Quagga Mussel Monitoring & Control

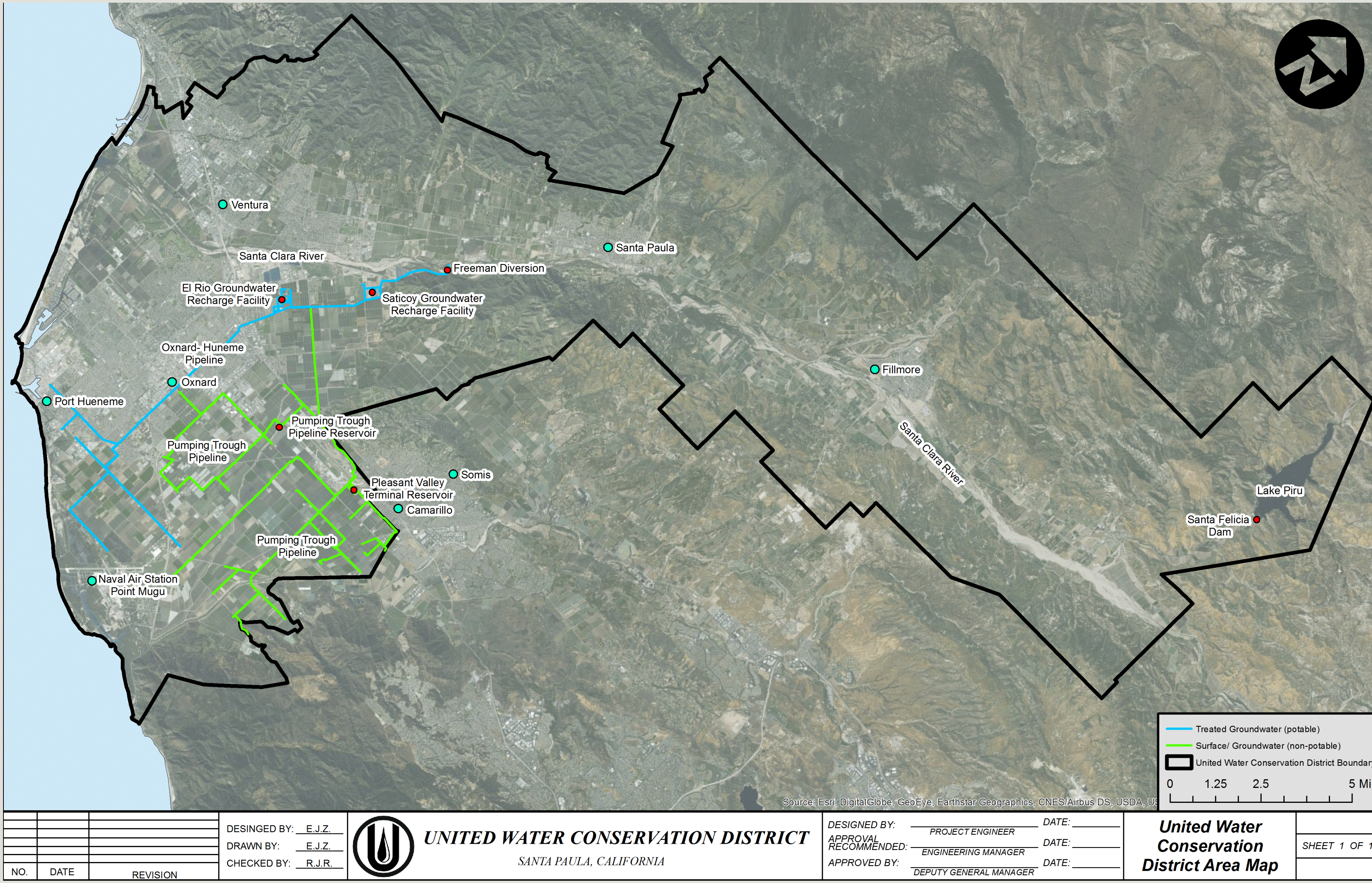
Lake Piru, Piru Creek, Santa Clara River

July 14, 2017

Purpose and Intent of Meeting

Provide an update on United's monitoring, containment, and control efforts and identify next steps and paths forward

United Water Conservation District



2. Monitoring and Infestation Delineation Update

Fish and Game Code §2301(d)(1)

Requirement A – Methods for delineation of infestation, including both adult quagga mussels and veligers

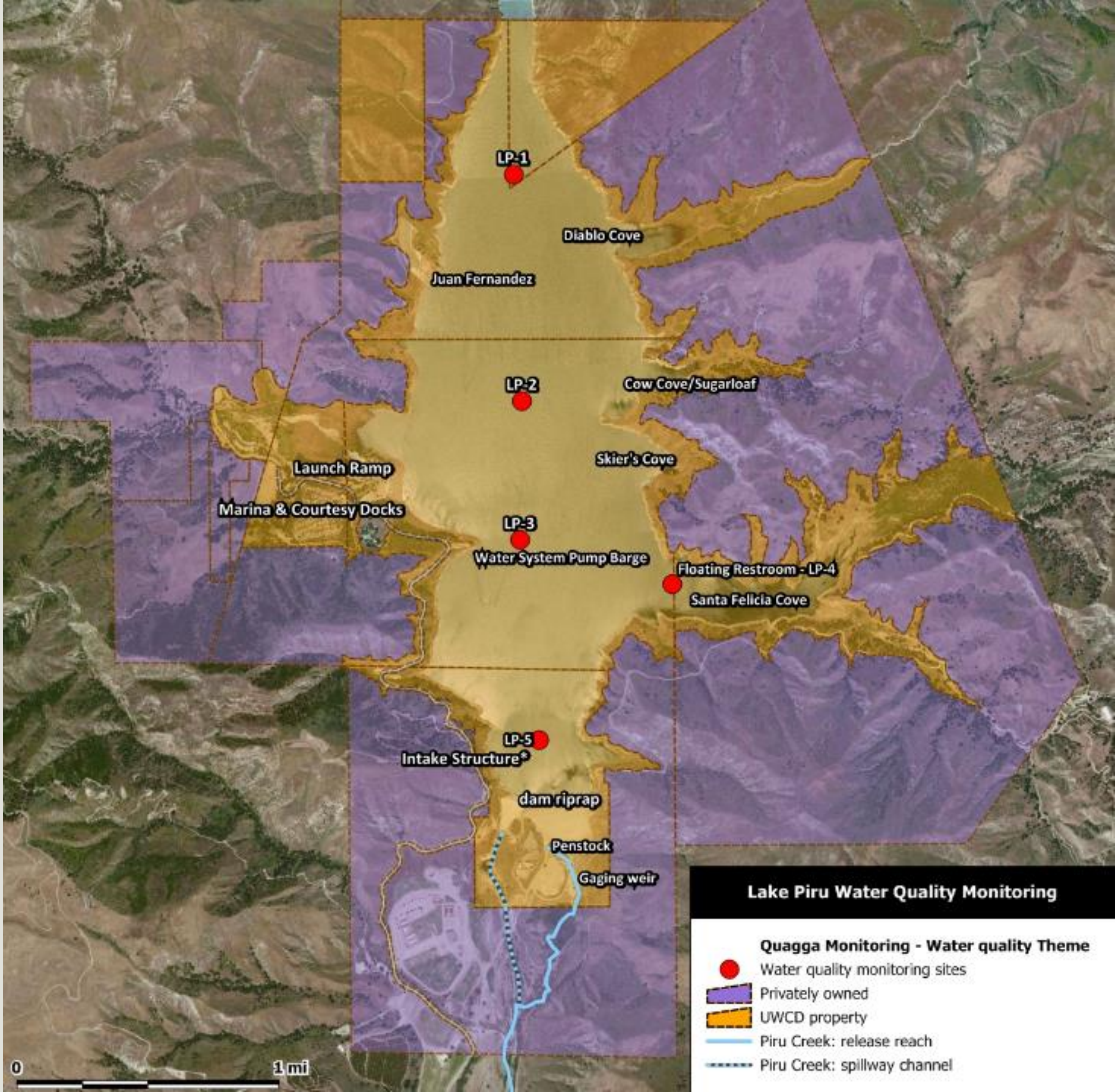
Requirement B – Methods for control or eradication of adult quagga mussels and decontamination of water containing larval mussels

Requirement C – A systematic monitoring program to determine any changes in conditions

2. Monitoring and Infestation Delineation Update

- Water quality
- Mussel recruitment in Lake Piru and downstream
- Spread of mussels since infestation
- Observed veliger dispersal
- Downstream considerations
- What are these results telling us?

2. Water Quality



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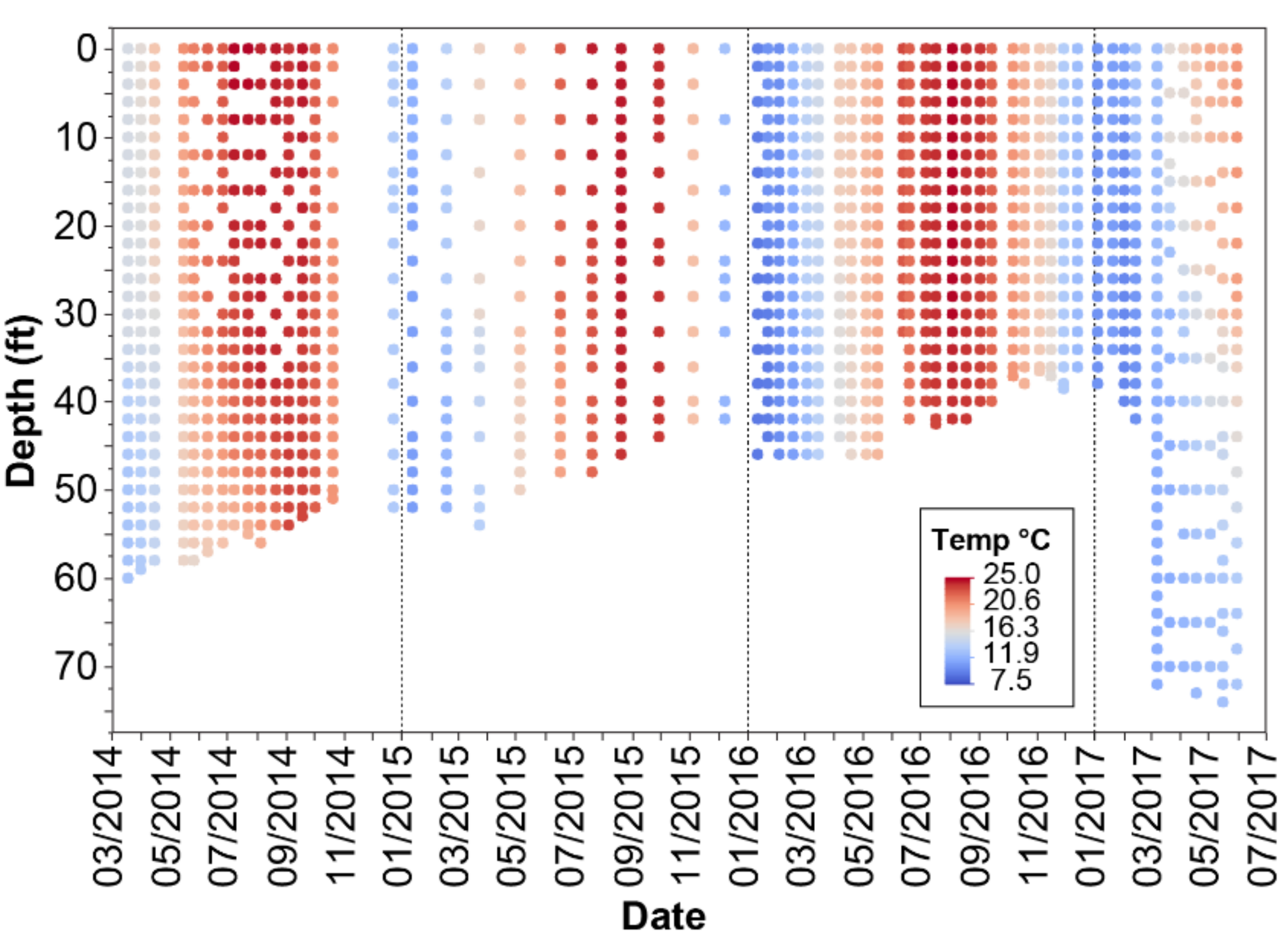

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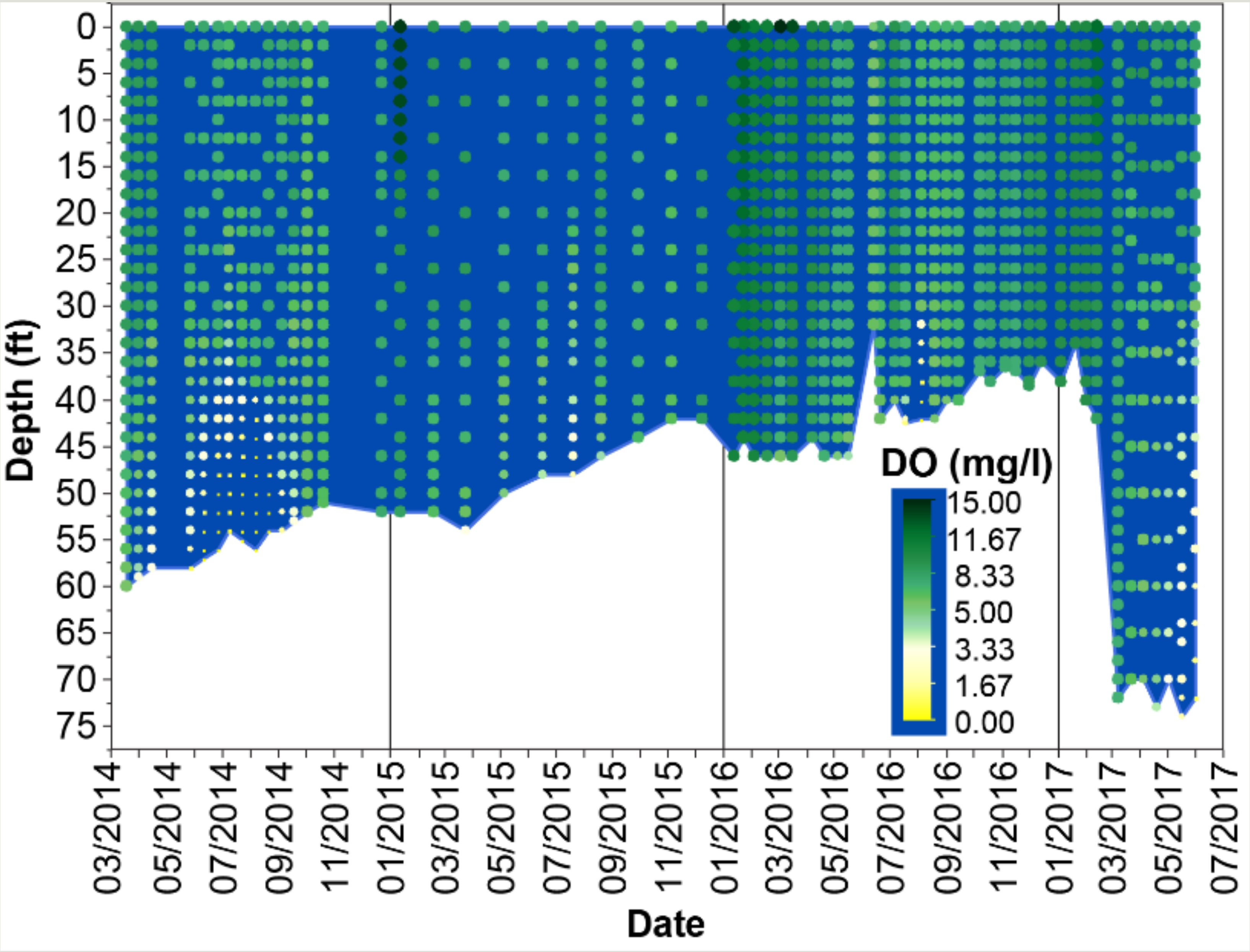
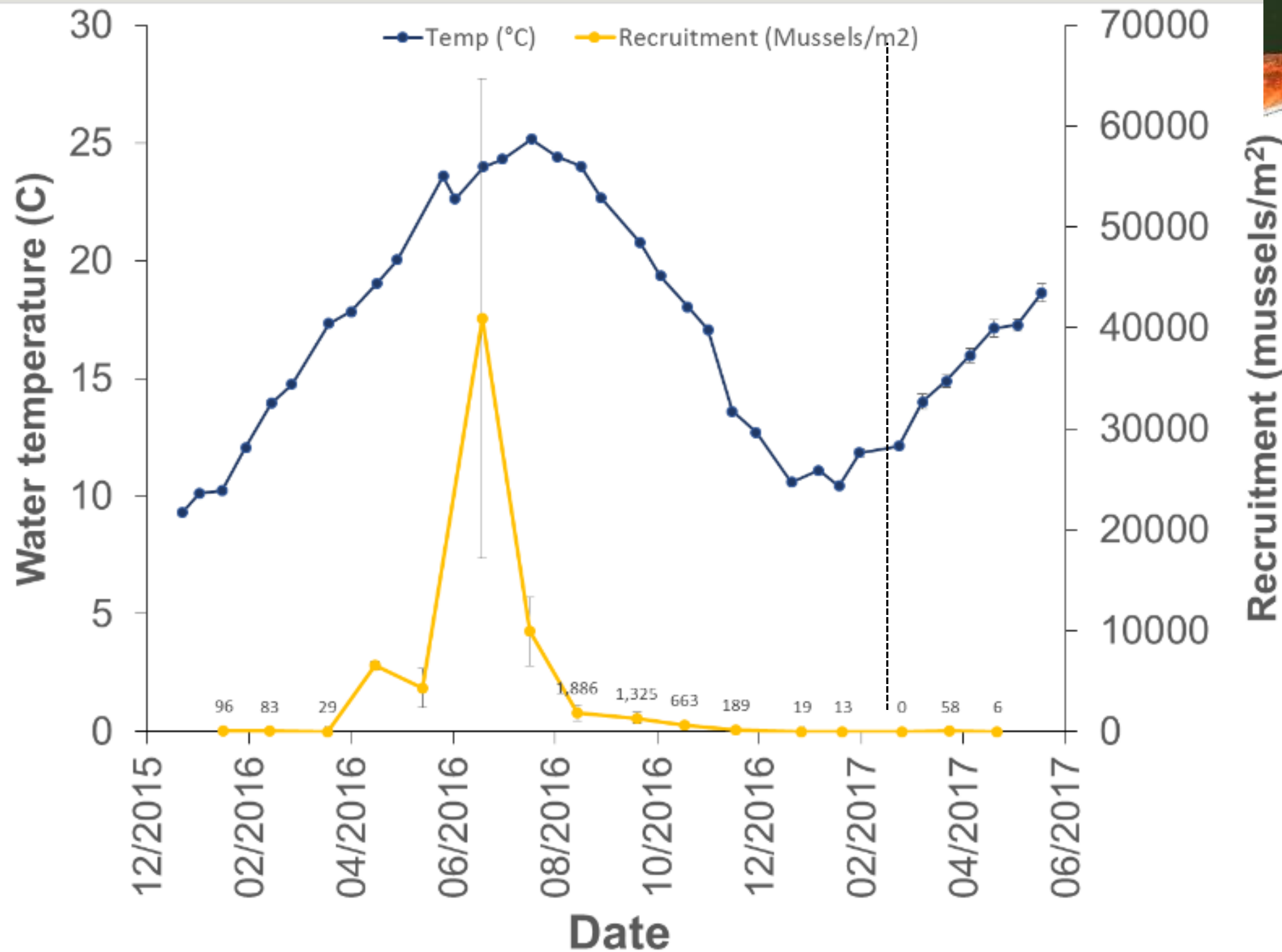
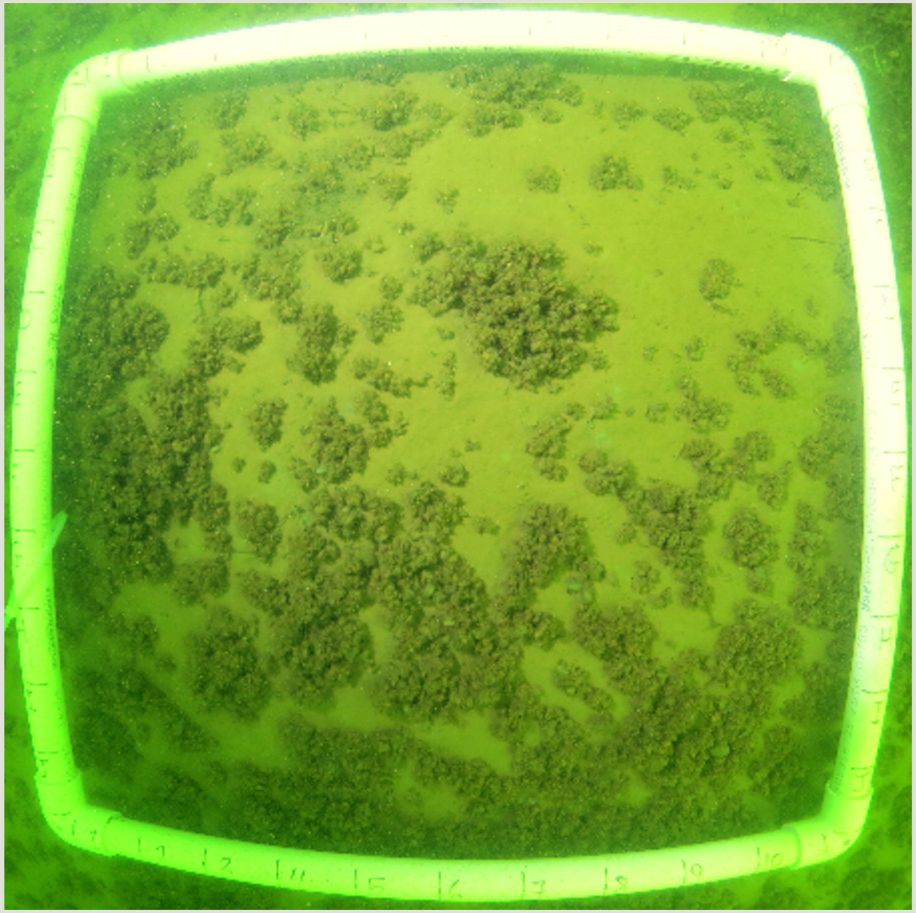


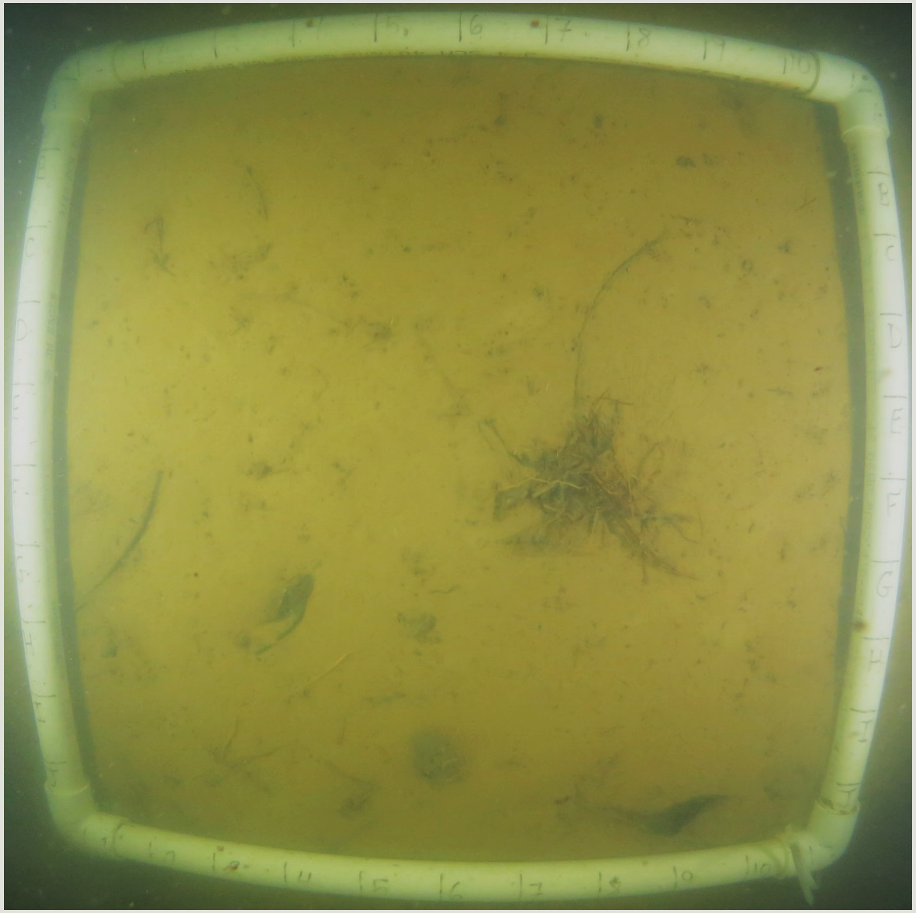
2. Mussel Recruitment in Lake Piru



2. Mussel Recruitment in Lake Piru
Reduction in mussel coverage on soft sediment

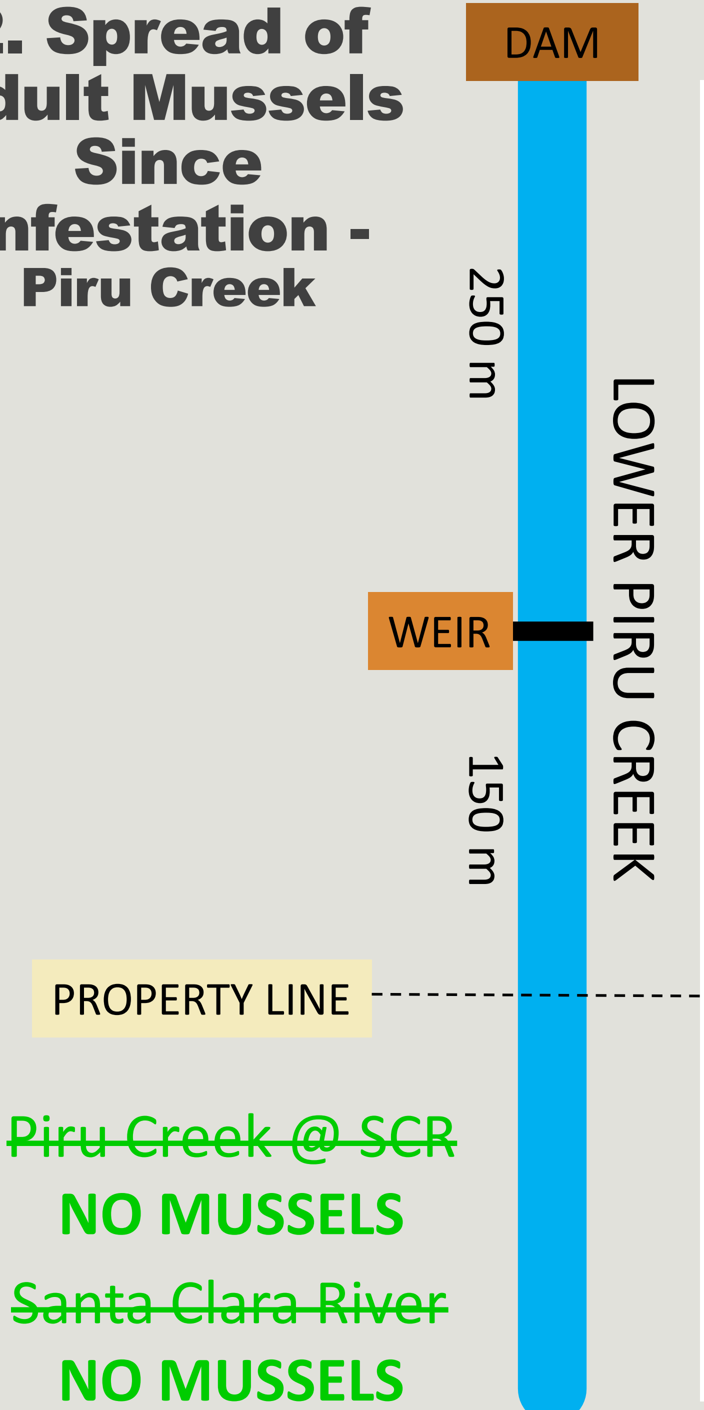


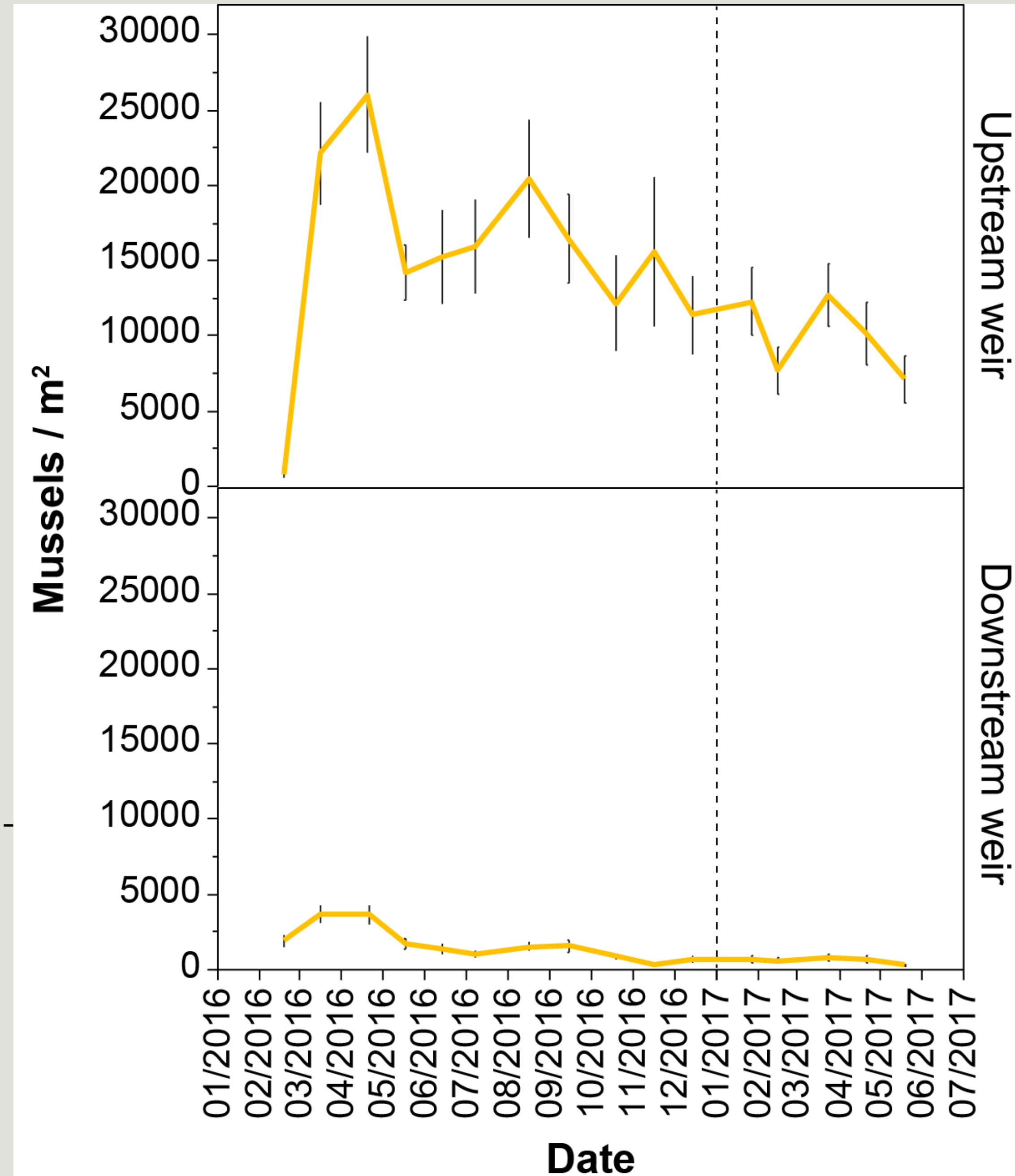
September 2016



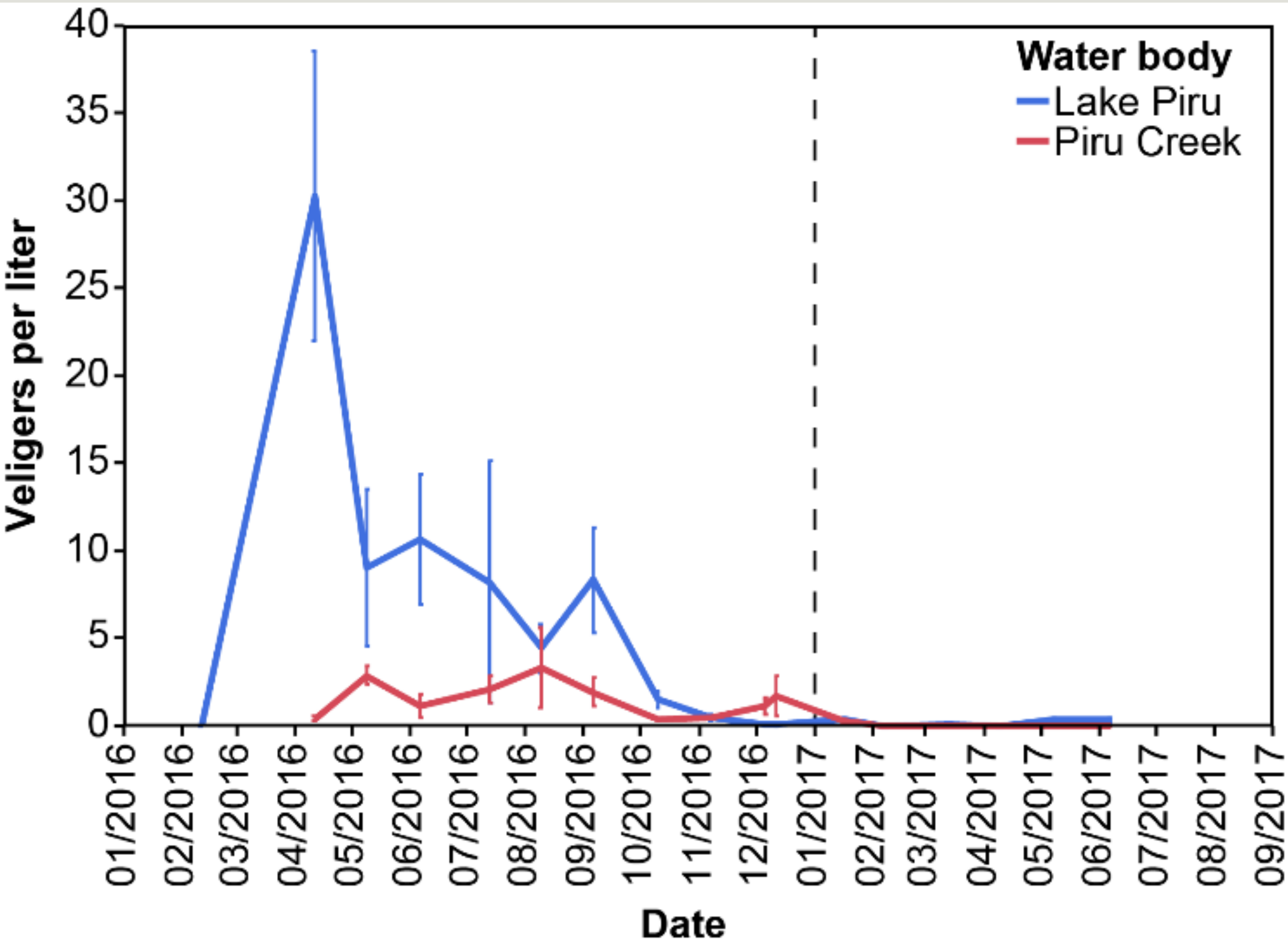
March 2017

2. Spread of Adult Mussels Since Infestation - Piru Creek





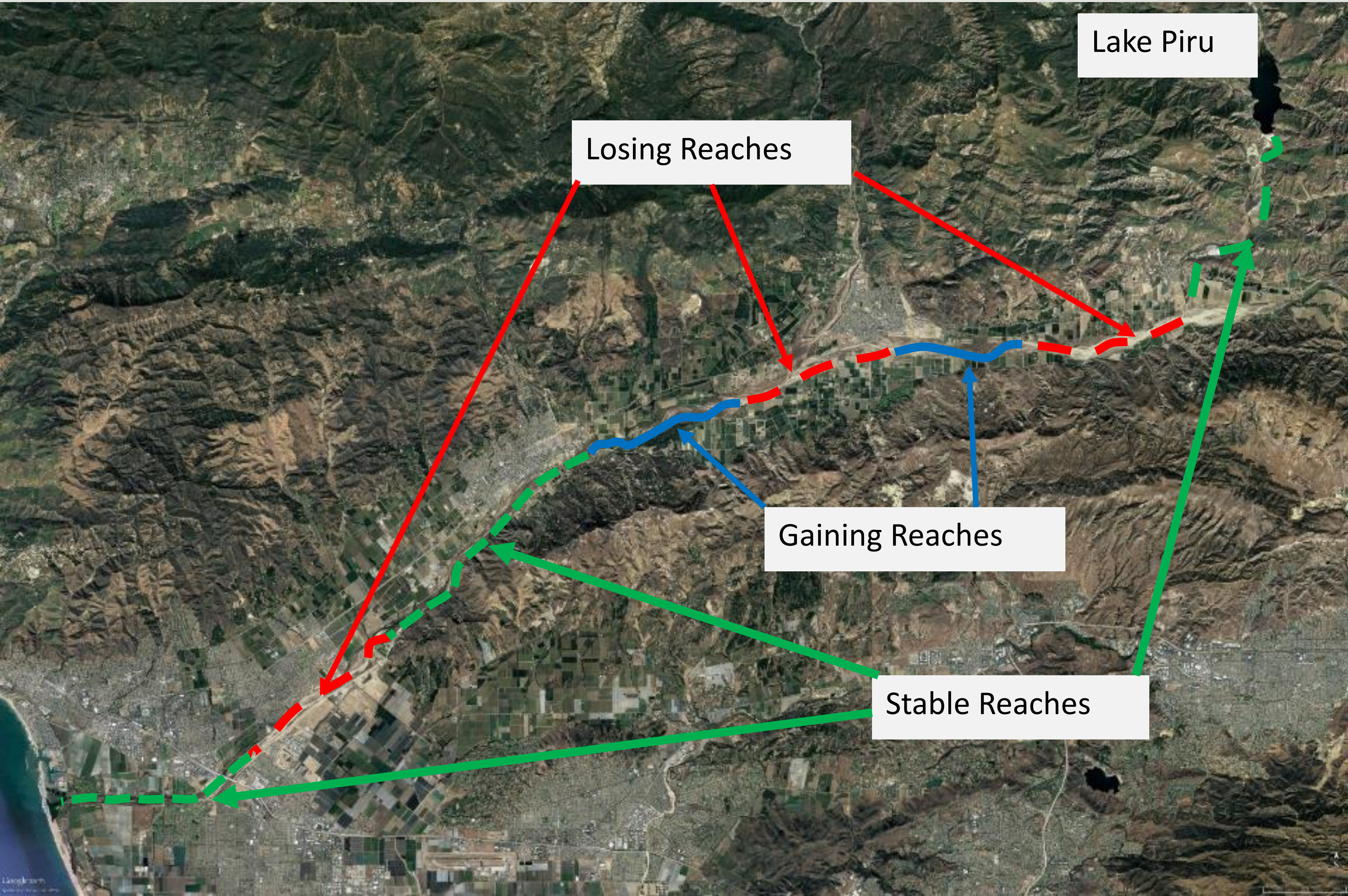
2. Observed Veliger Dispersal



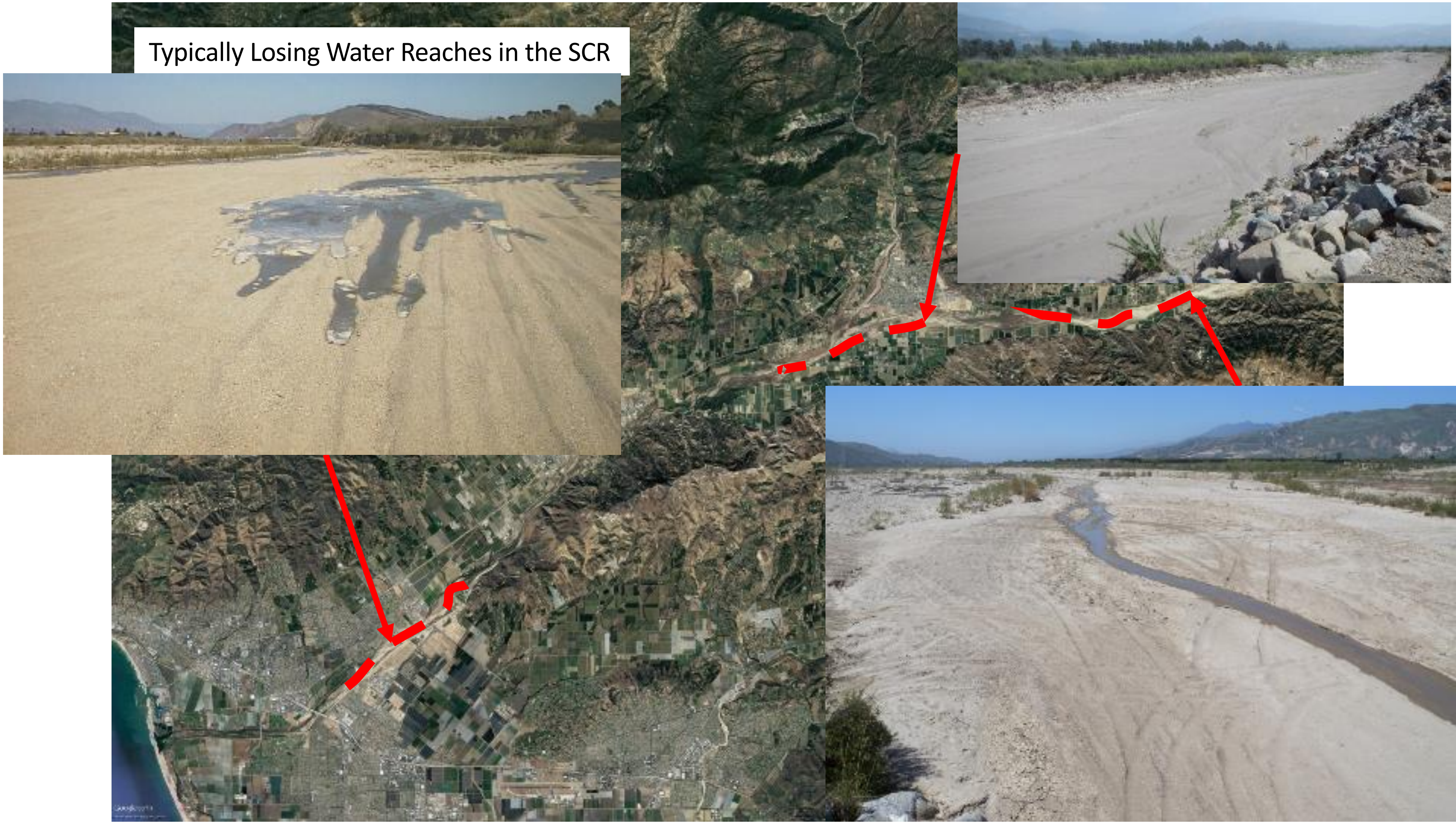
~~Piru Creek @ SCR~~
NO VELIGERS
~~Santa Clara River~~
NO VELIGERS

2. Spread of Mussels since Infestation - Adult Quagga Mussel Surveys

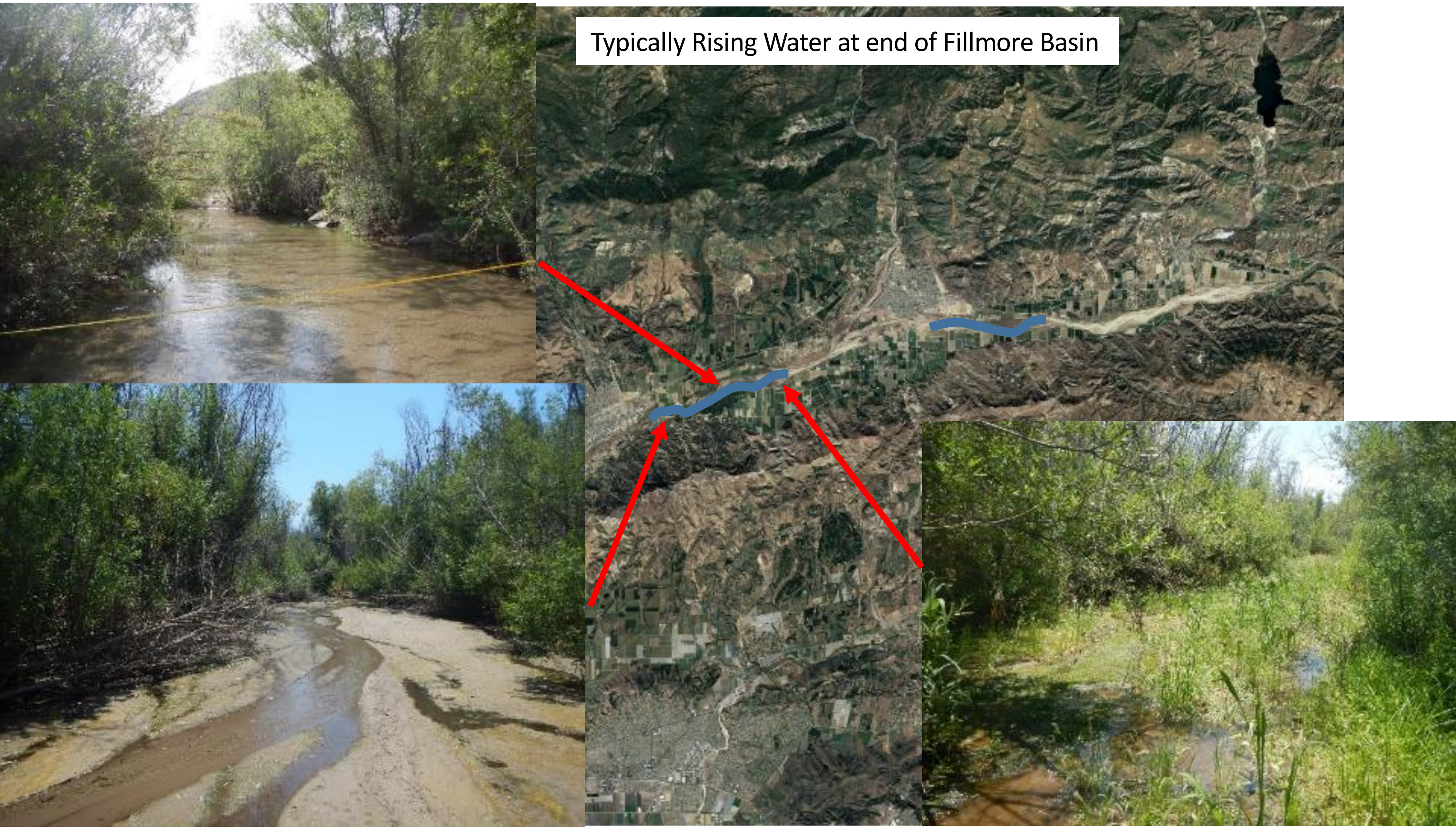
2. Downstream Considerations – Santa Clara River Hydrology

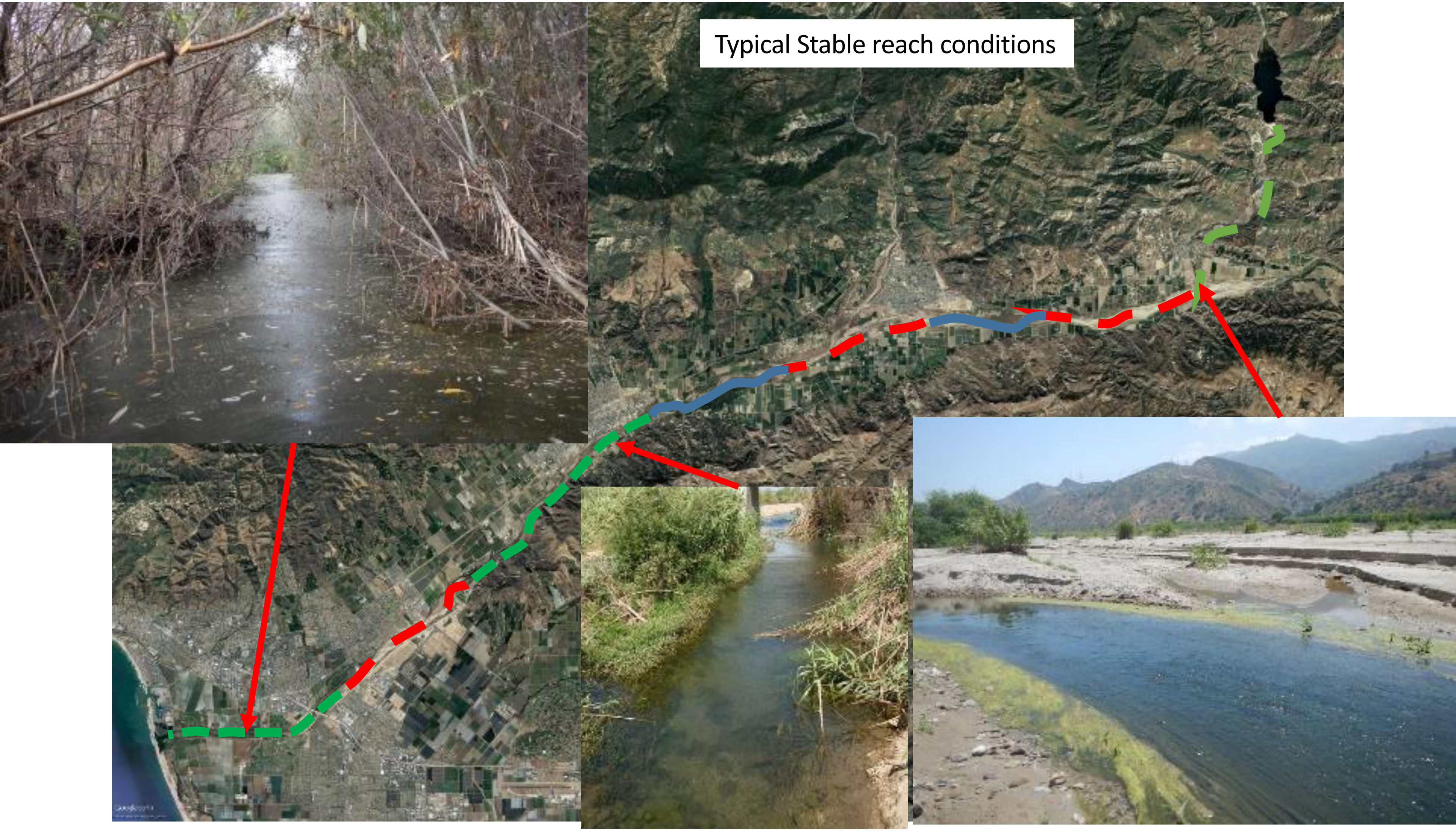


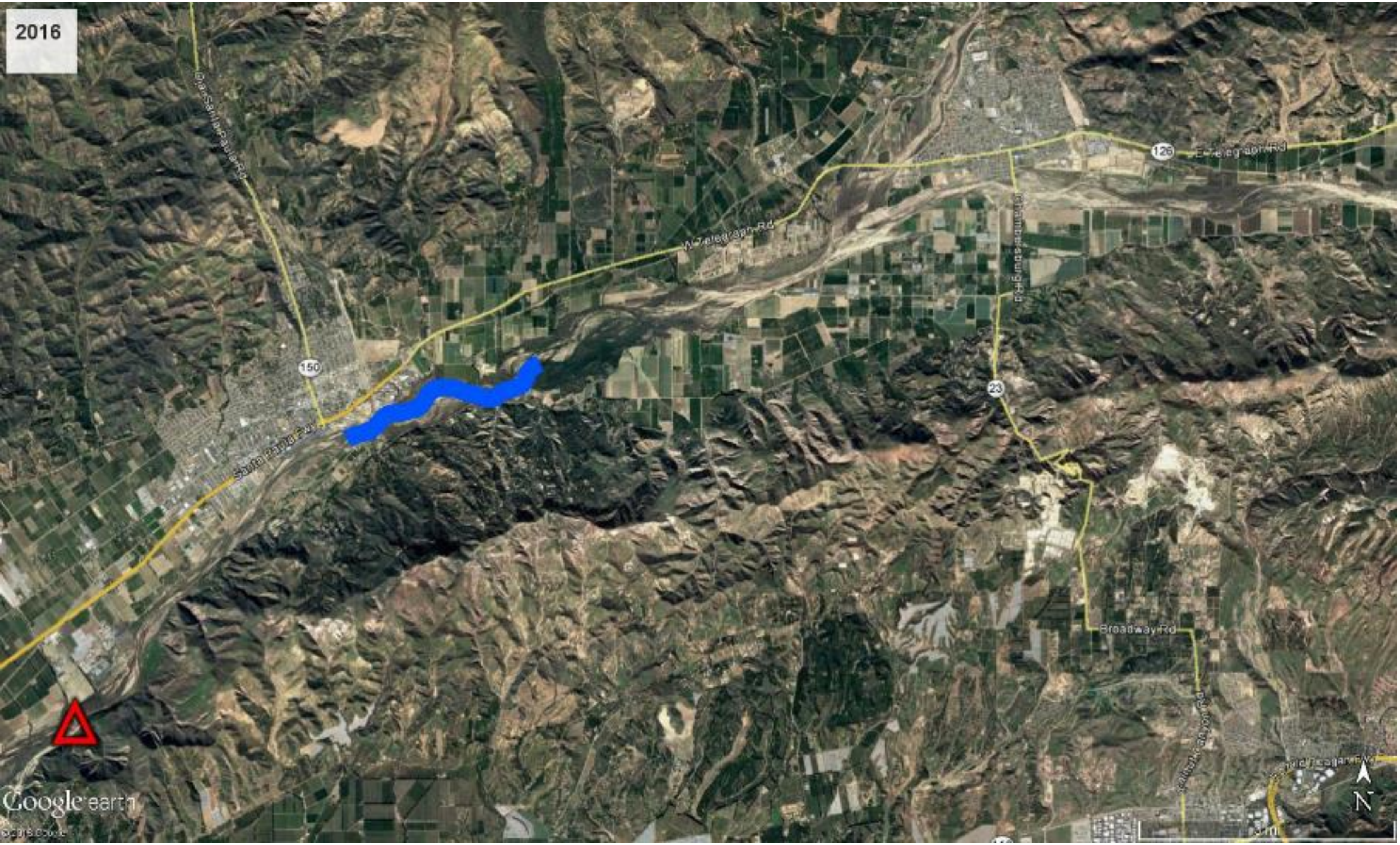
Typically Losing Water Reaches in the SCR



Rising Water below the Piru Basin in the SCR


Typically Rising Water at end of Fillmore Basin


Typical Stable reach conditions



2016
150
Santa Paula Fwy
W Telegraph Rd
126
E Telegraph Rd
23
Broadway Rd
Google earth
N

2. Downstream Considerations- High Volume Releases

- **77 cfs release in December 2016**

Release state water to Piru Basin only and test the recommissioned hydroelectric Turbine Unit 1

- **200 cfs release in January 2017**

Migration release for southern California steelhead triggered under United's FERC license, Water Release Plan

NOTE - NMFS ***did not*** *concur that suspending migration releases in 2017 was not likely to adversely affect southern California steelhead*

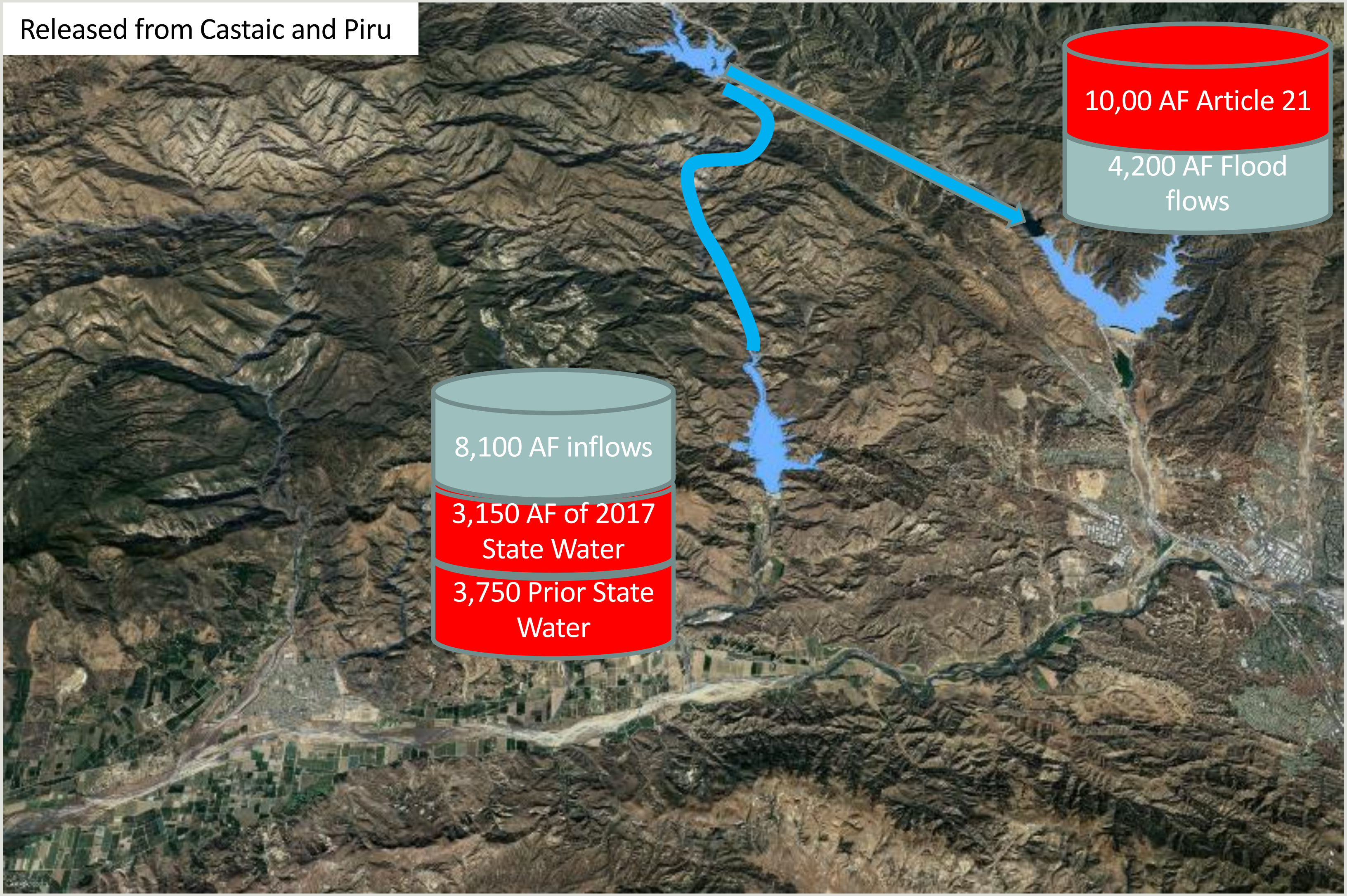
- **500 cfs release in June 2017**

Release SWP Table A and Article 21 water to combat unsafe levels of nitrates in the Oxnard Forebay Groundwater Basin that provides drinking water supplies to the Oxnard Plain region (~250,000 population)

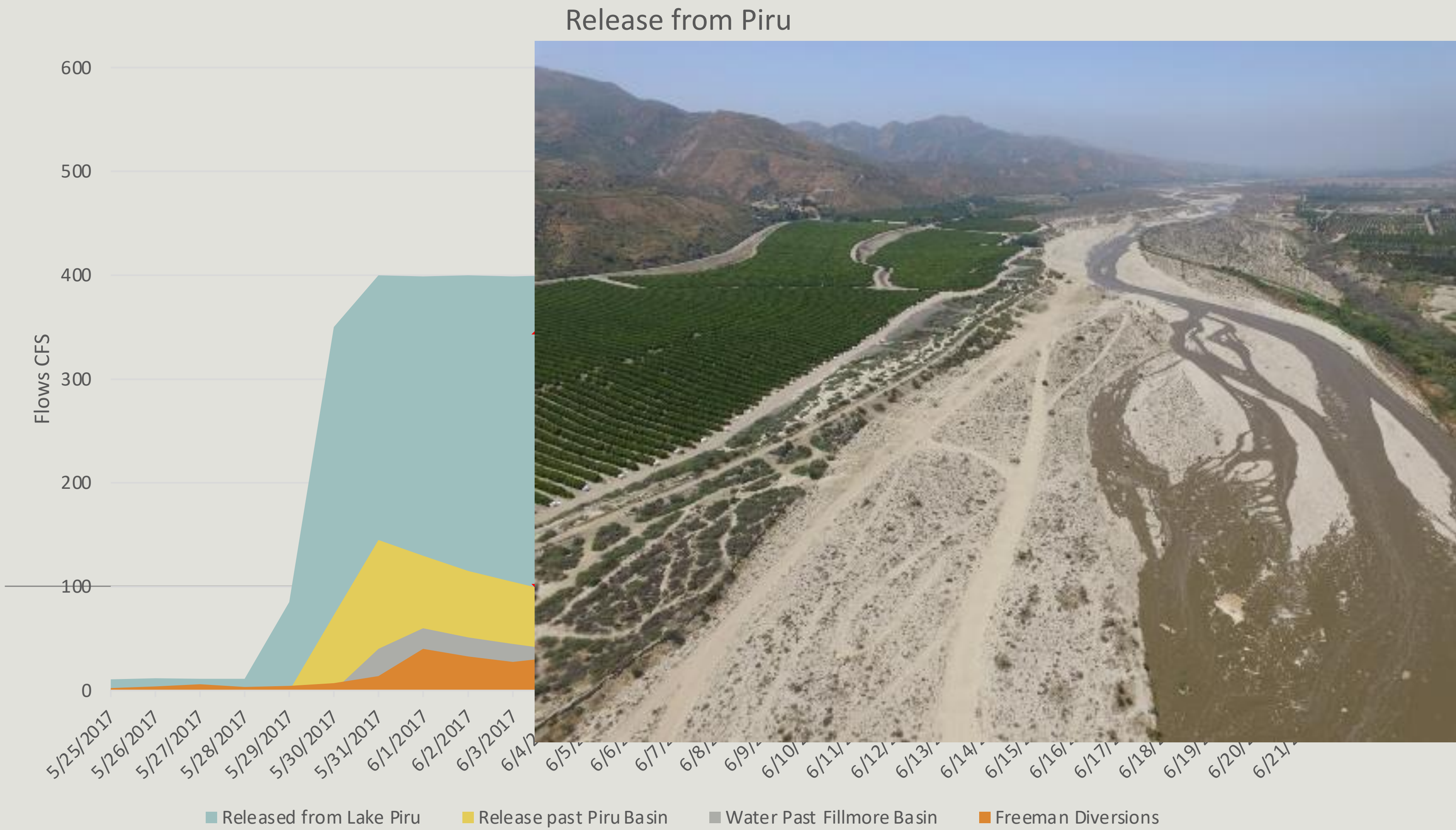
2. Downstream Considerations – High Volume Releases

2017 Dual Release from Lake Piru and Castaic Lake

2. Downstream Considerations – High Volume Releases

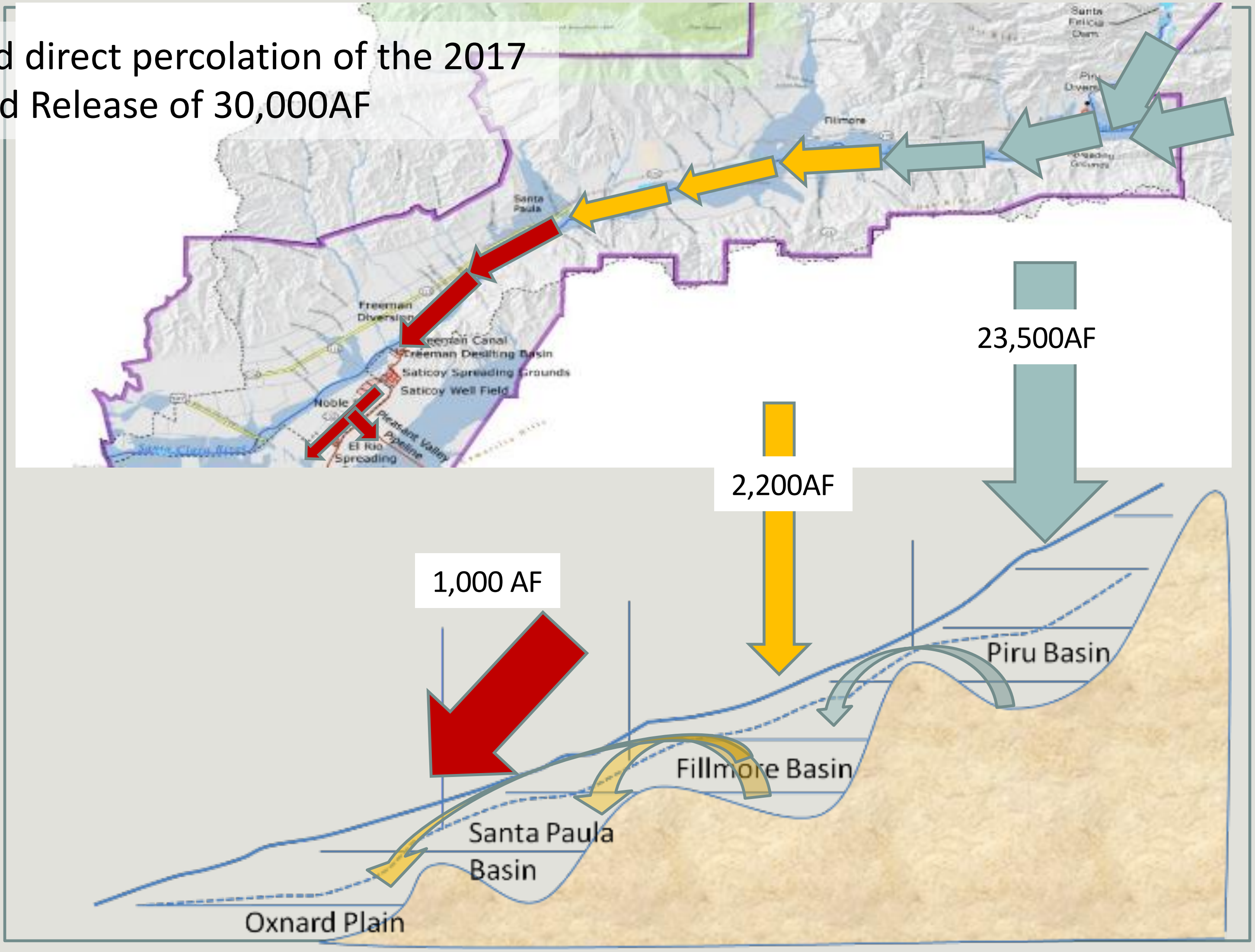


2. Downstream Considerations – High Volume Releases

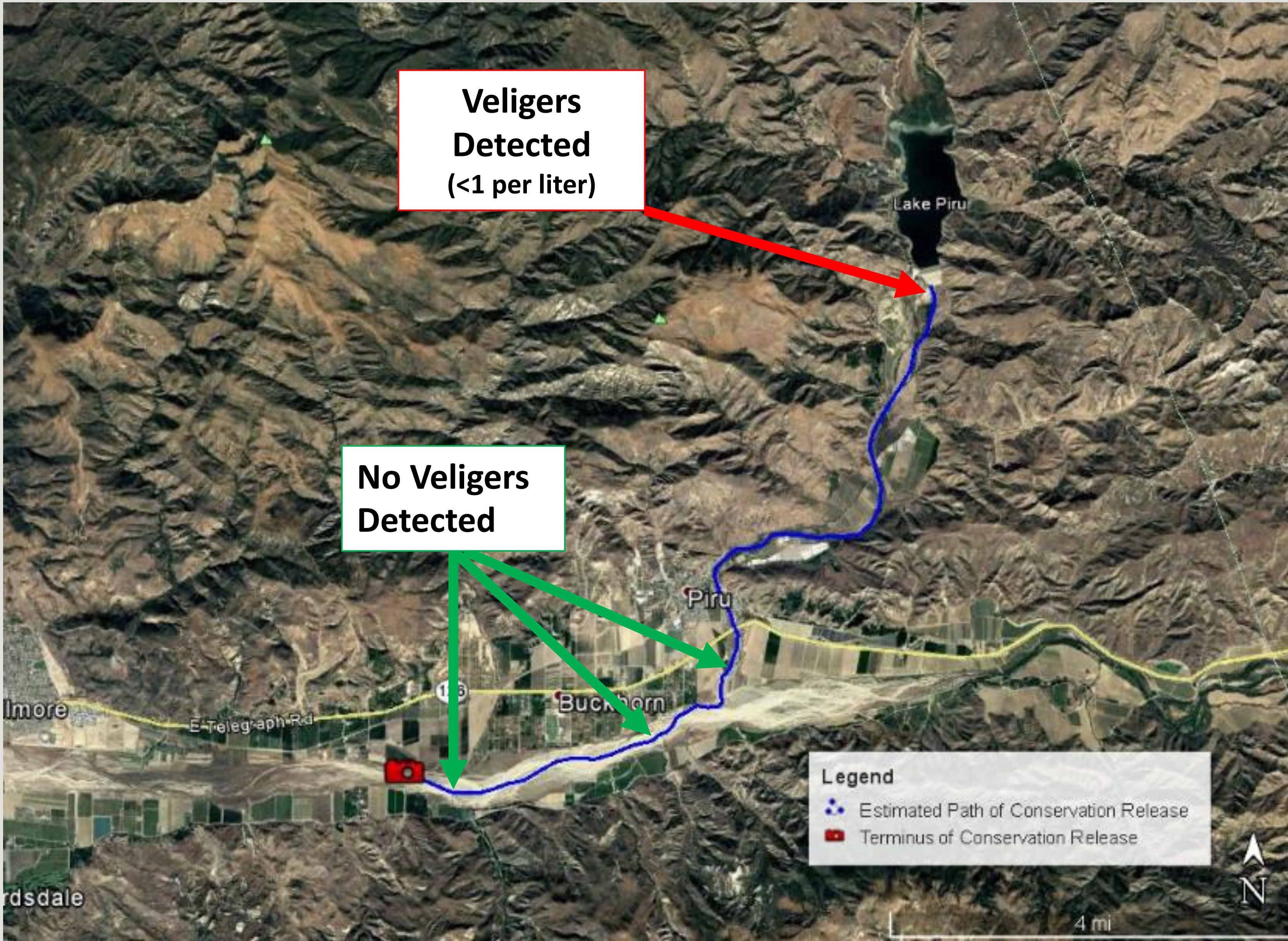


2. Downstream Considerations – High Volume Releases

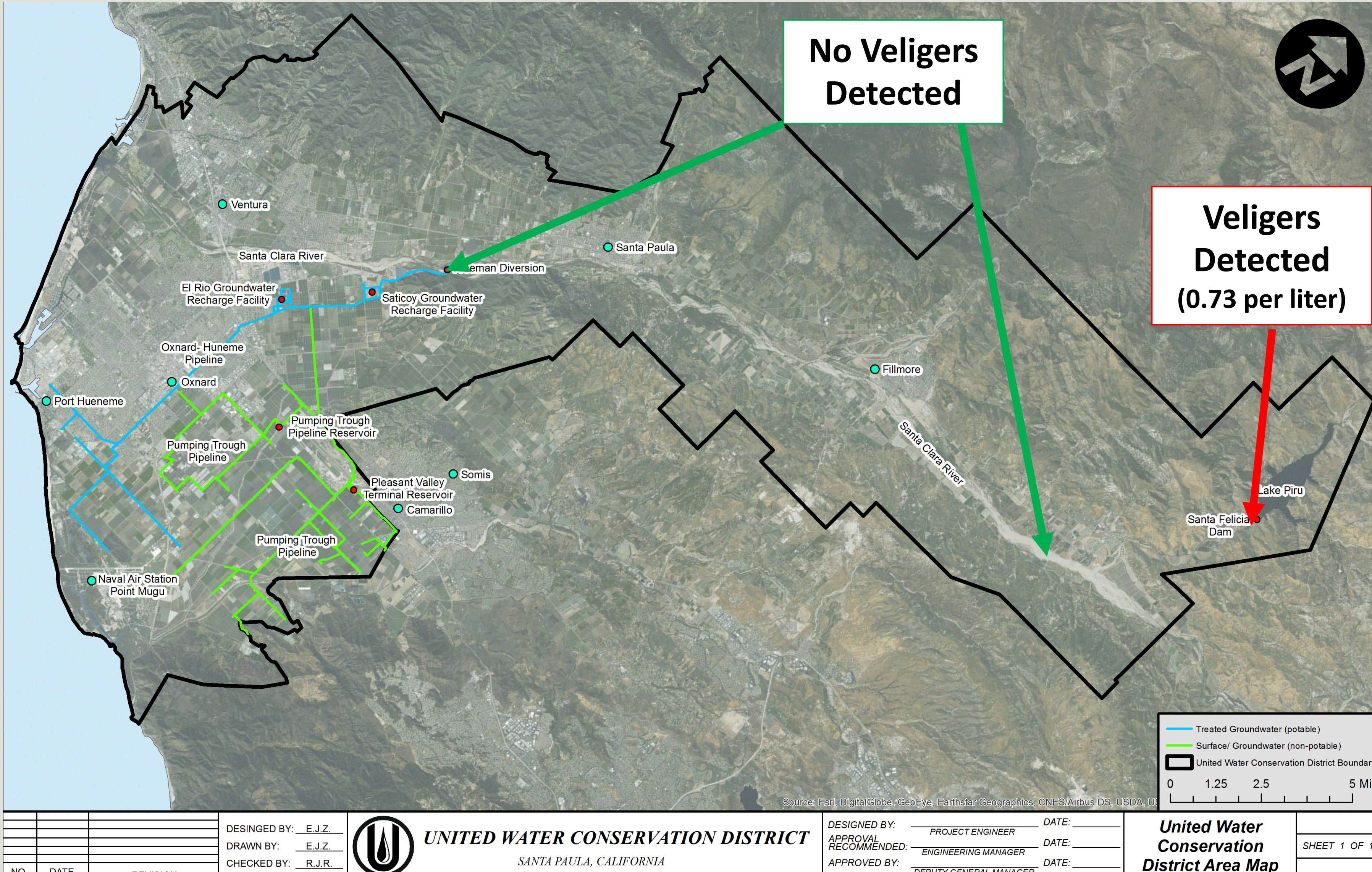
Estimated direct percolation of the 2017 Combined Release of 30,000AF



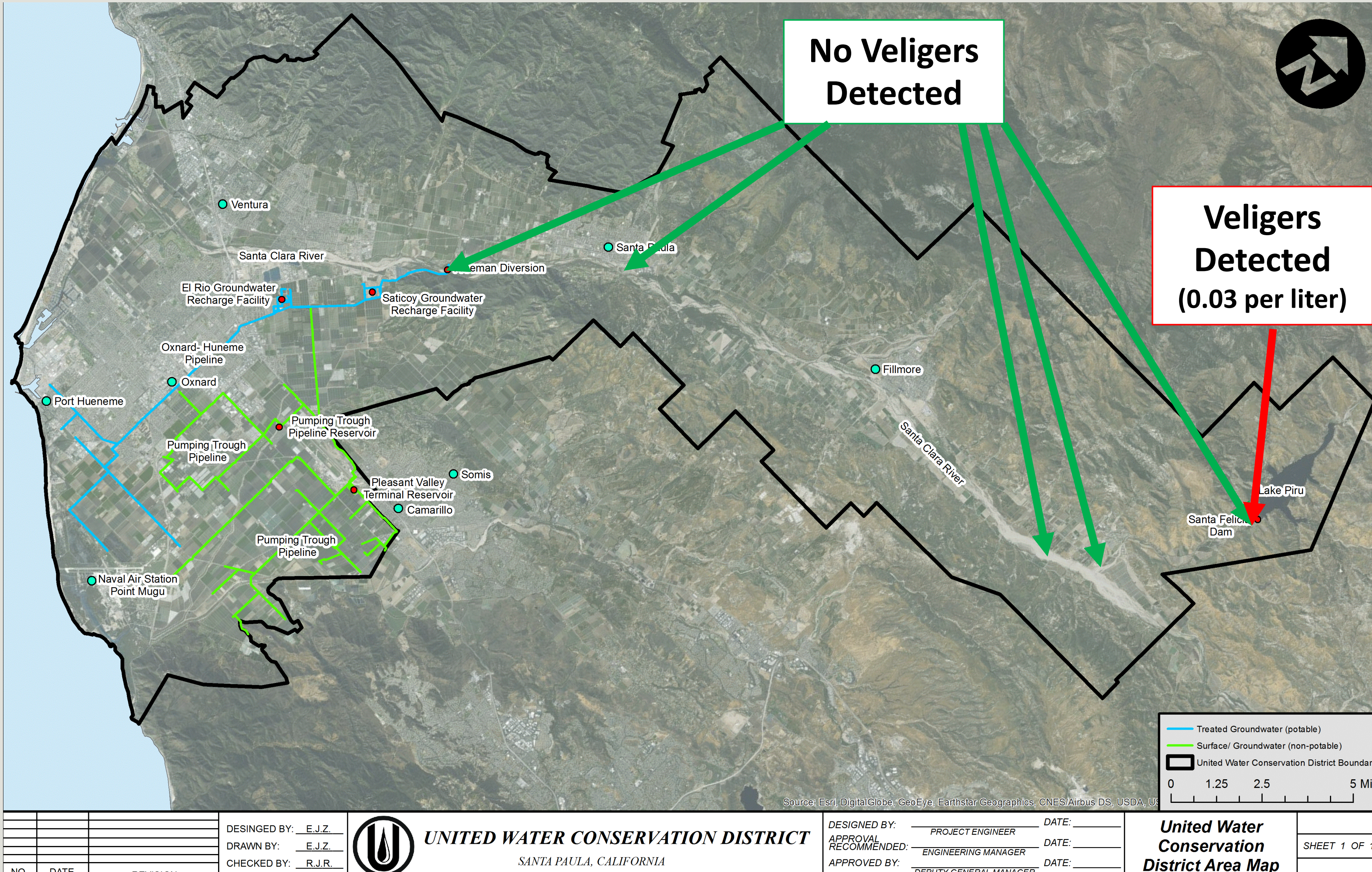
2. Downstream Monitoring during High Volume Releases – 77 cfs Release in December 2016



2. Downstream Monitoring during High Volume Releases – 200 cfs Release in January 2017



2. Downstream Monitoring during High Volume Releases – 500 cfs Release in June 2017



2. What are these results telling us?

- The quagga mussel population exhibits source-sink dynamics consistent with the literature
- Lake conditions have changed with the last rainy season and the easing of drought
- Sediment smothered part of the population in 2017
- Veligers are **not** surviving the passage through lower Piru Creek or they are below detection limits in the mainstem Santa Clara River even during three higher volume releases

Containment and Control Measures

Fish and Game Code §2301(d)(1)

- ✓ Requirement A – Methods for delineation of infestation, including both adult quagga mussels and veligers (the larval form of quagga mussels)

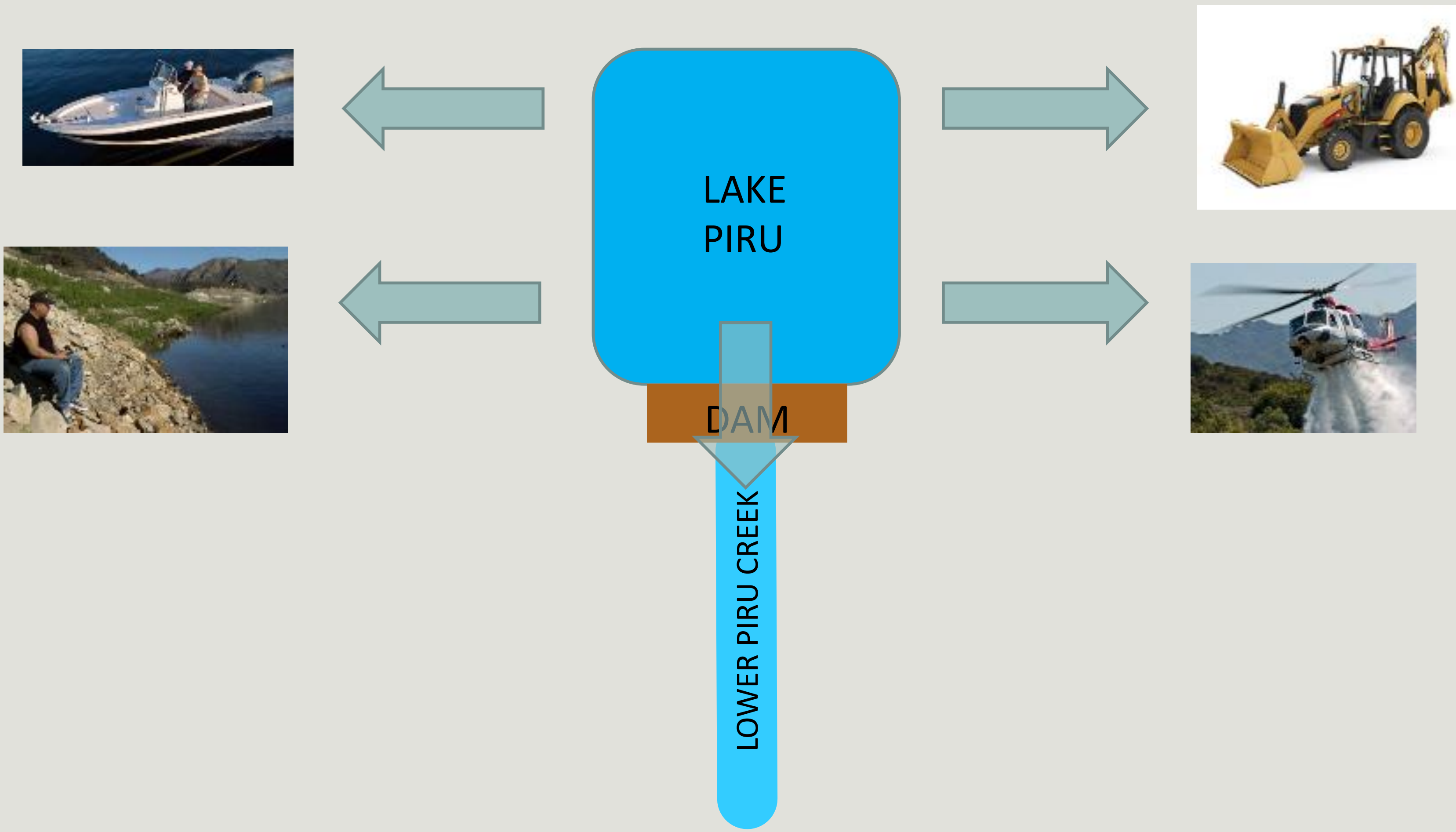
- ❑ Requirement B – Methods for control or eradication of adult quagga mussels and decontamination of water containing larval mussels

- ✓ Requirement C – A systematic monitoring program to determine any changes in conditions

Containment and Control Measures

- Measures currently implemented
- Measures actively being developed or requiring more Information
- Measures analyzed and considered Infeasible
- Where does this leave us?

3. Measures Currently Implemented - Containment



3. Measures Currently Implemented

Containment - Water Vessels, Equipment, and Vehicles

- Recreational Vessels – Public Outreach, Training, Inspections, QID, and Decontamination
- Shoreline Fishing – Public Outreach, Signage, and Ordinance Enforcement
- United Equipment and Vehicles – Decontamination SOPs
- Firefighting Equipment and Vehicles – MOUs (1 obtained, 2 in progress)

Measures Currently Implemented

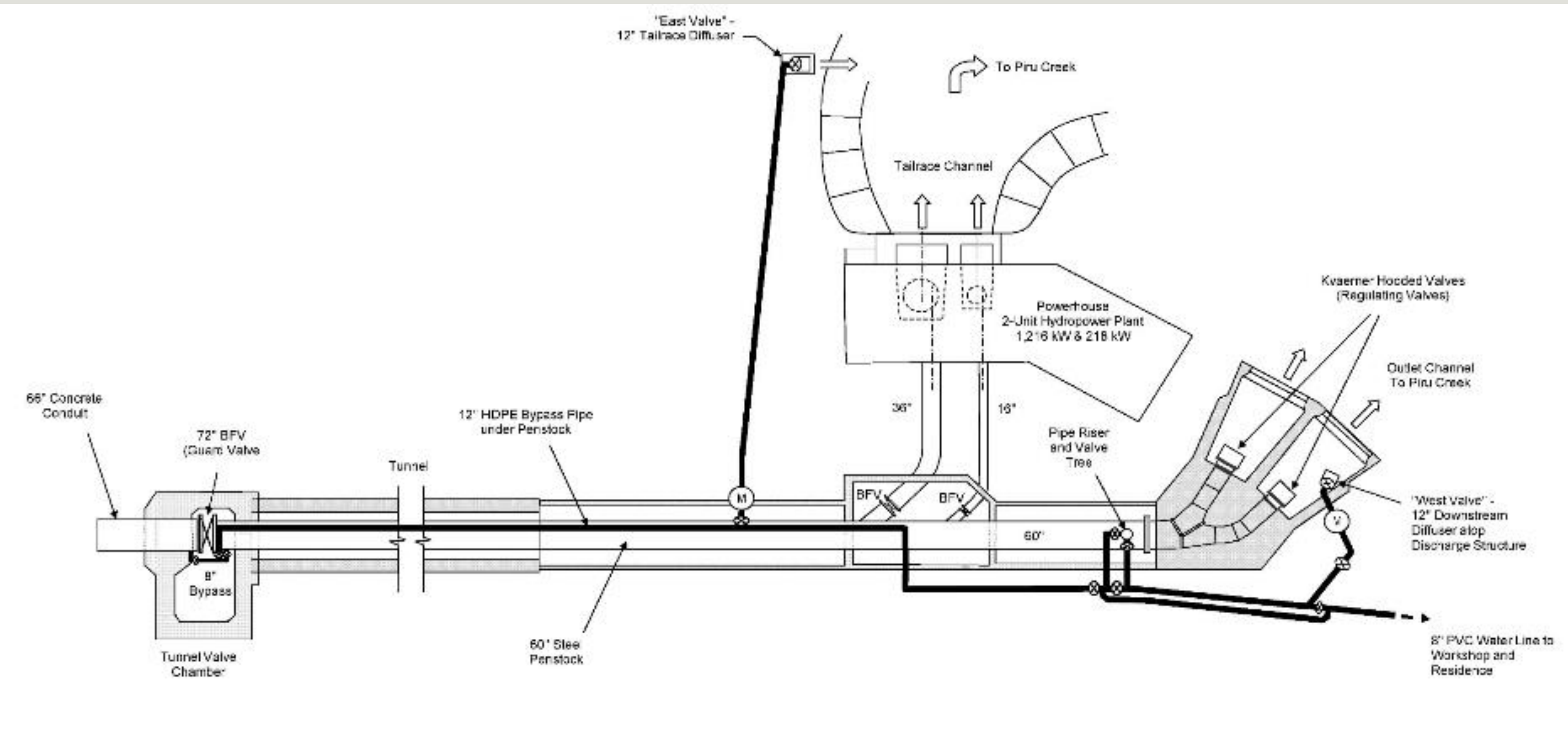
Containment - Quagga Mussel Transference to Lower Piru Creek

Santa Felicia Dam Infrastructure

3. Measures Currently Implemented

Containment - Quagga Mussel Transference to Lower Piru Creek

Santa Felicia Dam Infrastructure



3. Measures Currently Implemented

Containment - Quagga Mussel Transference to Lower Piru Creek

- Recommissioned hydroelectric Turbine Unit 1 and currently operating to maximize shear stress when possible

- Unit 1 - $250,000
- Cost Recovery – Approximately 10 years
  - Revenue $30,000/year

- Unit 2 - $386,000

3. Measures Currently Implemented SFD Quagga Mussel Veliger Transport Study (GEI, May 2016) – Existing Infrastructure

- Turbulence and shear forces can increase veliger mortality

- Limited field studies
  - San Diego County Water Authority 2010
  - Denver Water Company 2009

- Challenges
  - Duration
  - Flow transitions
  - Energy

- $92,000 to prepare technical memorandums

3. Measures Currently Implemented

Containment - Quagga Mussel Transference to Lower Piru Creek

Operations to Maximize Shear Stress

Release Type	Habitat Releases					Transitional Flows		High-Volume Releases (Migration/Conservation Releases)	Spill Events
Release Range (cfs)	5	7	10	15	20	20	32-199	200-400	10–150,000*
Release Mechanism	Low-flow valves	Turbine Unit 1 *not always feasible at low end of range because of insufficient head pressure				Low-flow valves	Cone Valves	Turbine Unit 1 + Turbine Unit 2 + Cone valves	Santa Felicia Dam Spillway and Spillway Channel
100% Veliger Mortality?	Yes for sizes 235 and larger; No for sizes 200 and smaller	Yes for sizes 200 µm and larger; No for sizes 115 µm and smaller		Yes for sizes 115 µm and larger; No for sizes 89 µm and smaller	Yes for sizes 89 µm and larger; No for sizes 57 µm and smaller	Yes for sizes 200 µm and larger; No for sizes 115 µm and smaller	No	Yes – 107 cfs through turbines for sizes 89 µm and larger No – extra 93-293 cfs would have to go through cone valves where most survive up to 200 cfs	Yes

3. Control Measures Implemented – Mechanical Removal of Quagga Mussels

Mechanical Removal from Infrastructure 5 Times/Year

3. Control Measures Implemented – Mechanical Removal of Quagga Mussels

	2015	2016
Biomass Removed	4,048 kg	1,671 kg
Cumulative Number of Dives (5 Divers)	235 dives	229 dives
Cumulative dive time for 5 divers	12,260 minutes	11,080 minutes

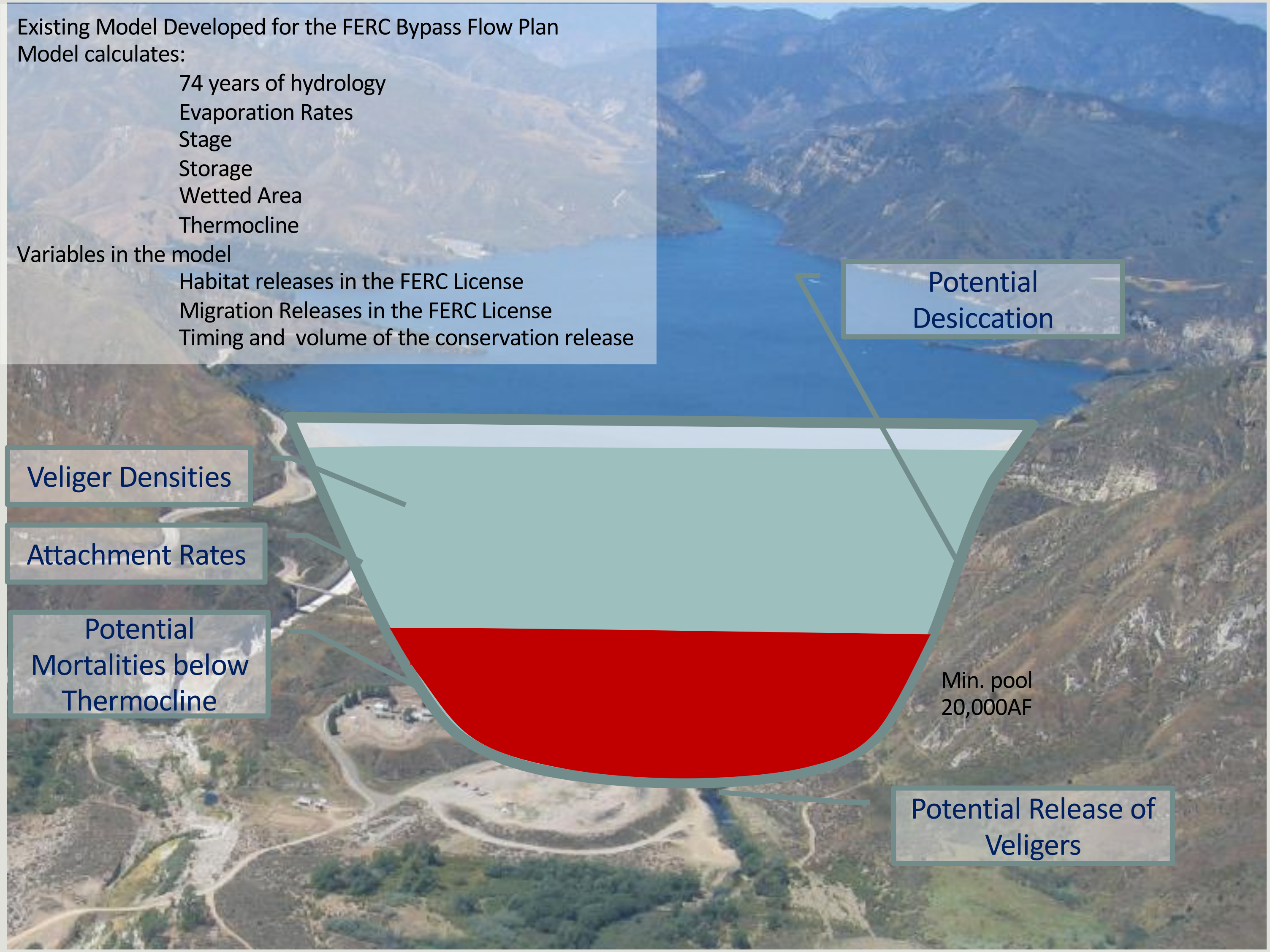
3. Control Measures Implemented – Lower River System

- DRAFT Lower River System Quagga Control Operations Manual
- Isolated irrigation systems from the Santa Clara River surface water system
- All surface water directed to recharge basins
- Recharge basins are completely dried-out in the off season

3. Containment and Control Measures Being Developed/Requiring More Information

- Lake level management
- Chemical treatment (for Lake Piru, Piru Creek, and infrastructure)
- New intake structure and outlet works

3. Measures Being Developed/Requiring More Information- Lake Level Management



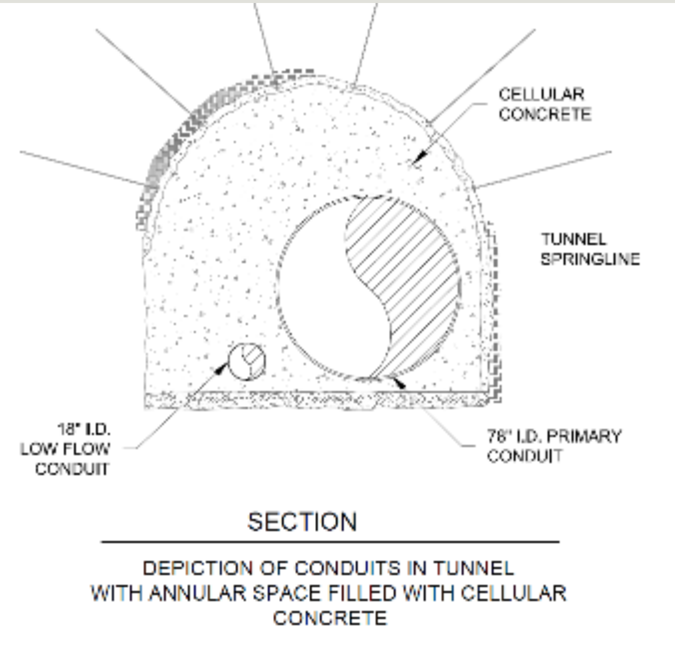
3. Measures Being Developed/Requiring More Information- Chemical Treatment Pilot Study

- Potassium chloride (potash)
- Copper sulfate pentahydrate (EarthTecQZ®)
- Citric acid formulation (ZMX)
- Carbon dioxide

3 Treatment Concentrations
(low, medium, high)
x
3 Temperatures
(10°C, 18°C, and 25°C)

3. Measures Being Developed/Requiring more Information – New Intake Structure and Outlet Works

- New project to replace existing outlet works
- Pipe redundancy (78” and 18” diameter)
  - Allow for treatment of a pipe while maintaining required flows
- Movable intake screens
- Chemical Treatment Challenges
  - Corrosion
  - Contact Time vs. Toxicity
  - Quantity
  - Flow Range
  - Maintenance - submerged/encased infrastructure



3. Measures Being Developed/Requiring more Information – New Intake Structure and Outlet Works

- Example: Carbon Dioxide Continuous Treatment

Flow (cfs)	CO_2 at 175 mg/L (lb/day)	CO_2 at 200 mg/L (lb/day)
5	4,800	5,400
7	6,600	7,600
20	18,900	21,600
200	188,400	215,300
500	470,900	538,200

•CO_2 numbers were rounded up to the nearest hundred.

- Contact Time - testing shows 100% mortality when exposed for 10 days at 18°C

18" Diameter (1,200 ft long pipe)	
Flow (cfs)	Time (minutes)
7	5
20	1.8

3. Measures Being Developed/Requiring more Information – New Intake Structure and Outlet Works

- Maximizing Shear Stress
  - Can continue increased veliger mortality through hydropower plant
- Shear Stress Challenges
  - Operational Reservoir Elevation
  - Dissolved Oxygen
  - Wear on infrastructure

3. Other Measures Requiring More Information or More Commercial Development

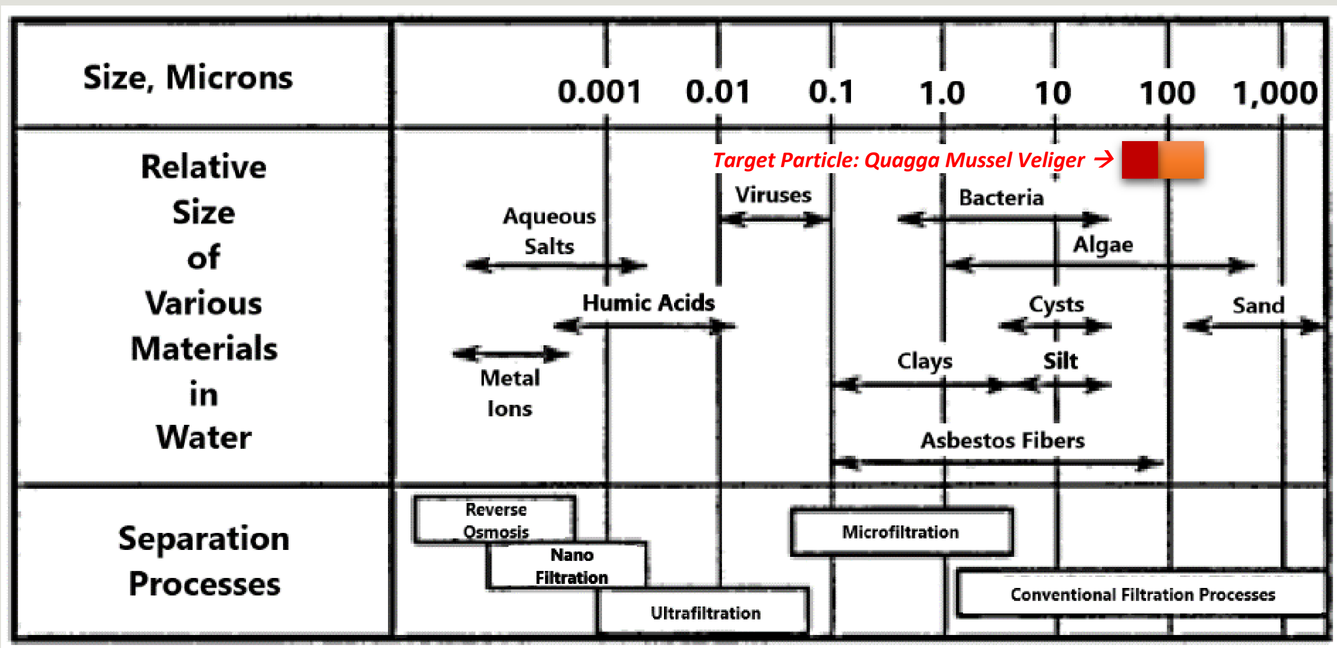
- Surface coatings (nonfouling release)
  - Coatings for Mussel Control – Results from Six Years of Field Testing (Bureau of Reclamation, July 2014)
  - Field Tested Coatings

- Electrical or Acoustic deterrents
  - Prevents attachment but does not kill veligers
  - Cavitation is already a concern in the infrastructure
  - Need more technological improvements

3. Measures Analyzed and Considered Infeasible at This Time

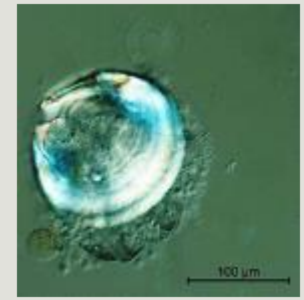
- Filtration
- Pipelines
- Manifold System
- Tarping
- Suspending or Modifying Releases
- Plankton Tows
- Fish Biocontrol
- Zequanox

3. Measures Analyzed and Considered Infeasible - Filtration

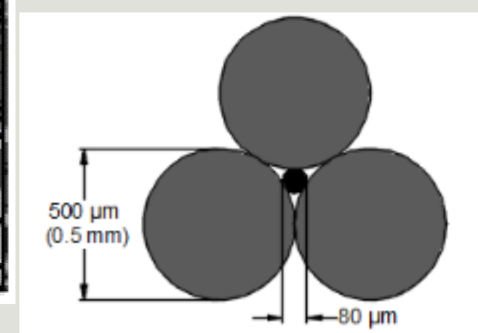


Quagga Mussel Veliger – Ability to Pass Through Opening Smaller than Actual Size

Quagga Mussel Veliger – Actual Size



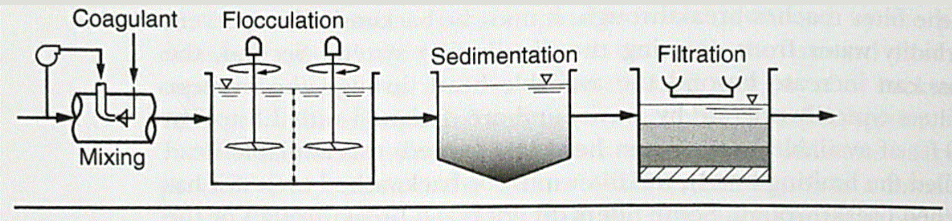
Quagga Mussel Veliger Typical Size Ranges from 80 to 200 µm



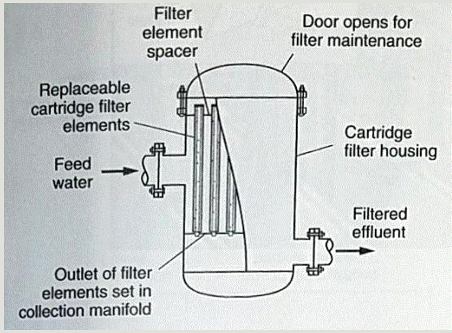
Generalized Filtration by Straining of 80 µm Particle

3. Measures Analyzed and Considered Infeasible - Filtration

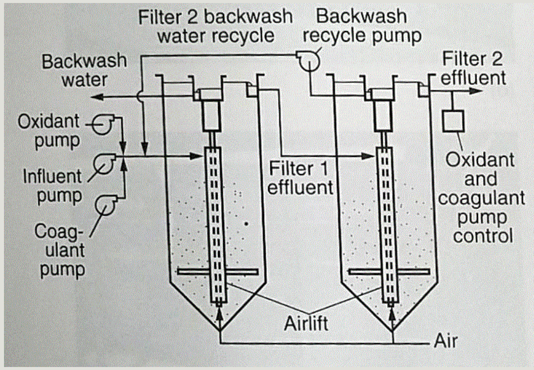
Conventional Filtration



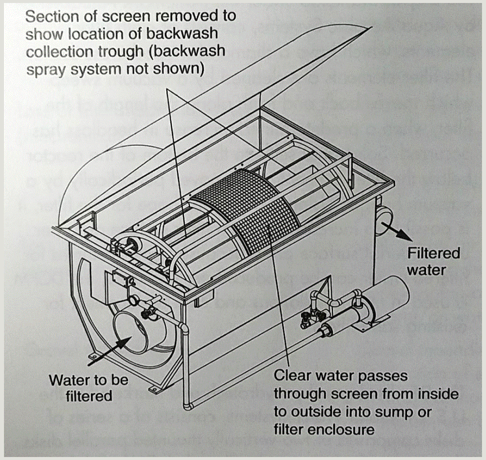
Cartridge Filter



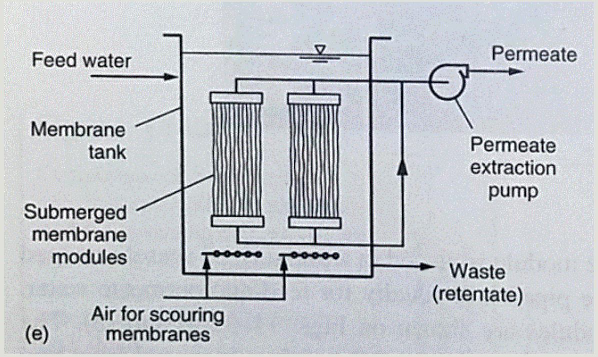
Two-Stage Filtration



Microscreen Filter



Membrane Filters



3. Measures Analyzed and Considered Infeasible - Filtration

Type	Treatment Process	Principal Removal Mechanism		Approximate Turbidity Requirement	Approximate Particle Size Removal Range	Typical Flow Range	Typical Pressure Range	Filtration Suitability	
		Straining	Depth Filtration					Lake Piru / Santa Felicia Dam	Freeman Diversion / Lower River System
Conventional Filtration (Rapid or Slow Sand)	1. Coarse Screen 2. Coagulant Flash Mixing 3. Flocculation 4. Sedimentation 5. Filtration	X	X	--	1 µm or larger	2 to 6 gpm/ft^2	Gravity or pressurized vessel, up to terminal head loss	Plausible	Plausible
Direct Filtration	1. Coarse Screen 2. Coagulant Flash Mixing 3. Flocculation 4. Filtration	X	X	< 15 NTU	1 µm or larger	2 to 6 gpm/ft^2	Gravity or pressurized vessel, up to terminal head loss	Not possible - turbidity can exceed 15 NTU	Not possible - turbidity regularly exceeds 15 NTU
In-line Filtration	1. Coarse Screen 2. Coagulant Flash Mixing 3. Filtration	X	X	< 10 NTU	1 µm or larger	2 to 6 gpm/ft^2	Gravity or pressurized vessel, up to terminal head loss	Not possible - turbidity can exceed 10 NTU	Not possible - turbidity regularly exceeds 10 NTU
Two-stage Filtration	1. Coarse Screen 2. Coagulant Flash Mixing 3. Roughing Filter 4. Filtration	X	X	< 100 NTU	1 µm or larger	2 to 6 gpm/ft^2	Gravity or pressurized vessel, up to terminal head loss	Plausible - but turbidity can slightly exceed 100 NTU	Not possible - turbidity regularly exceeds 100 NTU
Bag/Cartridge Filtration	1. Coarse Screen 2. Bag/Cartridge Filtration	X		< 5 NTU	1 µm or larger	< 1 gpm/ft^2	Up to 30 psid	Not possible - turbidity exceeds 5 NTU	Not possible - turbidity regularly exceeds 5 NTU
Microscreen - Disk or Drum	1. Coarse Screen 2. Microscreen	X		< 40 NTU	10 µm or larger	2 to 5 gpm/ft^2	Gravity up to terminal head loss	Plausible - but turbidity can exceed 40 NTU	Not possible - turbidity regulary exceeds 40 NTU
Microfiltration - Membrane	1. Coarse Screen 2a. Bag/Cartridge Filters, or 2b. Microscreen 3. Microfiltration	X		Prescreening: < 40 NTU Microfiltration: < 10 NTU	0.1 µm or larger	24 to 35 gpd/ft^2 or 0.017 to 0.024 gpm/ft^2	5 to 30 psig	Plausible - but turbidity can exceed 40 NTU	Not possible - turbidity regulary exceeds 40 NTU

3. Measures Analyzed and Considered Infeasible - Filtration

<table>
<tr><th colspan="5">Table 1 – Summary of Proposed Filtration Plant Design Criteria and Costs for Quagga Mussel Control at Santa Felicia Dam (GEI, 2016)</th></tr>
<tr><th>Release Activity</th><th>Flow Range (cfs)</th><th>Proposed Filtration Plant Design Criteria</th><th>Construction Cost</th><th>Annual O&M Cost</th></tr>
<tr><td>Low-Flow Habitat Release (Year Round)</td><td>5 to 7</td><td rowspan="2">Capacity: 25 cfs
Filter Type: Gravity, Anthracite/Sand/Ilmenite
Flow Rate: 8 gpm/ft^2
Filter Area: 1,549 ft^2
Total Plant Area: 17,000 ft^2</td><td rowspan="2">$14,920,000</td><td rowspan="2">$640,000 – $1,000,000</td></tr>
<tr><td>Modified Habitat Flow (Jan to Jun)</td><td>7 to 25</td></tr>
<tr><td>Fish Migration (Jan to Jun)</td><td>7 to 200</td><td rowspan="3">Capacity: 600 cfs
Filter Type: Gravity, Anthracite/Sand/Ilmenite
Flow Rate: 8 gpm/ft^2
Filter Area: 37,021 ft^2
Total Plant Area: 406,000 ft^2</td><td rowspan="3">$185,710,000</td><td rowspan="3">$3,383,333 – $8,150,000</td></tr>
<tr><td>Conservation Release (Aug to Nov)</td><td>7 to 400</td></tr>
<tr><td>Emergency Draw-down</td><td>600 to 800</td></tr>
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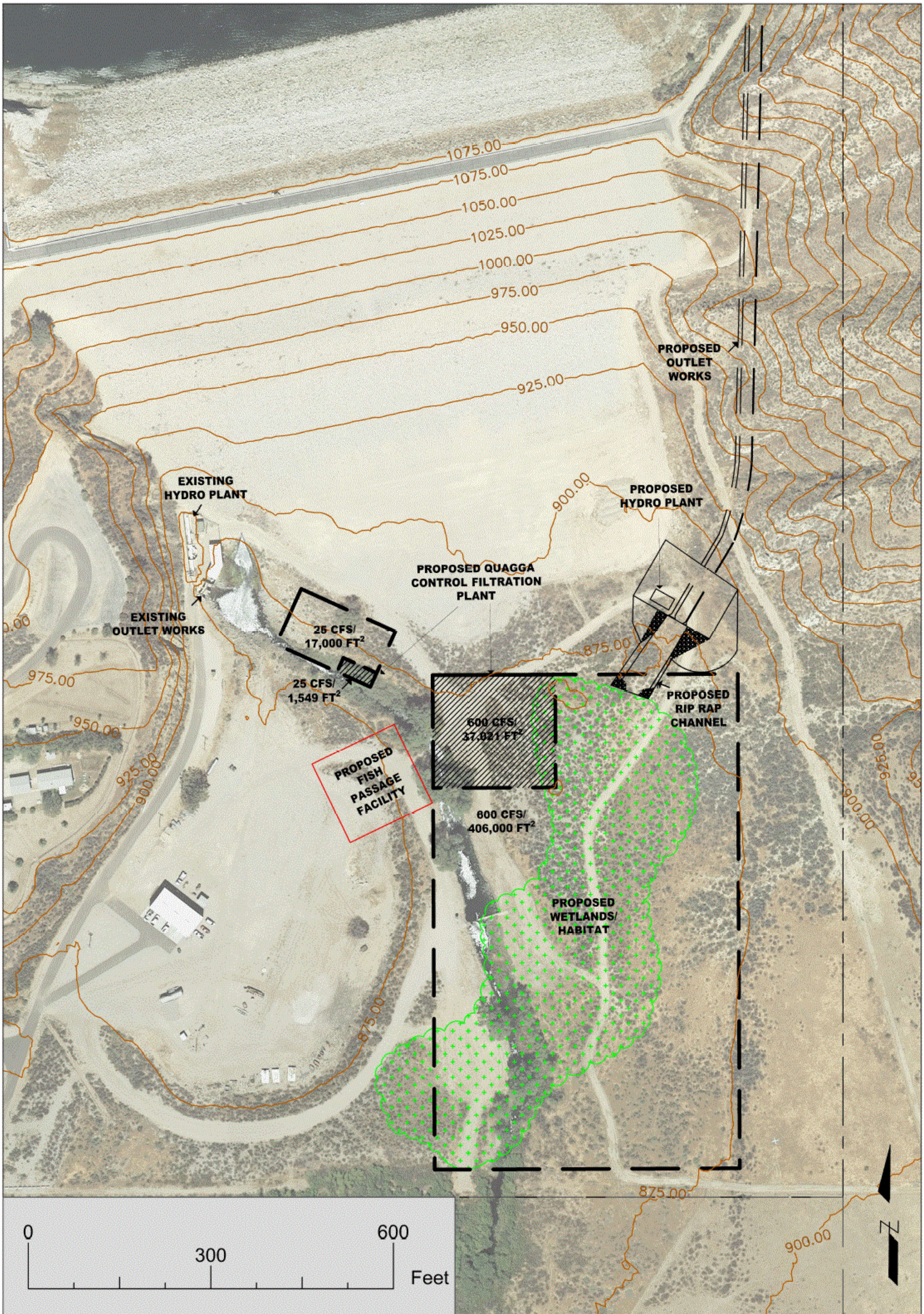


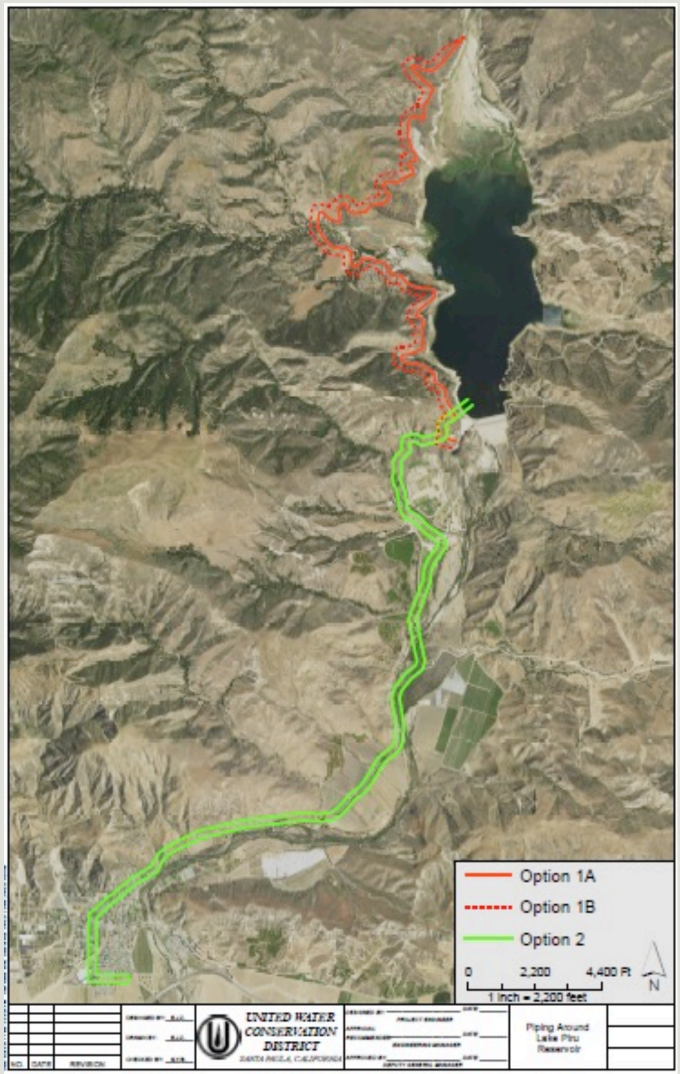
PROPOSED OUTLET WORKS
PROPOSED HYDRO PLANT
EXISTING HYDRO PLANT
EXISTING OUTLET WORKS
PROPOSED QUAGGA CONTROL FILTRATION PLANT
25 CFS/ 17,000 FT²
25 CFS/ 1,549 FT²
600 CFS/ 37,021 FT²
600 CFS/ 406,000 FT²
PROPOSED RIP RAP CHANNEL
PROPOSED FISH PASSAGE FACILITY
PROPOSED WETLANDS/ HABITAT
1075.00
1050.00
1025.00
1000.00
975.00
950.00
925.00
900.00
875.00
N
0
300
600
Feet

3. Measures Analyzed and Considered Infeasible - Filtration

Table 1 – Summary of Proposed Filtration Design Criteria and Costs for Quagga Mussel Control at the Freeman Diversion and Lower River System Facilities (AECOM, 2016)				
Alternative	**Flow Range (cfs)**	**Proposed Filtration Design Criteria**	**Construction Cost**	**Annual O&M Cost**
In-River Infiltration Gallery	0 to 75	*Capacity:* 75 cfs *Filter Type:* Gravity, Coarse Sand/Gravel, Rock *Flow Rate:* 1.5 to 3 gpm/ft^2 *Filter Area:* 28,050 ft^2	$34,820,000 – $51,710,000	$1,150,000 – $1,650,000
In-Pond Infiltration Gallery		*Capacity:* 75 cfs *Filter Type:* Gravity, Coarse Sand/Gravel, Rock *Flow Rate:* 3 gpm/ft^2 *Filter Area:* 12,342 ft^2	$22,390,000 – $22,920,000	$1,150,000 – $1,400,000
Saticoy Well-Field Expansion (Natural Filtration)		*Capacity:* 75 cfs (limited by pumping only) *Filter Type:* Slow Sand, Existing Ground *Flow Rate:* Not evaluated *Filter Area:* 133 acres	$8,760,000 – $13,450,000	$1,190,000 – $1,530,000


PROPOSED QUAGGA FILTRATION PLANT IN-RIVER 75 CFS 28,050 FT²
PROPOSED FISH RAMP NOTCH
SANTA CLARA RIVER
DESILTING BASIN
PROPOSED QUAGGA FILTRATION PLANT IN-POND 75 CFS 12,312 FT²
WEIR
MOSS SCREEN
GRAND CANAL
A
B
C
D
E
F
G
H
I
J
L
M
N
O
Proposed Quagga Filtration Plant
Proposed Fish Ramp Notch
Direction of Flow
Saticoy Ponds
Saticoy Wells
N
0 475 950 1,900 Feet
1 inch = 950 feet

3. Measures Analyzed and Considered Infeasible – Pipeline Options



3. Measures Analyzed and Considered Infeasible – Piping Around Lake Piru

Description: Option 1A

Analysis: Installation of two (2) 36-inch pipelines to accommodate 7-20 cfs flows and redundancy from Middle Piru Creek to Lower Piru Creek

Cost: $17.9 M

Explanation for Infeasibility Determination: Cost and alignment issues. Cost does not include HDD, permits, EIR, operational/energy costs, and pumps. Cannot guarantee continuous habitat flows to Lower Piru Creek. Cannot provide migration flows.

3. Measures Analyzed and Considered Infeasible – Piping Around Lake Piru

Description: Option 1B

Analysis: Installation of two (2) pipelines. One 36-inch line to accommodate 7-20 cfs. One 72-inch line to accommodate 200 cfs migration flows from Middle Piru Creek to Lower Piru Creek

Cost: $22.2 M

Explanation for Infeasibility Determination: Cost and alignment issues. Cost does not include HDD, permits, EIR, operational/energy costs, and pumps. Cannot guarantee continuous habitat flows or migration releases to Lower Piru Creek.

3. Measures Analyzed and Considered Infeasible – Piping around Lower Piru Creek

Description: Option 2

Analysis: Installation of two (2) 36-inch pipelines from Lake Piru Reservoir to Piru Spreading Grounds

Cost: $51.5 M

Explanation for Infeasibility Determination: Cost and alignment issues. Cost does not include HDD, permits, EIR, land purchase/easements, and pumps. Water pumped back to dam would have significant degradation of water quality. Currently, no water rights to extract water from this area (SIGMA Rights).

3. Measures Analyzed and Considered Infeasible – Manifold System

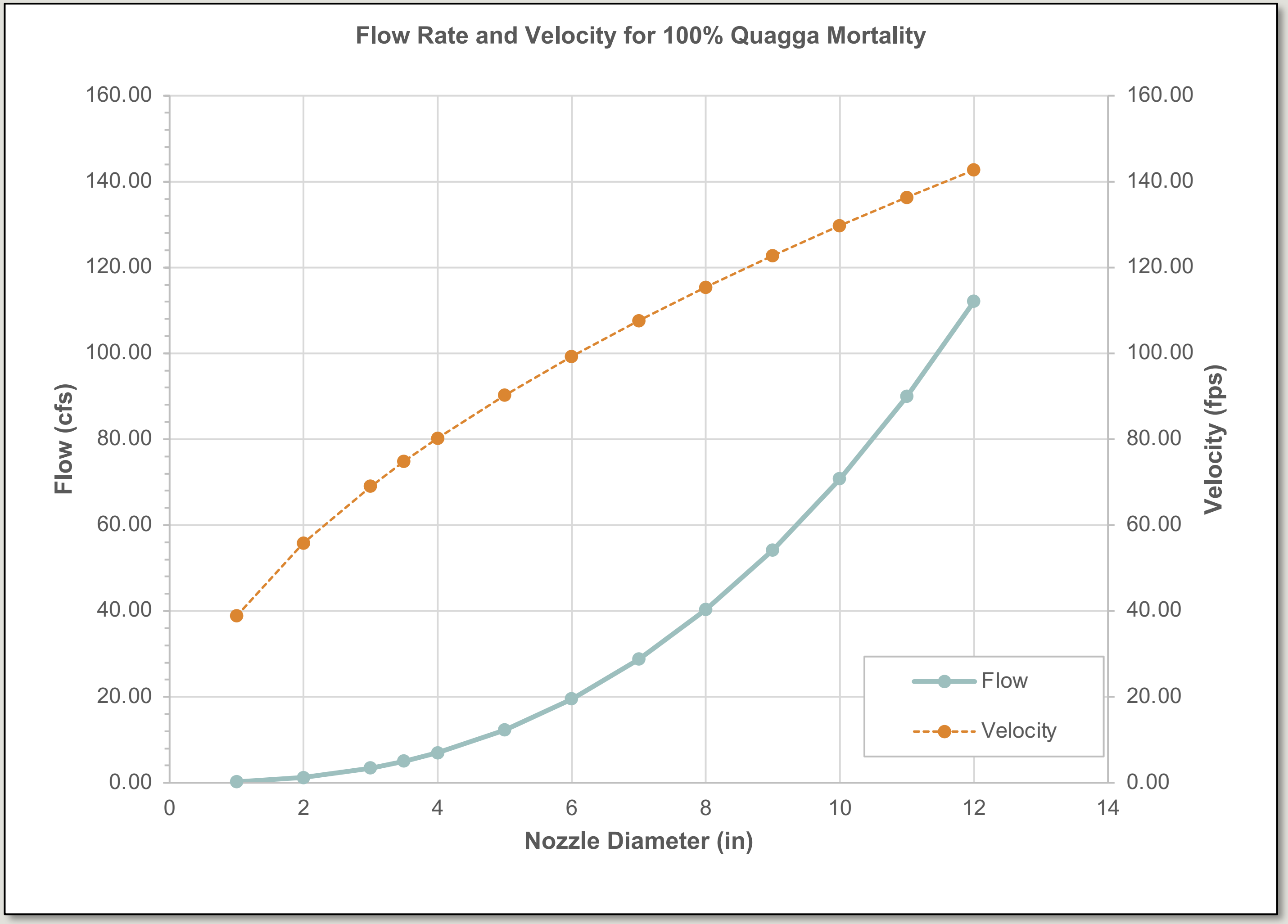
Description: Manifold system designed to increase shear stress – existing facilities

Analysis: GEI Technical Memorandum – Santa Felicia Dam Preliminary Quagga Mussel Veliger Transport Study (July 2017)

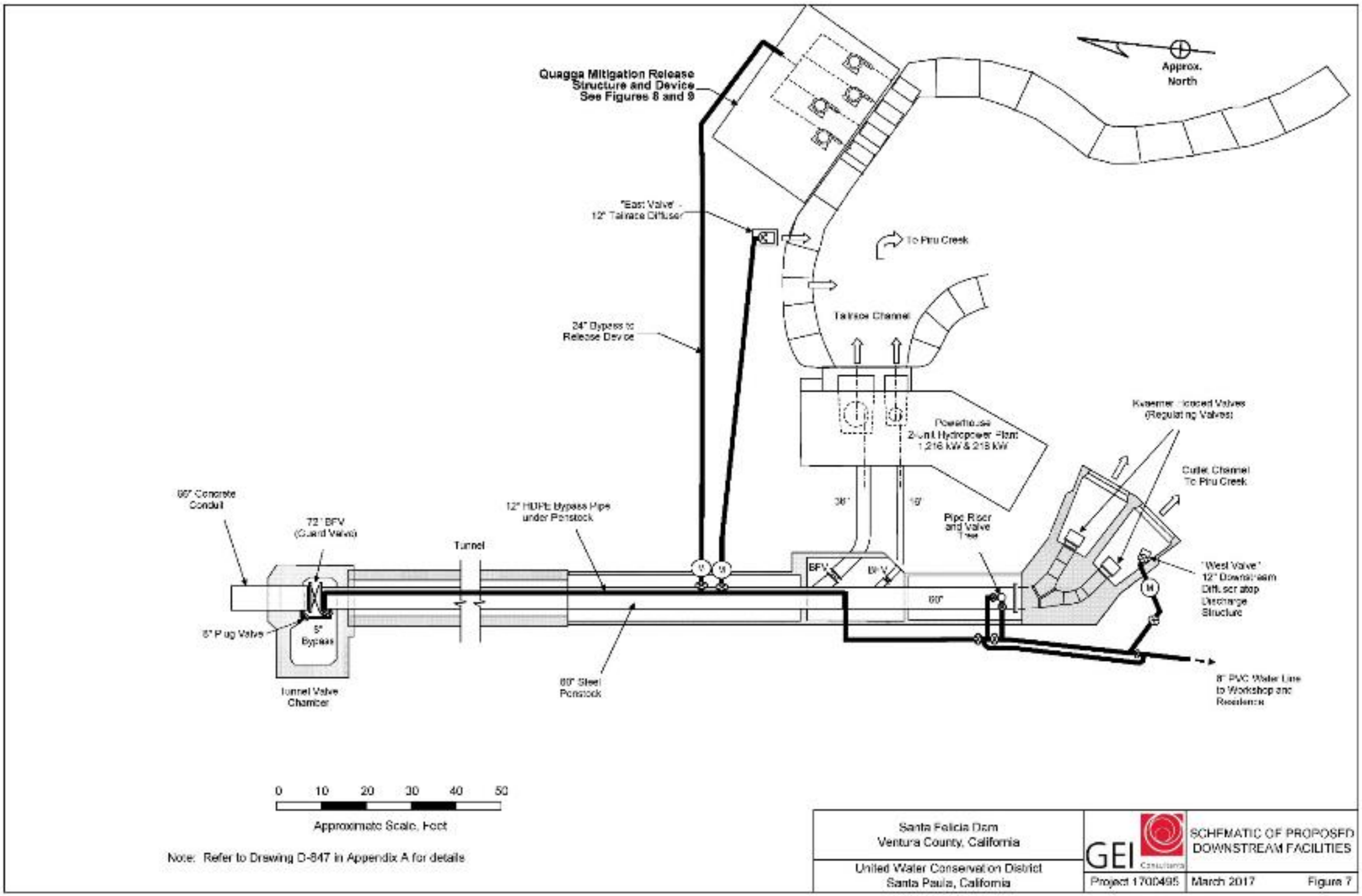
Cost: $XX M

Explanation for Infeasibility Determination: Capital cost and continual operation cost limitations. Physical flow limitations. Frequent repairs/replacement due to continual cavitation damage. Only addresses flows from 5 cfs to 25 cfs.

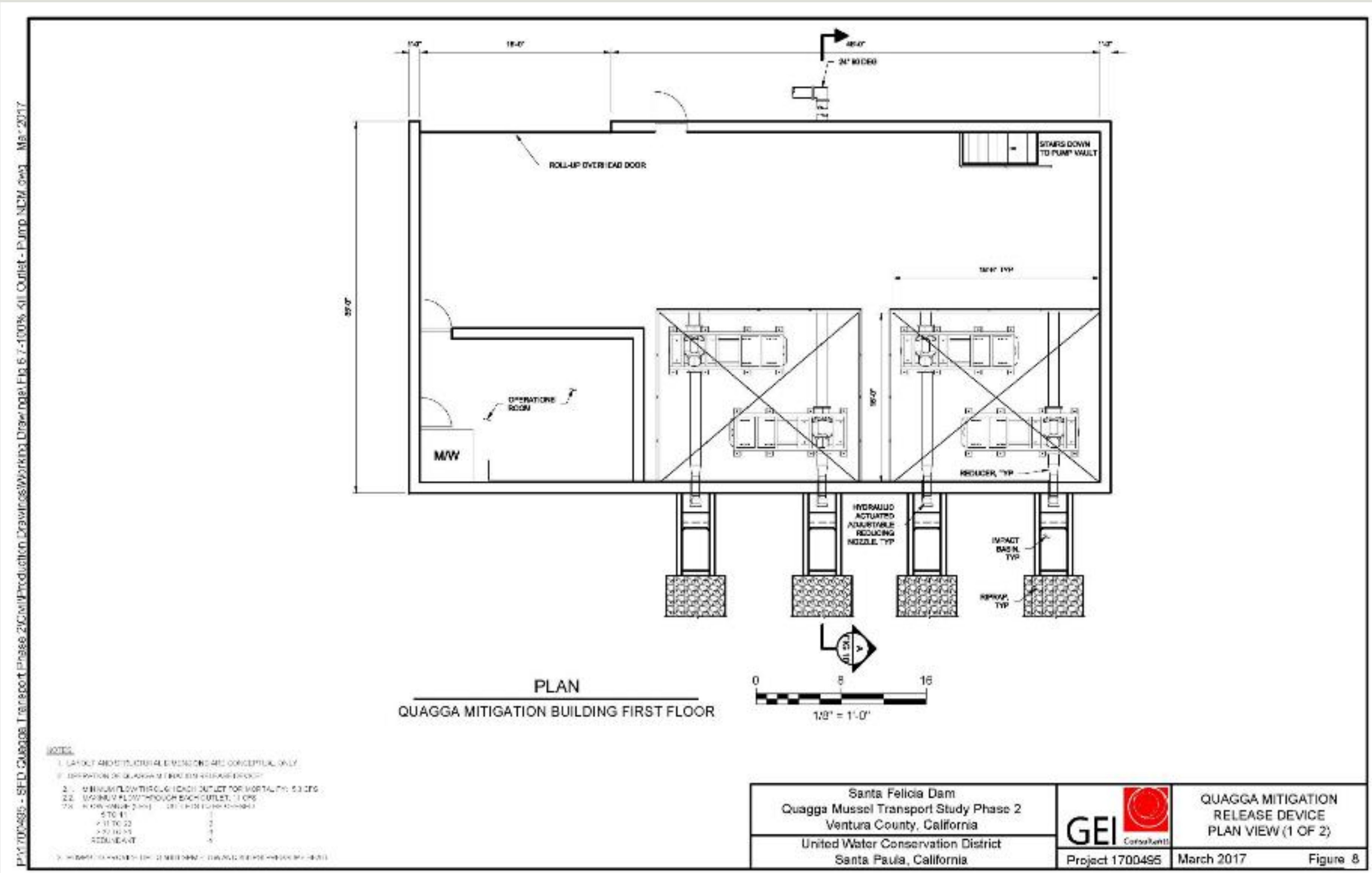
3. Measures Analyzed and Considered Infeasible – Manifold System



3. Measures Analyzed and Considered Infeasible – Manifold System



3. Measures Analyzed and Considered Infeasible – Manifold System



Containment/Control Measures Analyzed and Considered Infeasible – Tarping

3. Where does this leave us?

- Options narrowing
- Fish and Game Code conflicts with Federal ESA and FERC license
- Toxicity x contact time is a continuing challenge for infrastructure design
- Value to considering control and containment in the context of monitoring results and what we know about quagga biology and conditions in the SCR system
- Reality of fiscal constraints

4.1 Financial Considerations

- FY 2016-2017 Quagga actual expenditures -- $600,000
- District total budget for FY 2017-2018 -- $30 million
- Capital costs for quagga control – 10s to 100s millions
- Existing dam safety & ESA compliance obligations – Minimum of $150 million
- Limited ability to fund quagga control program
  - Total borrowing capacity – $50 million
  - Limited ability to raise user charges
  - Pending reductions in groundwater pumping (SGMA)
  - External funding sources?

5. Fish and Game Code – What is necessary to approve United's Plan?

Fish and Game Code §2301(d)(1)

- Requirement A – Methods for delineation of infestation, including both adult quagga mussels and veligers (the larval form of quagga mussels)

- Requirement B – Methods for control or eradication of adult quagga mussels and decontamination of water containing larval mussels

- Requirement C – A systematic monitoring program to determine any changes in conditions

6. Future Directions

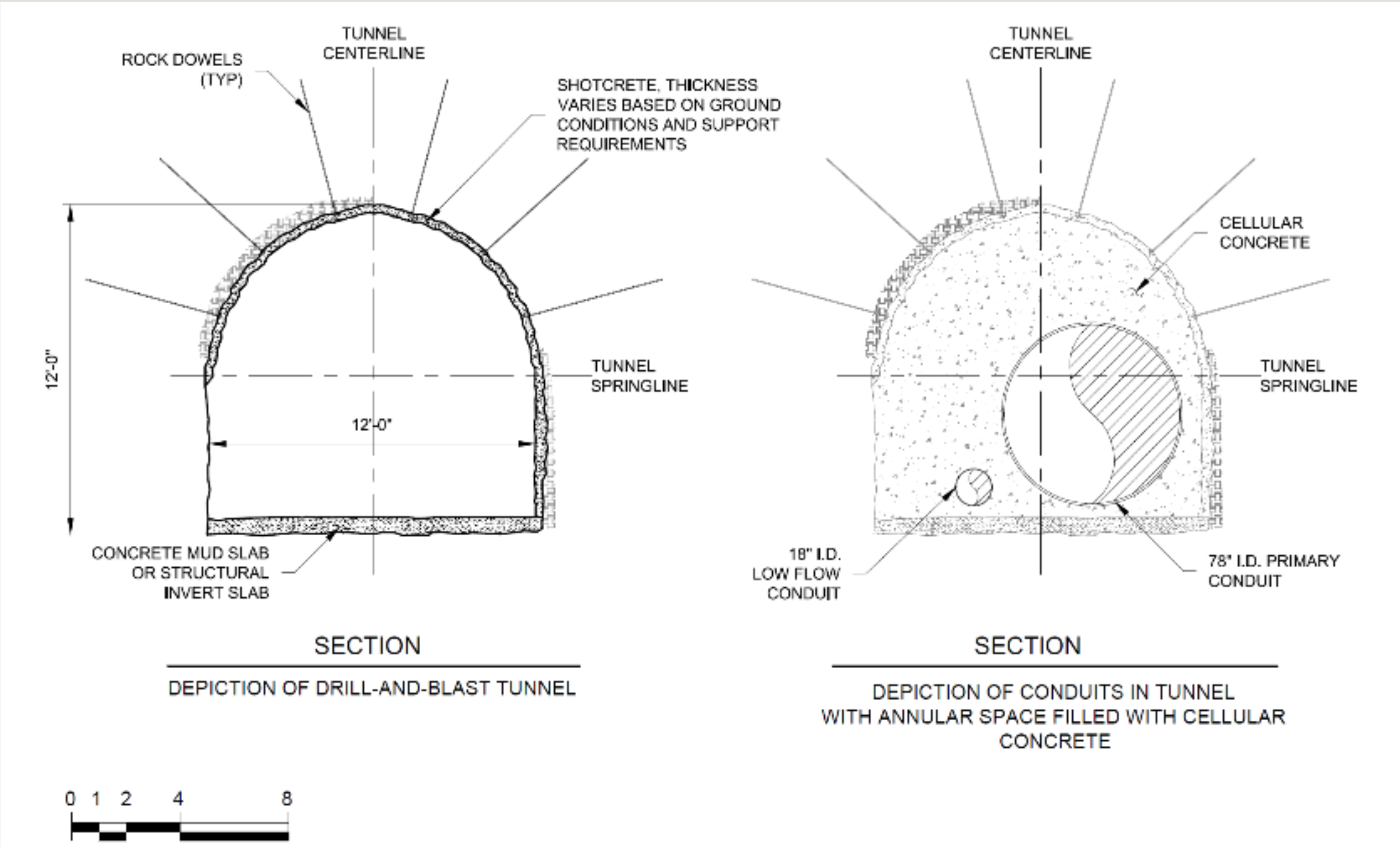
- Monitoring
- Containment
- Control
- Other

Extra Slides if Needed for Discussion

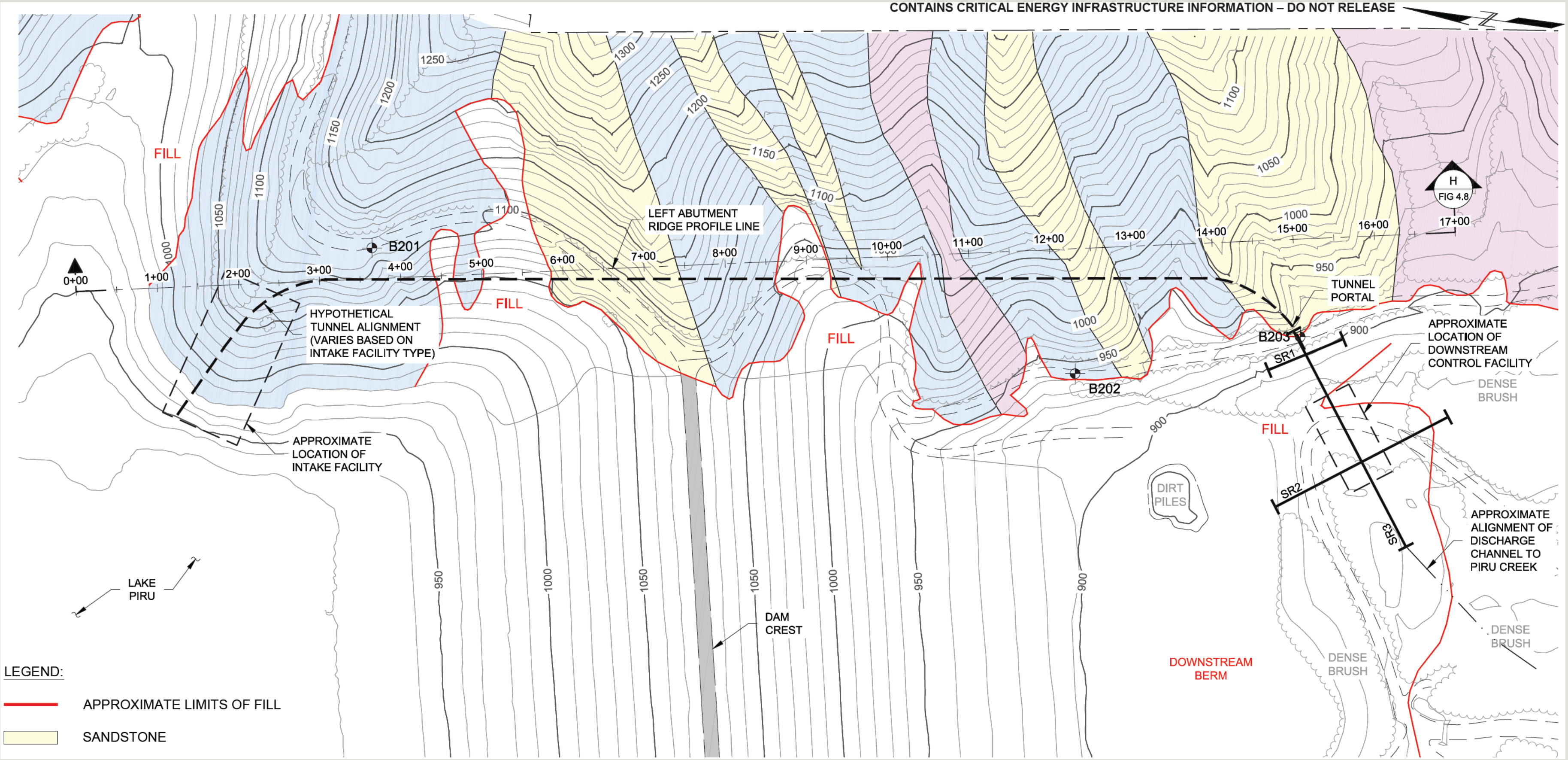
Summary of Quagga Mussel Survival through the Santa Felicia Dam Outlet Works – Maximum Discharge, (GEI, July 2017)

Location		Penstock (5-ft Dia.)		Cone Valves		PH Unit 1 164kW	
Maximum Discharge (cfs)		700		500		20.3	
Veliger Life Stage	Size (um)	d*	Survival	d*	Survival	d*	Survival
Trochophore	57	0.62	100%	1.17	100%	1.92	98%
Trochophore	89	0.98	100%	1.82	98%	2.99	0%
D-Shaped Veliger	115	1.26	100%	2.36	94%	3.87	0%
Veliconcha	200	2.19	97%	4.10	0%	6.72	0%
Pediveliger	235	2.58	76%	4.81	0%	7.90	0%
Plantigrade	329	3.61	0%	6.74	0%	11.06	0%
Location		PH Unit 2 806 kW		Low-flow BFVs		Plug Valve	
Maximum Discharge (cfs)		87.6		10		7	
Veliger Life Stage	Size (um)	d*	Survival	d*	Survival	d*	Survival
Trochophore	57	2.30	95%	1.08	100%	1.12	100%
Trochophore	89	3.59	0%	1.69	99%	1.75	99%
D-Shaped Veliger	115	4.63	0%	2.18	97%	2.26	96%
Veliconcha	200	8.06	0%	3.80	0%	3.93	0%
Pediveliger	235	9.47	0%	4.46	0%	4.62	0%
Plantigrade	329	13.26	0%	6.25	0%	6.47	0%

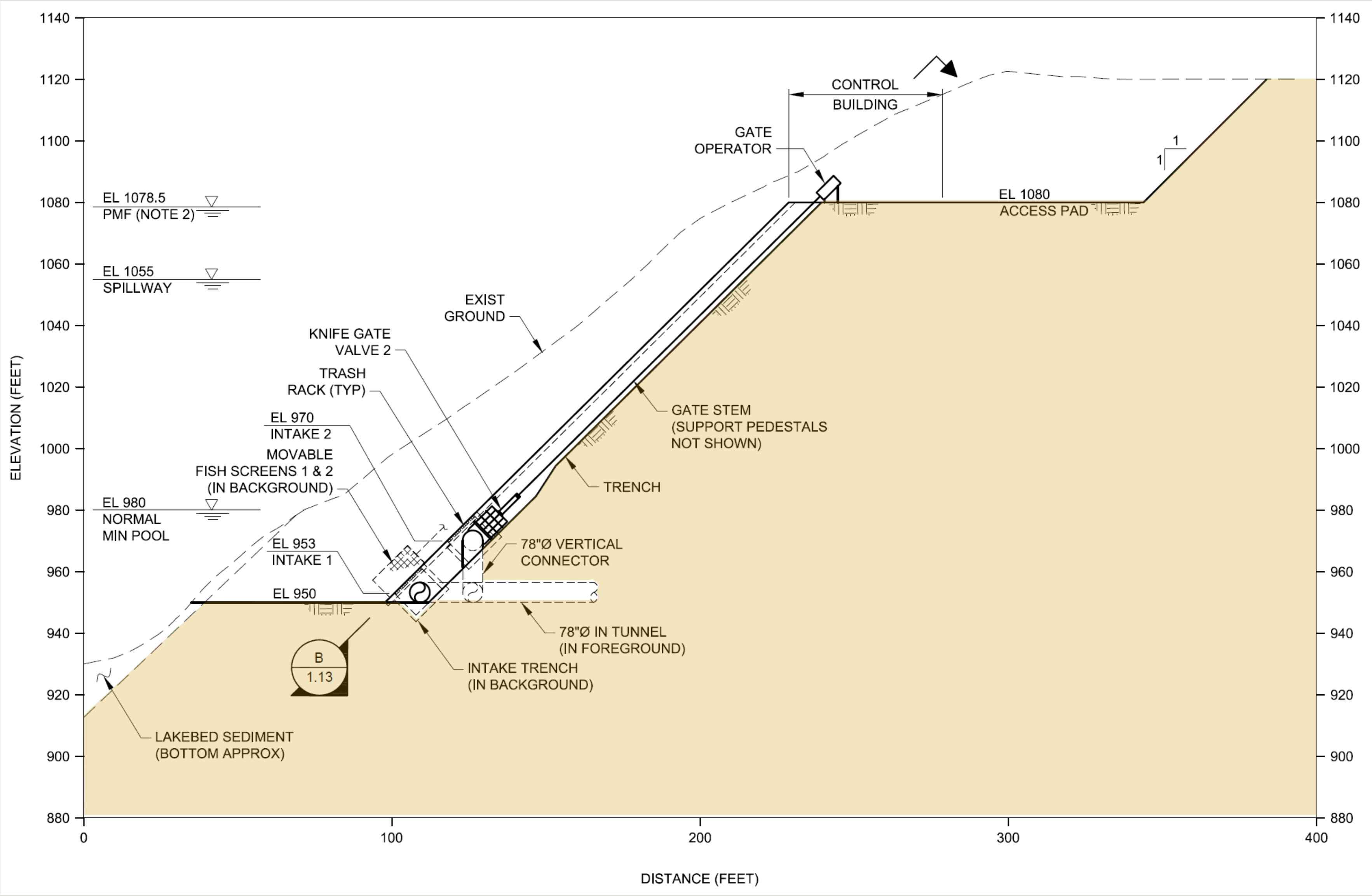
New Outlet Works Conceptual Design



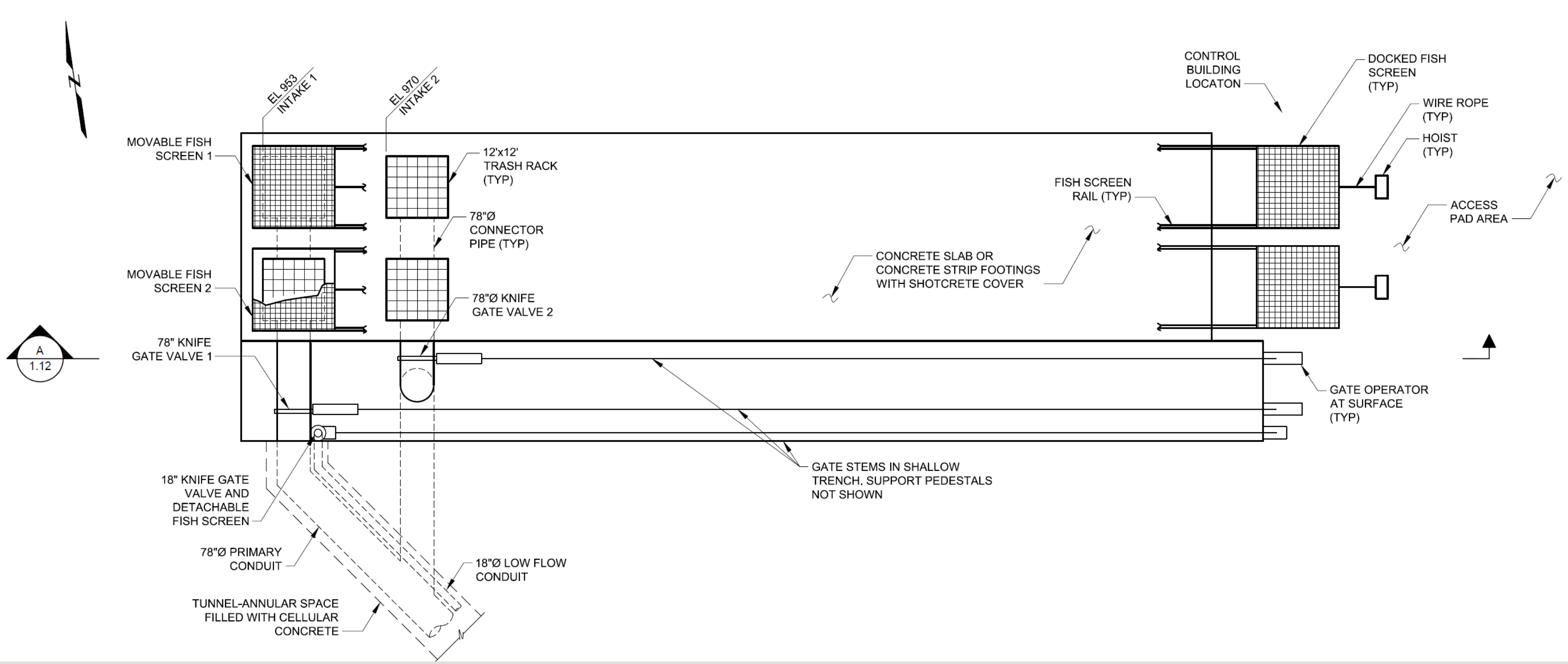
New Outlet Works Conceptual Design



New Outlet Works Conceptual Design



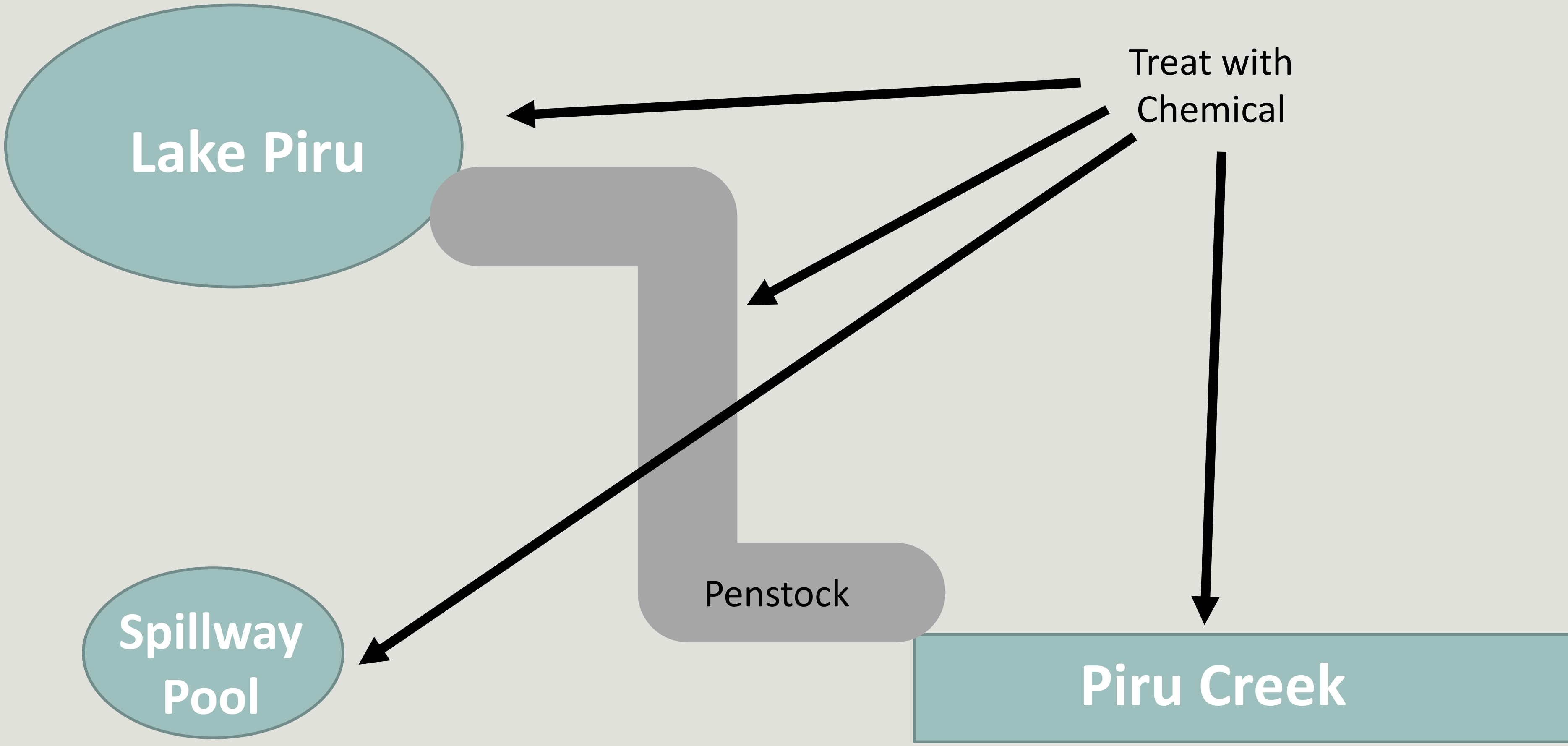
New Outlet Works Conceptual Design



Pilot Study Preliminary Results

Treatment	Concentration	Temperature		
		10°C	18°C	25°C
Potassium Chloride	Low (150 ppm)	N/A	N/A	Pending
	Medium (200 ppm)	N/A	18 days	Pending
	High (250 ppm)	N/A	14* days	Pending
Copper Sulfate Pentahydrate (EarthTecQZ)	Low (60 ppb)	N/A	N/A	Pending
	Medium (120 ppb)	27 days	24 days	Pending
	High (180 ppb)	21 days	15 days	Pending

Aggressive Treatment or Eradication



Regulatory Requirements:

Waivers to FERC license requirements (water release and recreation)

Application of EPA registered molluscicide

Section 7 Consultation under FESA - burden of proof that there are no effects to O. mykiss or there is an acceptable level of sublethal effects?????

FREEMAN DIVERSION QUAGGA MUSSEL CONTROL

FEASIBILITY ASSESSMENT AND PREFERRED ALTERNATIVES

Robert Richardson
Associate Engineer
UWCD

Quagga Mussel Control Options

CHEMICAL	BIOLOGICAL	PHYSICAL
Potassium Permanganate PROS: No DBPs, low dose for adult mussels CONS: Expensive, not acutely toxic to veligers, pink coloration	**Proprietary Molluskicides** PROS: May be effective for still water CONS: Likely ineffective for turbid water or rapid flow	**Ultraviolet Light** PROS: Disrupts target organism DNA rendering it unable to reproduce, no residuals left CONS: High power cost, high turbidity can render this technology ineffective
Chlorine PROS: Toxic to adults and veligers, relatively inexpensive CONS: Elevated DBP risk, toxic to other species, adults can close in response		**Thermal** High temperatures of over 100ºF are needed to achieve 100% mortality. Power plant heat or a large fuel source is needed for this option.
Chloramines PROS: Lower DBP risk compared to chlorine, longer lasting residual CONS: May be less toxic than chlorine, requires chlorine and ammonia storage		**Filtration** PROS: Can be highly effective at removing small particles if designed appropriately CONS: Small particles can pass through smaller pore sizes, affected by turbidity changes
Chlorine Dioxide PROS: Lower DBP risk compared to chlorine, reduced contact time CONS: Requires two chemical storage, chlorite/chlorate formation		**Coatings/Resistant Materials** Special coatings and smooth surfaces may prevent mussel attachment in structures, but the use of these has mixed success in the industry. Very difficult to apply for a large system.
Ozone PROS: Low DBP risk, stronger oxidant compared to chlorine, no residual left CONS: Bromate formation, very high cost, large footprint for on-site generation		**Turbulence** PROS: Turbulence over a certain period of time can result in high mortality rates of veligers CONS: Only works in certain locations with high-heads and controlled velocities
Deoxygenation Sodium sulfite can be added to water to scavenge oxygen. Large scale implementation has not been employed. Long-term effectiveness is unknown.		**Alternative Sources** Supplementation of water supply with a "veliger-free" source would help (such as recycled water), but would be insufficient to meet existing demand.
pH Control Quagga control involves pH ranges below 7 and above 9.5. Drinking water requires 6.5 to 8.5. Sulfuric acid can be added, but the long-term effectiveness is unknown.		**O&M** PROS: Control measures could be applied in specific locations, potentially lowest cost option CONS: Requires extensive monitoring, difficult to control
Copper/Potassium Sulfate PROS: Effective biocide, best applied to still water CONS: Copper in drinking water, could be toxic to multiple aquatic organisms and crops		
Proprietary Molluskicides PROS: May be effective for still water CONS: Likely ineffective for turbid water or rapid flow		

Could be implemented, with minor complications | **Could be implemented, with significant complications** | **Highly likely to be unsuccessful**

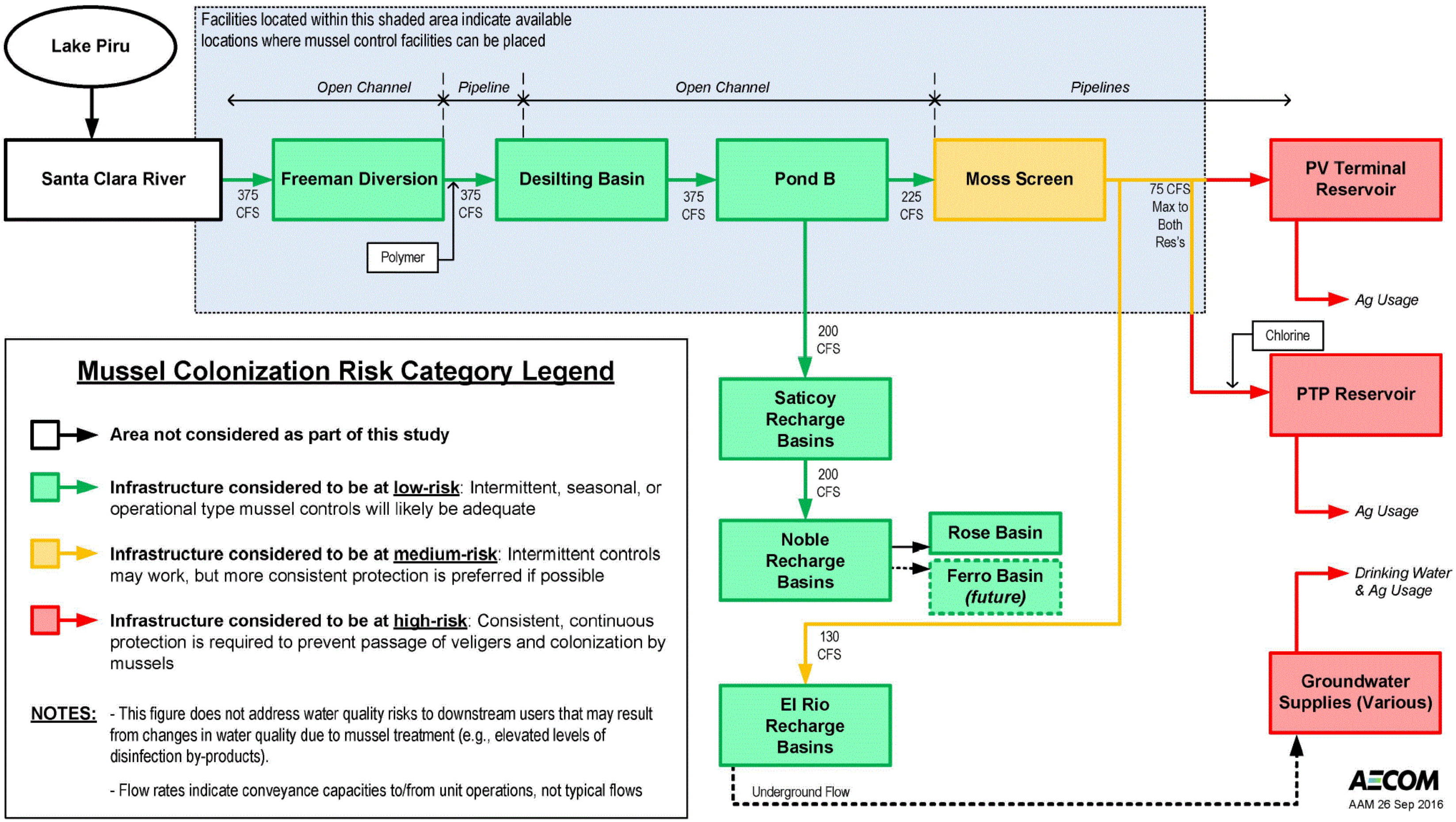


Figure 6-1. Infrastructure Overview and Locations Requiring Veliger/Mussel Control

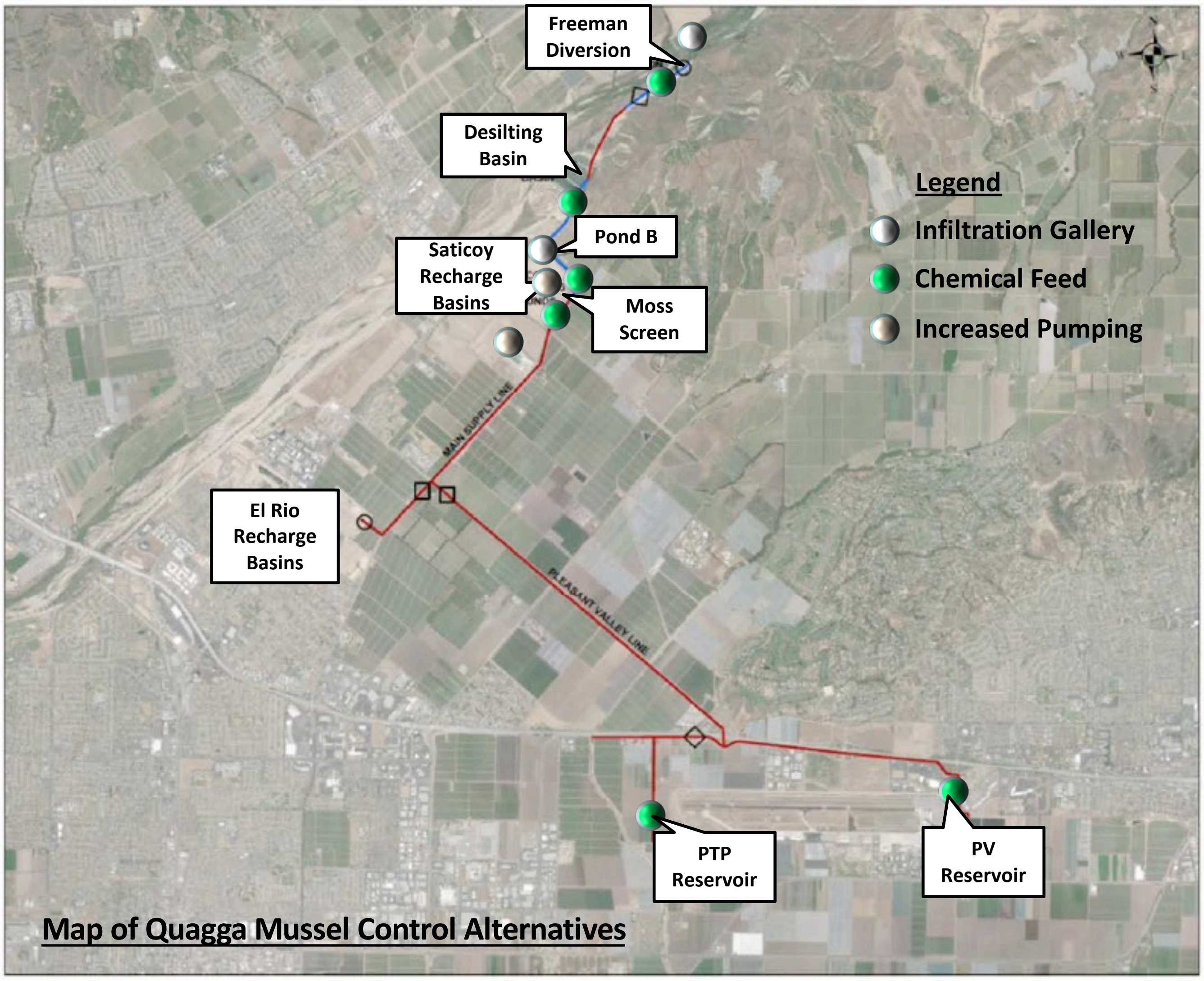

Freeman Diversion
Desilting Basin
Pond B
Saticoy Recharge Basins
Moss Screen
El Rio Recharge Basins
MAIN SUPPLY LINE
PLEASANT VALLEY LINE
PTP Reservoir
PV Reservoir
Legend
Infiltration Gallery
Chemical Feed
Increased Pumping
Map of Quagga Mussel Control Alternatives

Table 7-2. Multi-Criteria Analysis Categories and Resulting Rankings for Mussel Control Alternatives

Alternative	MCA Category Scoring From 1 to 5 (5 is Best)							
	Life-cycle Cost	Permitting	Constructability	Need for Secondary O&M	Footprint	Complexity	Additional Testing Required	Overall Risk Protection
1. River Infiltration Gallery	1	1	1	1	1	1	1	5
2a. Chemical Feed at Freeman	1	2	2	5	1	1	1	2
2b. Chemical Feed After Desilting Basin	1	2	2	5	1	1	1	2
3. Pond Infiltration Gallery	2	5	4	2	2	2	1	5
4. Increased Pumping at Recharge Basin	3	4	4	2	5	1	5	5
5a. Chemical Feed Before Moss Screen	4	4	4	3	2	2	2	2
5b. Chemical Feed After Moss Screen	4	4	4	2	2	2	2	2
6. Pre-Reservoir Chemical Feed	4	3	3	1	3	2	2	3
7. Non-Capital Facility Control	5	5	5	1	5	3	5	2
MCA Category Weightings:	***30%***	***5%***	***5%***	***10%***	***5%***	***10%***	***10%***	***25%***

RANK	ALTERNATIVE	RELATIVE PERFORMANCE	OVERALL RISK PROTECTION	20-YEAR LIFE CYCLE COST (MILLIONS OF $)	
				MIN	MAX
1	Non-Capital Facility Control	1.00	2	$3.4	$7.0
2	Increased Pumping at Recharge Basin	0.99	5 ☆	$22.8	$41.0
3 (TIE)	Pond Infiltration Gallery	0.80	5	$32.4	$53.5
3 (TIE)	Chemical Feed Before Moss Screen	0.80	2	$10.6	$24.6
3 (TIE)	Pre-Reservoir Chemical Feed	0.80	3	$4.7	$10.5
4	Chemical Feed After Moss Screen	0.77	2	$8.4	$19.0
5	River Infiltration Gallery	0.55	5	$41.8	$100
6 (TIE)	Chemical Feed at Freeman	0.48	2	$45.3	$85.6
6 (TIE)	Chemical Feed After Desilting Basin	0.48	2	$22.8	$53.5

☆ Most likely to guarantee 100% removal of quagga veligers