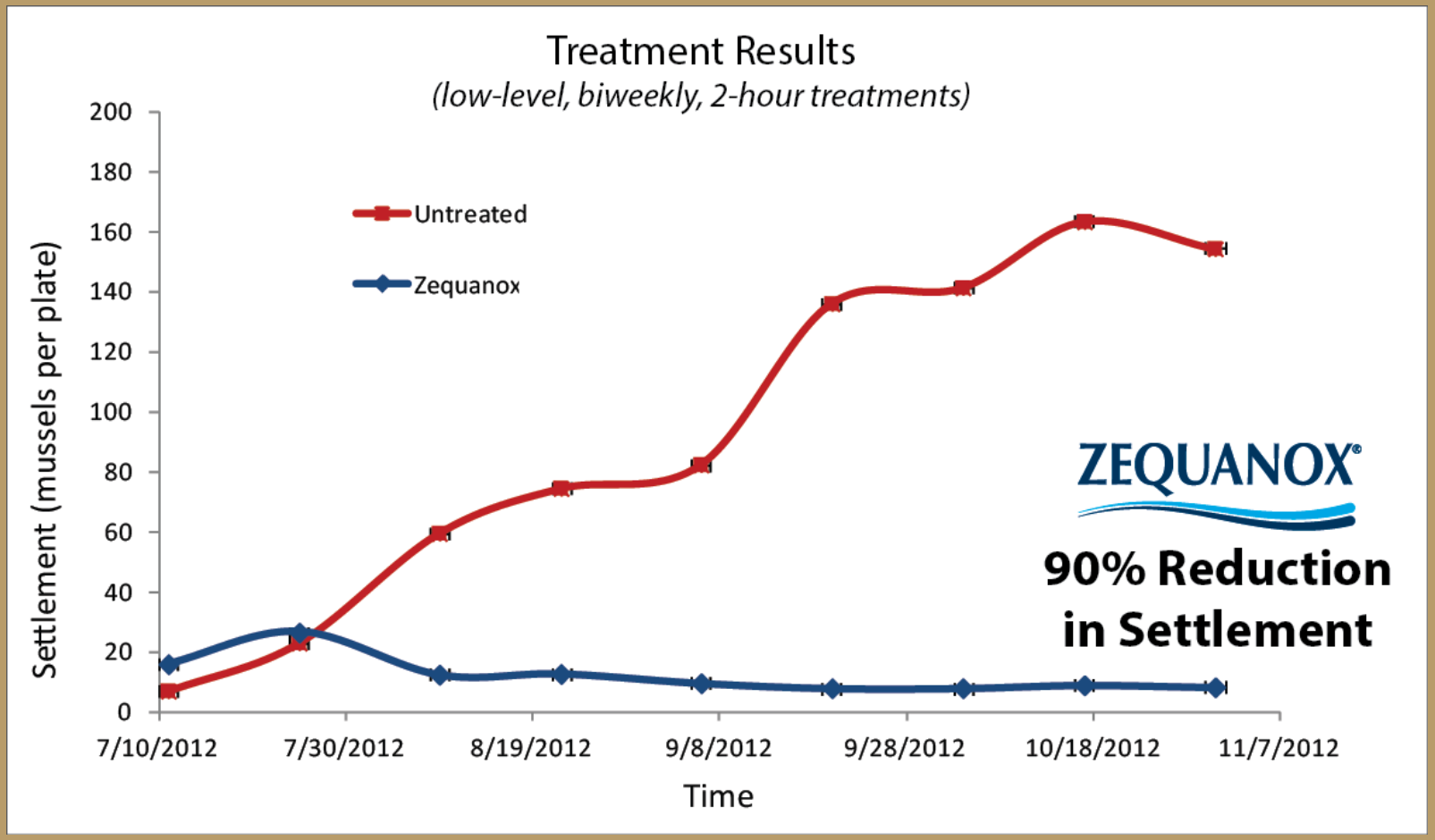
Goal is to limit the number of mussels that exceed 4 mm in size (adult sized)

Ideal for sensitive systems and equipment

Treatments are performed every other week throughout the settlement season

RECLAMATION

Bi-Weekly Regimen Reduces Settlement by 90%



RECLAMATION

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

RECLAMATION

Turbulence Study – April 2013

RECLAMATION

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.

RECLAMATION

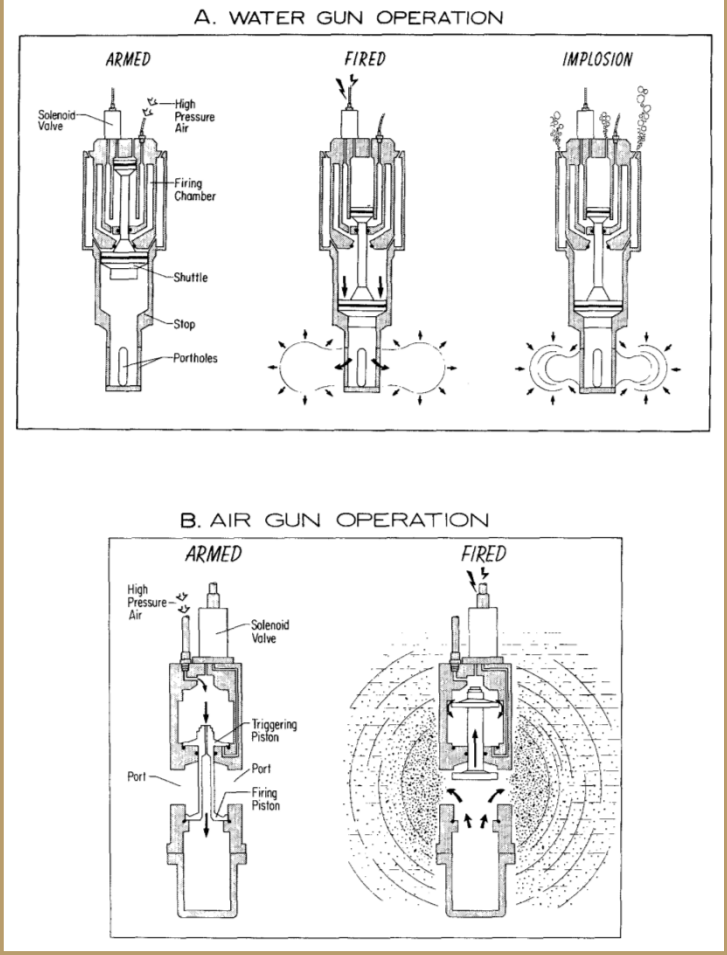
pH up evaluation

RNT Consulting pH evaluation for Reclamation

Precipitate observed after 24 hours at pH 9.3

RECLAMATION

FUTURE-Pulse-pressure evaluations for invasive quagga mussel control



RECLAMATION

QUESTIONS

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RECLAMATION