RECLAMATION

Managing Water in the West

A multiple stimulus fish barrier: laboratory and field evaluations

Dr. Mark Bowen – US Bureau of Reclamation, Denver CO, USA

Dr. Andy Turnpenny –Turnpenny Horsfield Aquatics, UK

Sam Johnston – HTI Inc, Seattle WA, USA

Dr. David Lambert -- Fish Guidance Systems Ltd, UK

Leslie Hanna – US Bureau of Reclamation, Denver CO, USA

Ray Bark - US Bureau of Reclamation, Denver CO, USA

Vivien Maisonneuve – SAIC, Inc.

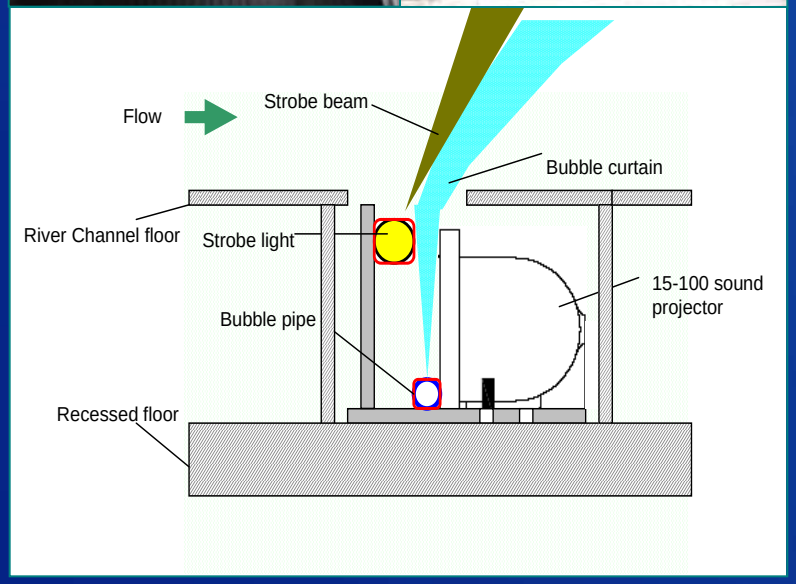
U.S. Department of the Interior
Bureau of Reclamation

Presentation Objectives

- Laboratory - Georgiana Slough Model
  - 1. Configuration I: 1 ft/s and 2.5 ft/s
  - 2. Configuration II: 1 ft/s and 1 ft/s
- Field Evaluations – Head of Old River
  - 1. 2009
  - 2. 2010
- Georgiana Slough

RECLAMATION

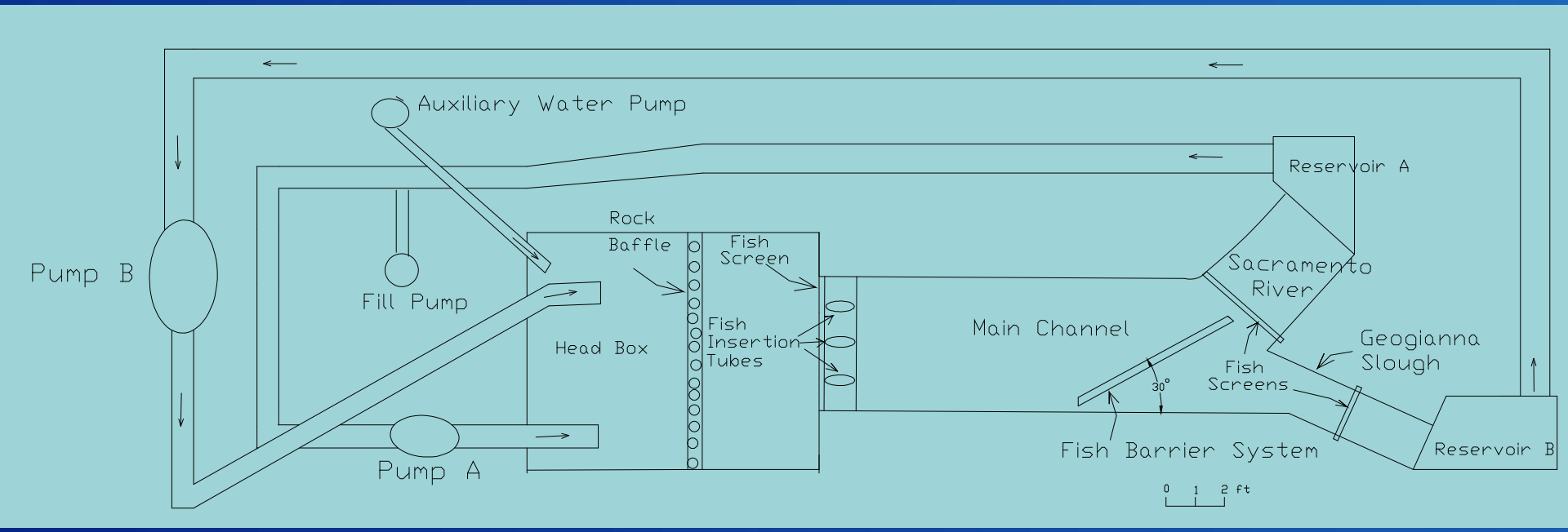
Non-Physical Fish Barrier Concept



- Combined multi-stimulus guidance system
- Angled across channel to guide fish
- Fixed to riverbed- minimal impact on navigation
- Uses patented sound + air bubble curtain (BAFF) + strobe lights
- Sound 5-600 Hz @160 dB re 1uPa; ambient within 3m
- Strobe 360 fpm

RECLAMATION

Georgiana Slough Model
Design Schematic



RECLAMATION

Configuration I

- Georgiana Slough Side: Mean velocity = 2.5 ft/s
- Sacramento River Side: Mean velocity = 1.0 ft/s

Configuration I – Delta Smelt Results

==========

Day, NTU=10, Barrier Off, NPB Deterrence Efficiency (DE) Mean = 37.8%.
Day, NTU=10, Barrier On, DE Mean = 52.6%.

Night, NTU=10, Barrier Off, DE Mean = 33.3%.
Night, NTU=10, Barrier On, DE Mean = 31.1%.

Day, NTU=30, Barrier Off, DE Mean = 35.1%.
Day, NTU=30, Barrier On, DE Mean = 33.5%.

Night, NTU=30, Barrier Off, DE Mean = 36.3%.
Night, NTU=30, Barrier On, DE Mean = 39.2%.

Table 1. Delta smelt deterrence efficiency (DE) at all completed combinations of time of day (Day, Night) and turbidity (10, 30 NTU).

Configuration I – Chinook Salmon Results

==========

Day, NTU=10, Barrier Off, DE Mean = 23.8%.
Day, NTU=10, Barrier On, DE Mean = 86.9%.

Night, NTU=10, Barrier Off, DE Mean = 19.6%.
Night, NTU=10, Barrier On, DE Mean = 41.6%.

Day, NTU=30, Barrier Off, DE Mean = 32.0%.
Day, NTU=30, Barrier On, DE Mean = 48.8%.

Night, NTU=30, Barrier Off, DE Mean = 35.2%.
Night, NTU=30, Barrier On, DE Mean = 51.7%.

Table 2. Chinook salmon deterrence efficiency at all completed combinations of time of day (Day, Night) and turbidity (10, 30 NTU).

RECLAMATION

Configuration II

- Georgiana Slough Side: Mean velocity = 1.0 ft/s
- Sacramento River Side: Mean velocity = 1.0 ft/s

Configuration II – Delta Smelt Results

==========

Day, NTU=10, Barrier “Off”, NPB Deterrence Efficiency (DE) Mean = 62.2%.
Day, NTU=10, All Barrier Components On, D Mean = 72.6%.
Day, NTU=10, Acoustic and Bubbles Only, D Mean = 83.6%.
Day, NTU=10, “Strobe Lights Only”, D Mean = 65.1%.

Night, NTU=10, Barrier “Off”, NPB D Mean = 55.5%.
Night, NTU=10, All Barrier Components On, D Mean = 52.8%.
Night, NTU=10, Acoustic and Bubbles Only, D Mean = 72.2%.
Night, NTU=10, “Strobe Lights Only”, D Mean = 58.8%.

Day, NTU=30, Barrier “Off”, NPB D Mean = 46.9%.
Day, NTU=30, All Barrier Components On, D Mean = 66.9%.

Night, NTU=30, Barrier “Off”, NPB D Mean = 52.9%.
Night, NTU=30, All Barrier Components On, D Mean = 50.6%.

Table 4. Delta smelt deterrence efficiency (D) at all completed combinations of barrier state (“Off”, “All NPB Components On”, “Sound and Bubbles”, “Strobe Lights Only”), time of day (Day, Night) and turbidity (10, 30 NTU).

RECLAMATION

Configuration II – Chinook Salmon Results

==========

Day, NTU=10, Barrier “Off”, NPB Deterrence Efficiency (D) Mean = 40.1%.
Day, NTU=10, “All Barrier Components On”, D Mean = 76.4%.
Day, NTU=10, “Acoustic and Bubbles Only”, D Mean = 80.8%.
Day, NTU=10, “Strobe Lights Only”, D Mean = 66.5%.

Night, NTU=10, Barrier “Off”, D Mean = 45.7%.
Night, NTU=10, “All Barrier Components On”, D Mean = 70.9%.
Night, NTU=10, “Acoustic and Bubbles Only”, D Mean = 81.3%.
Night, NTU=10, “Strobe Lights Only”, D Mean = 81.4%.

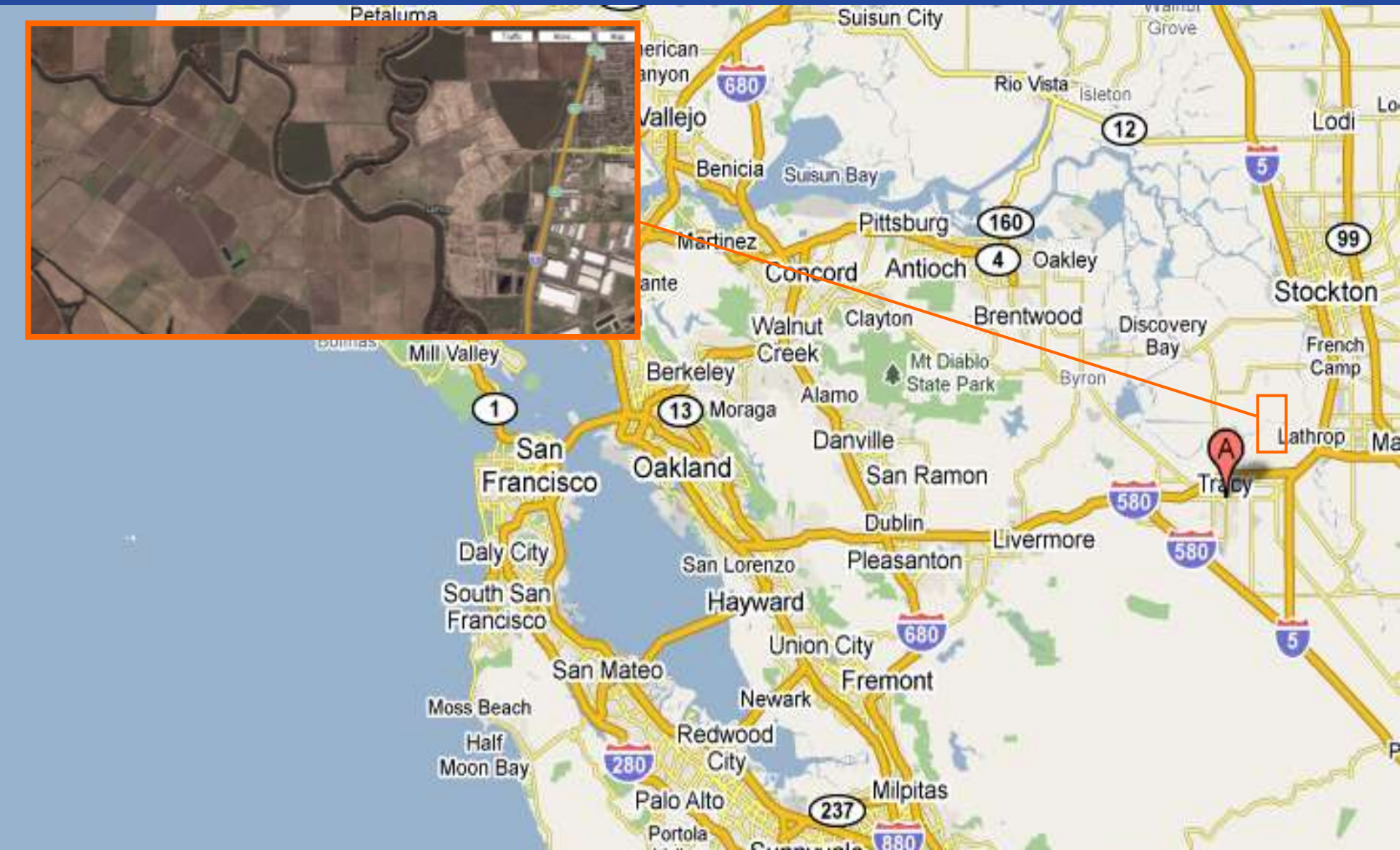
Day, NTU=30, Barrier “Off”, D Mean = 69.8%.
Day, NTU=30, Barrier “On”, D Mean = 79.9%.

Night, NTU=30, Barrier “Off”, D Mean = 73.1%.
Night, NTU=30, Barrier “On”, D Mean = 72.4%.

Field Evaluation I
Old River Barrier
2009

RECLAMATION

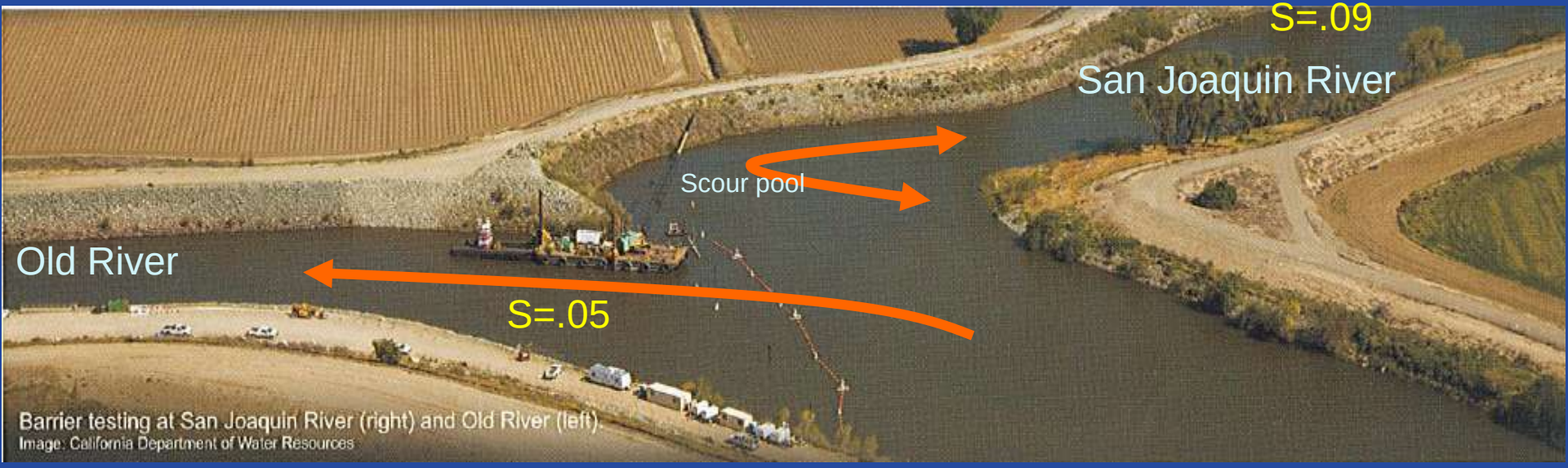
Project Location



Temporary Rock Barrier, Head of Old River

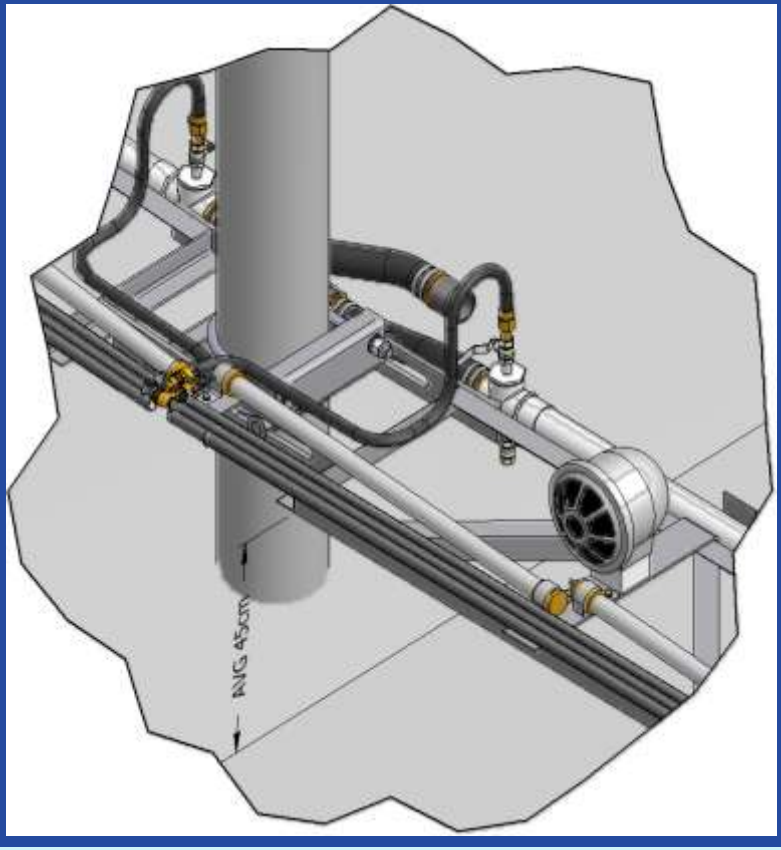
RECLAMATION

San Joaquin- Head of Old River Divergence



- River width upstream ~90m, depth up to 5+ m (tidal)
- Strong bedload movement of silt, sand, and gravel
- Water is moderately turbid (<1m visibility)

Barrier Construction-Detail at Pile



- Note clearance of 45cm from bed to allow bedload movement and sturgeon passage

Barrier Under Construction

RECLAMATION

Barrier During Operation

Control Equipment

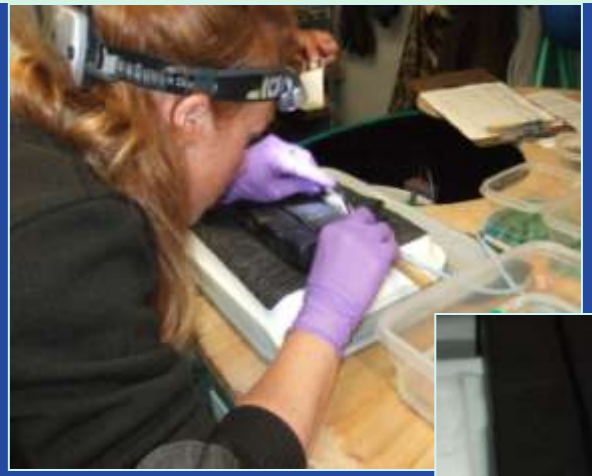
Compressors & Generators

Barrier Evaluation

Smolt Tagging and Release

- 933 tagged hatchery smolts released 24 km upstream as part of Vernalis Adaptive Management Program (VAMP)
- VAMP assesses survival rates through the Delta
- Fitted with HTI Model 795 acoustic tags
- Held overnight before release
- Released in 7 batches of ~135 fish: 3 day and 4 night releases between April 22nd and May 13th 2009
- Releases 3-4 days apart to separate for independence of observations

Chinook tagging at USBR Tracy Laboratory



Acoustic Telemetry

Hydrophones and Barrier Location

- Tag 6514 shown here: 6.514 s between pulses
- HTI tracking system at barrier provided real-time 2-D tracking via 4 hydrophones
- HTI Model 291 4-port receiver
- Resolution ~1 m

RECLAMATION

Trial Design

- Barrier operated "**OFF**" and "**ON**" after each release to increase sample size
- Initial barrier state for each release was randomly selected
- Real-time monitoring allowed us to switch operating state when we estimated 50% had passed. Then, barrier was switched every 25 hr after that first switch.
- Post processing, fixed station data from Old River, and mobile monitoring data allowed us to use tracking data to determine 1 of 5 outcomes:

1. Fish crosses barrier line to enter Old River (OR)
2. Fish continues down San Joaquin River (SJR)
3. Fish eaten by predator
4. Never arrived at Barrier
5. Unknown

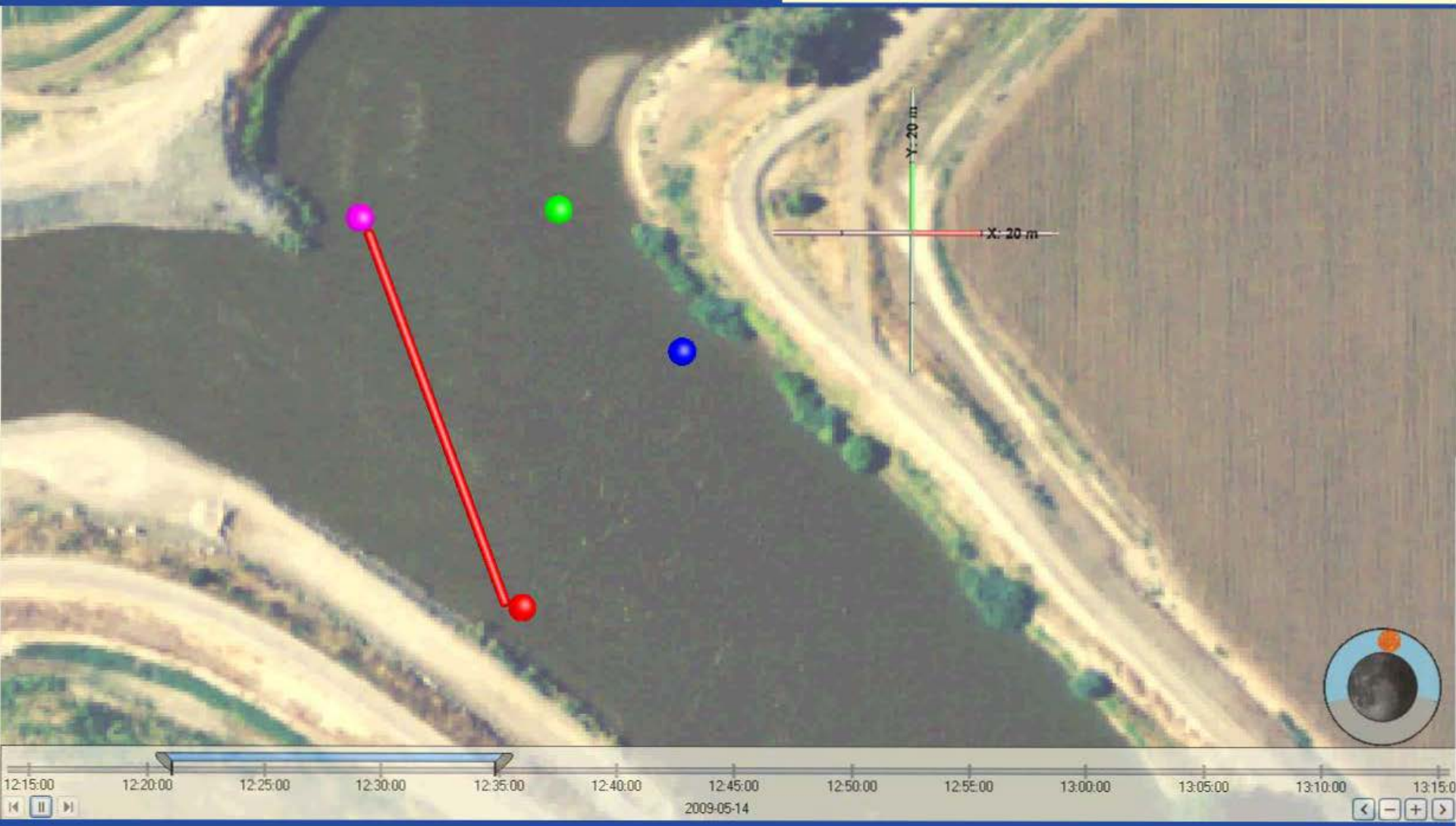
Acoustic Telemetry

Hydrophones and Barrier Location

- 575 of 933 fish released (61.6%) reached barrier tracking arena, indicating high losses during 24km river passage

RECLAMATION

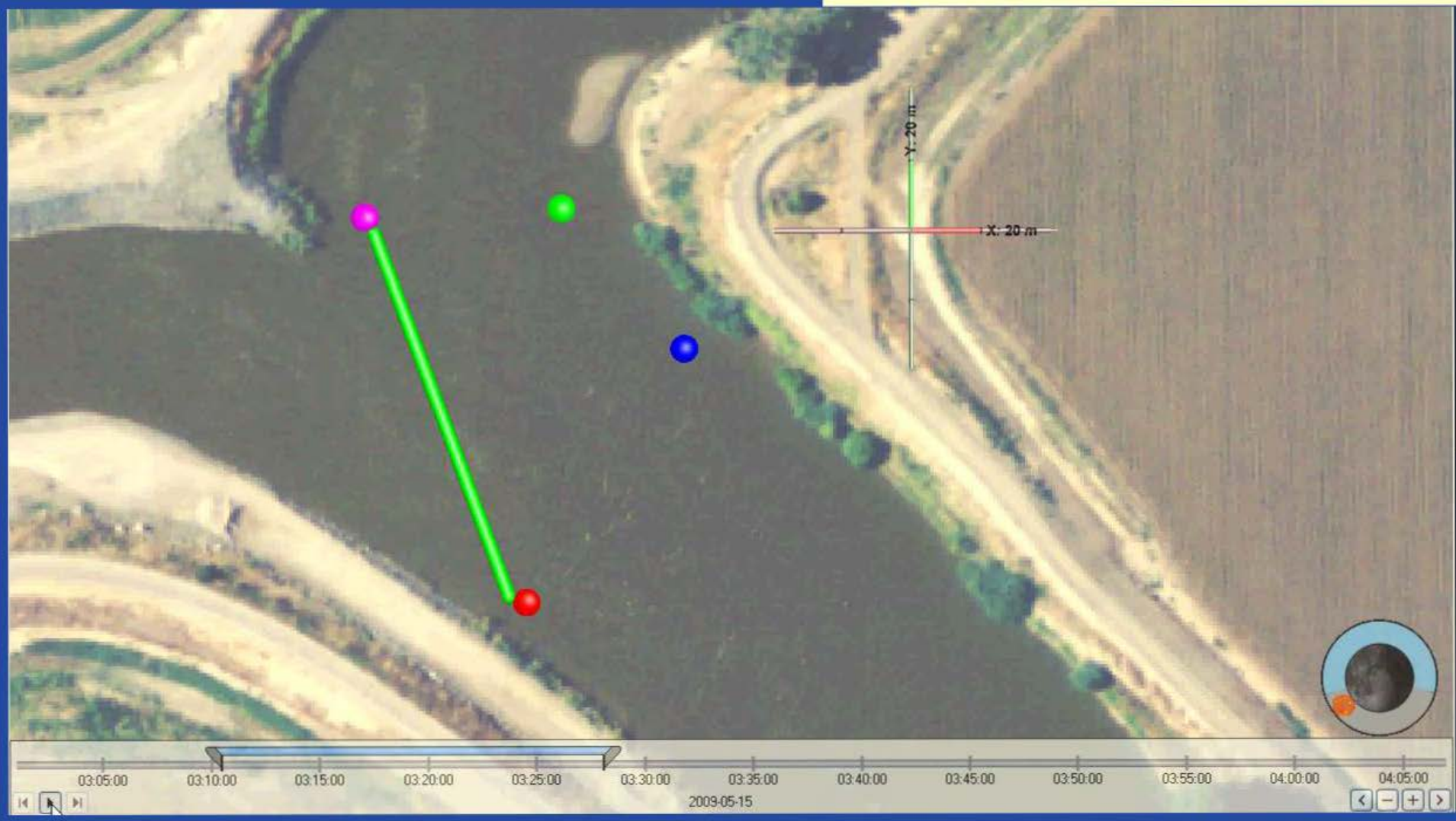
Tag 5072, May 14, 12:41 hr: BAFF Off - Undeterred



RECLAMATION

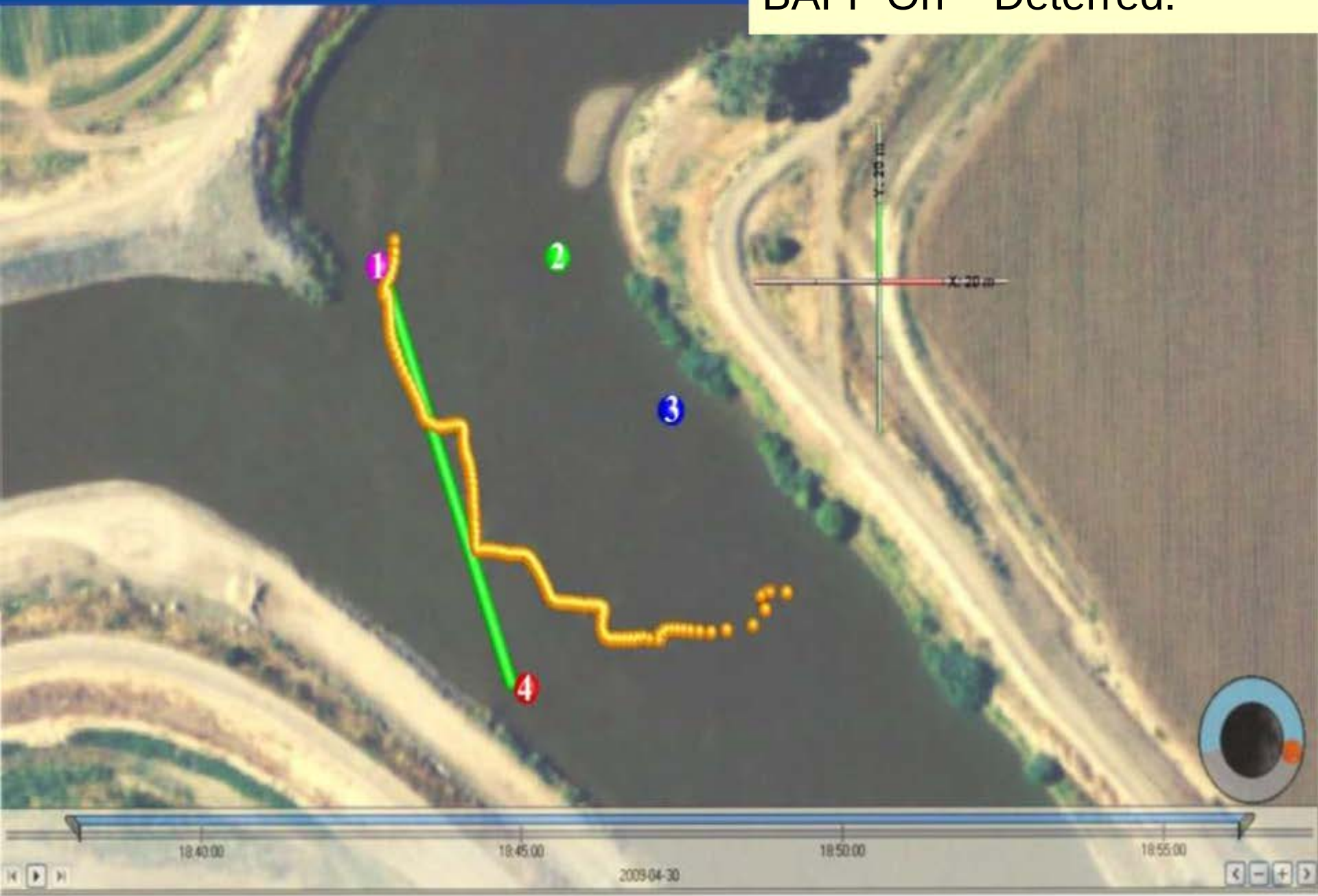
Tag 6514, May 15, 00:37 hr: BAFF On – Undeterred.

Tag 5674, May 15, 03:38hr: BAFF On – Deterred

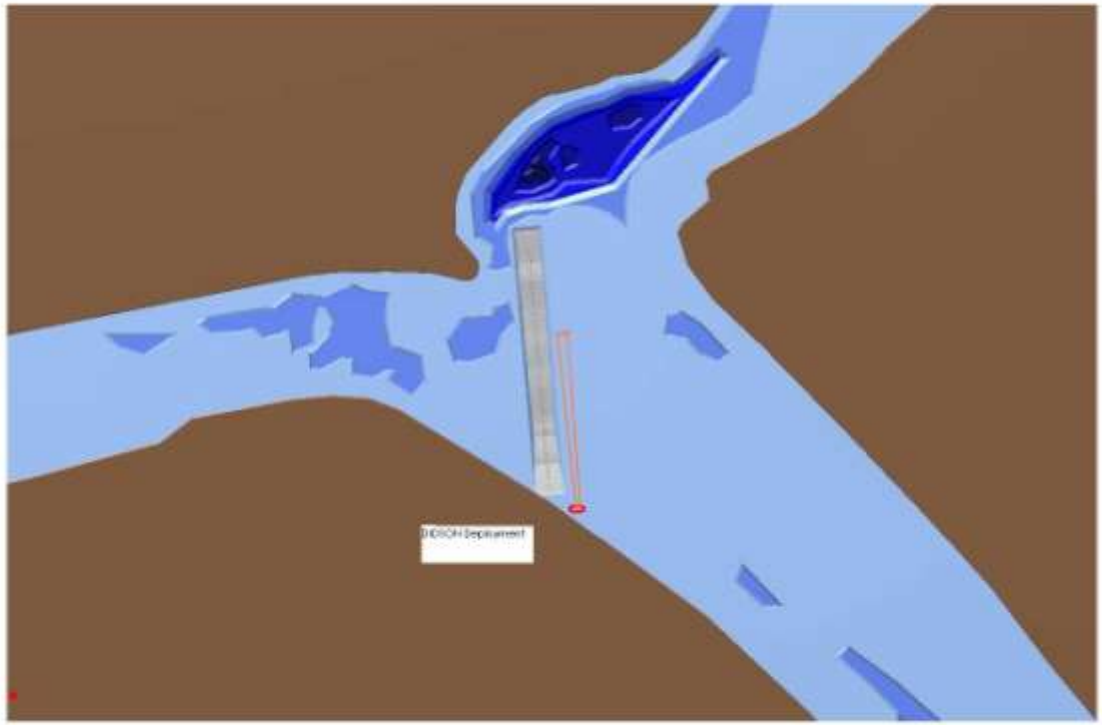


RECLAMATION

Tag 5344, April 30, 18:46hr:
BAFF On – Deterred.

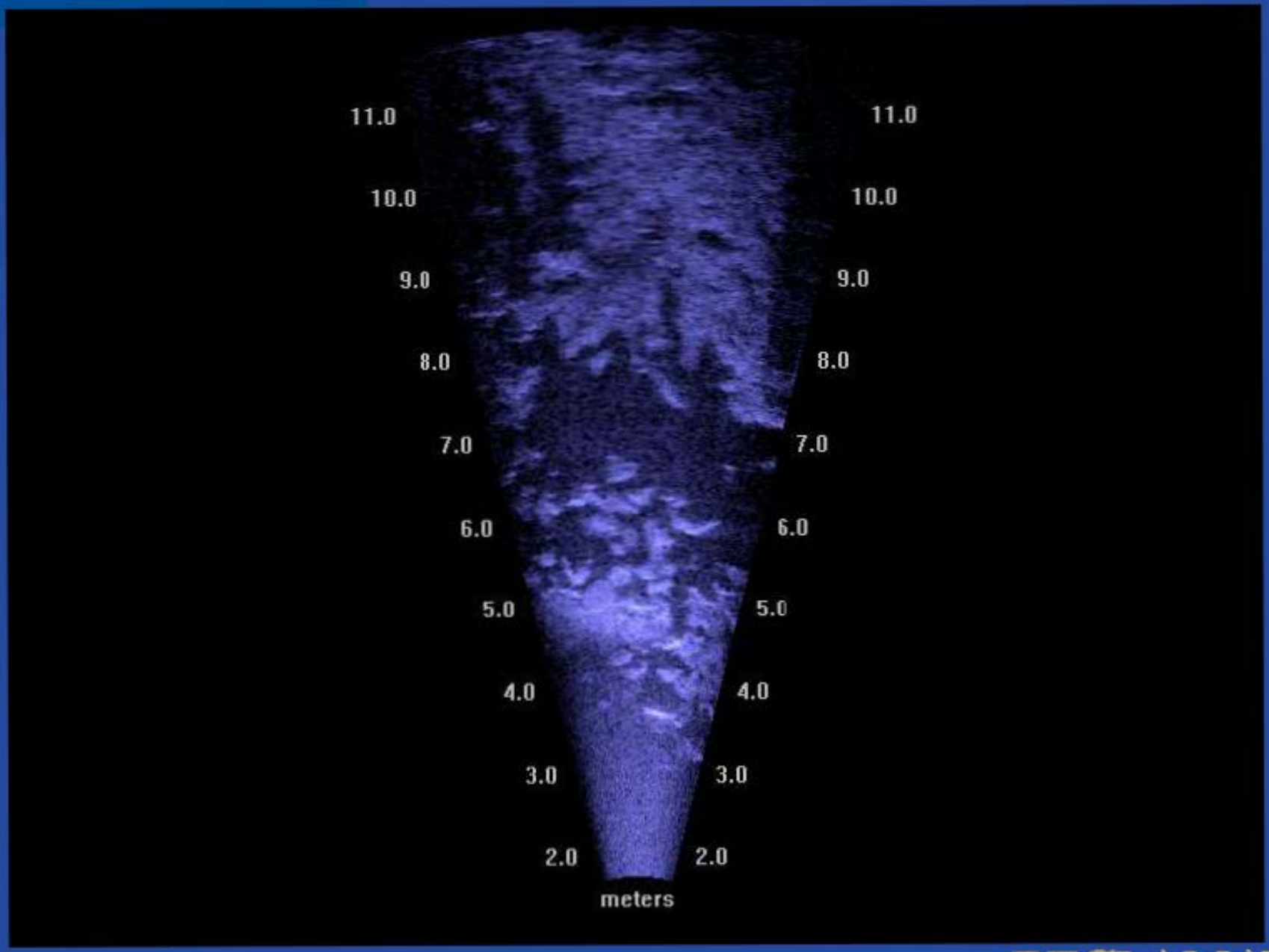


Analyzing Predator Behavior



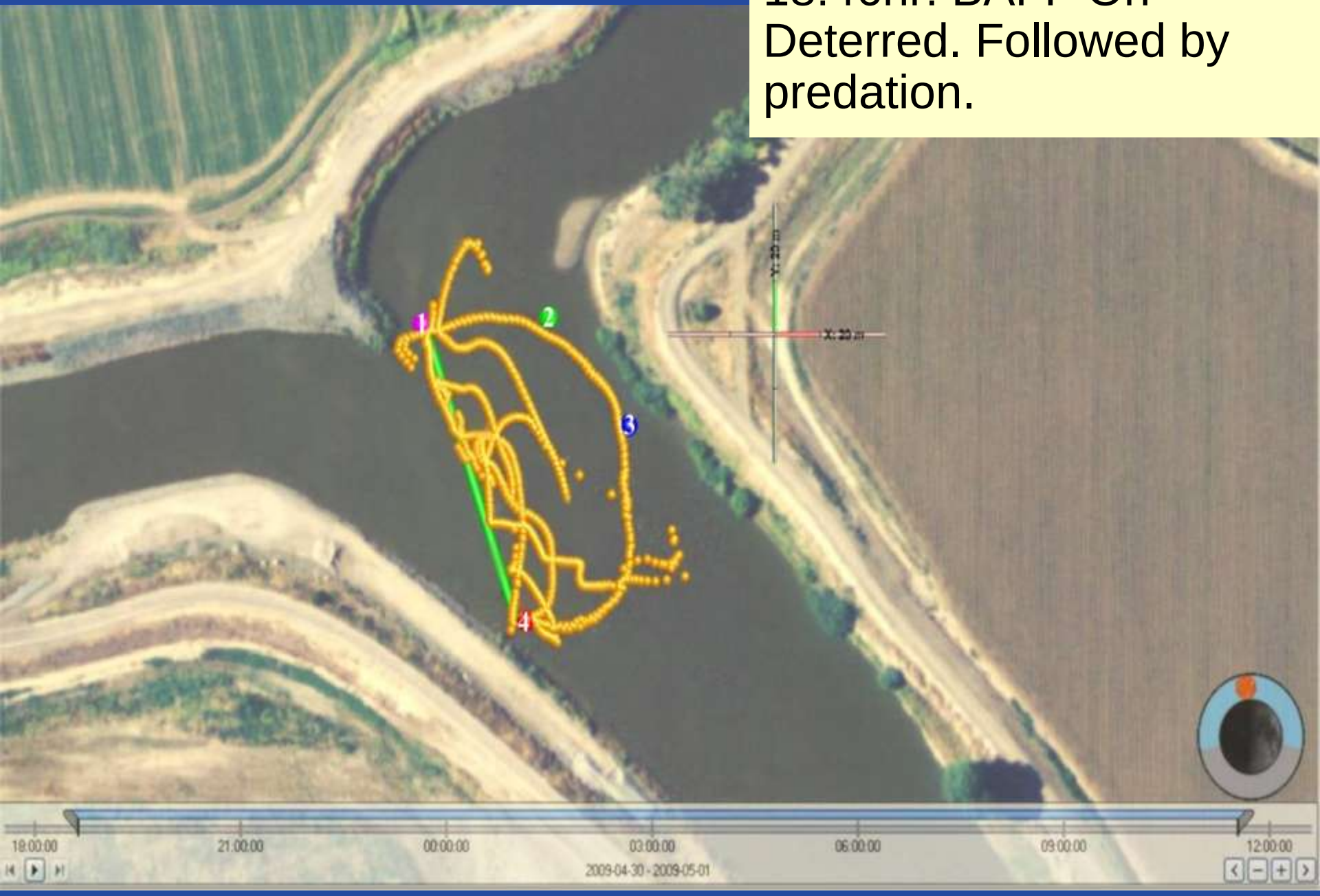
DIDSON Deployment and Beam Orientation

Predator Behavior



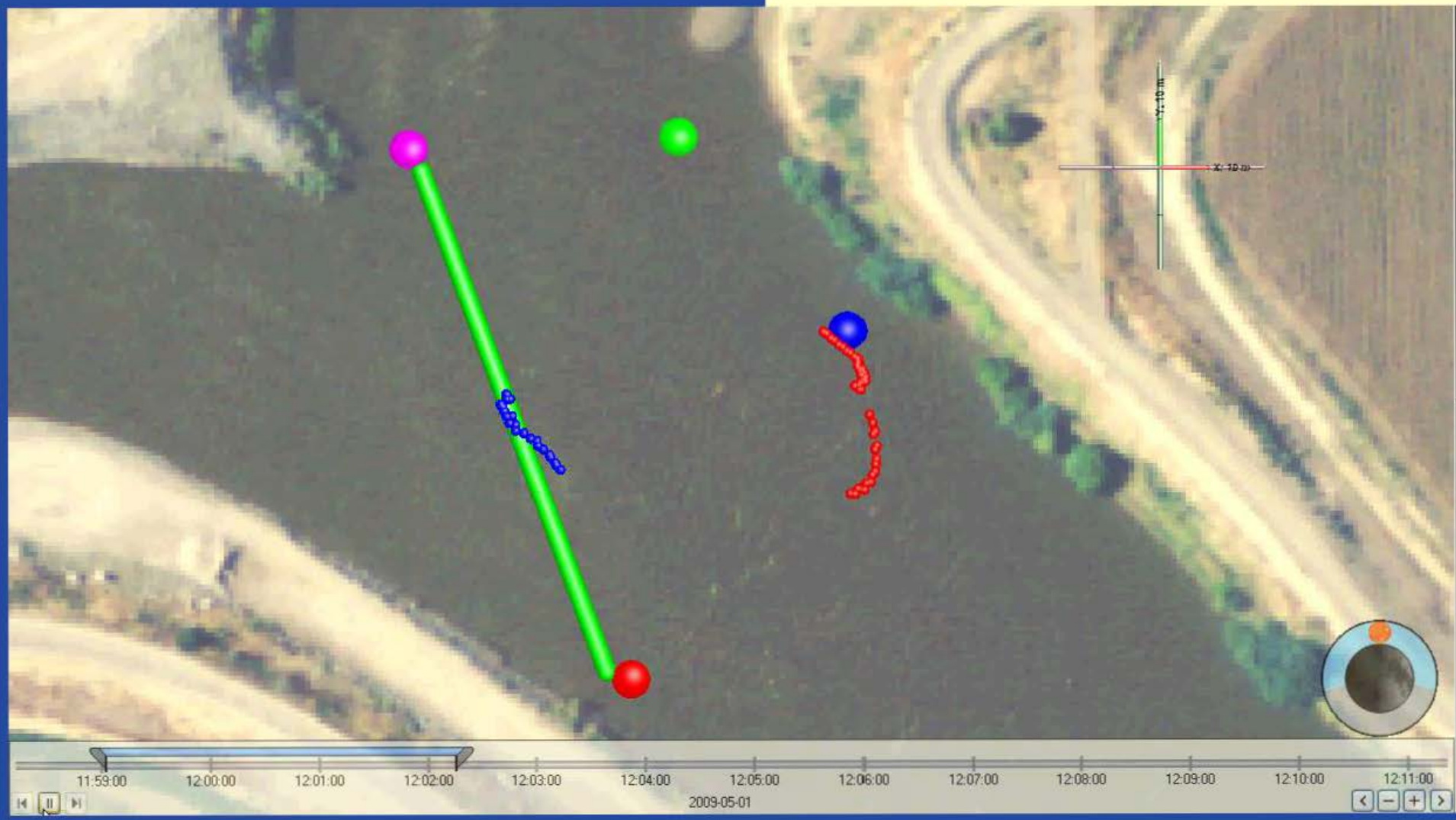
RECLAMATION

Tag 5344, May 30, 18:46hr: BAFF On – Deterred. Followed by predation.



Tag 6786 in Blue

Tag 6800 in Red



RECLAMATION

Grand Deterrence Efficiency was estimated at

81.4%

with barrier operating.

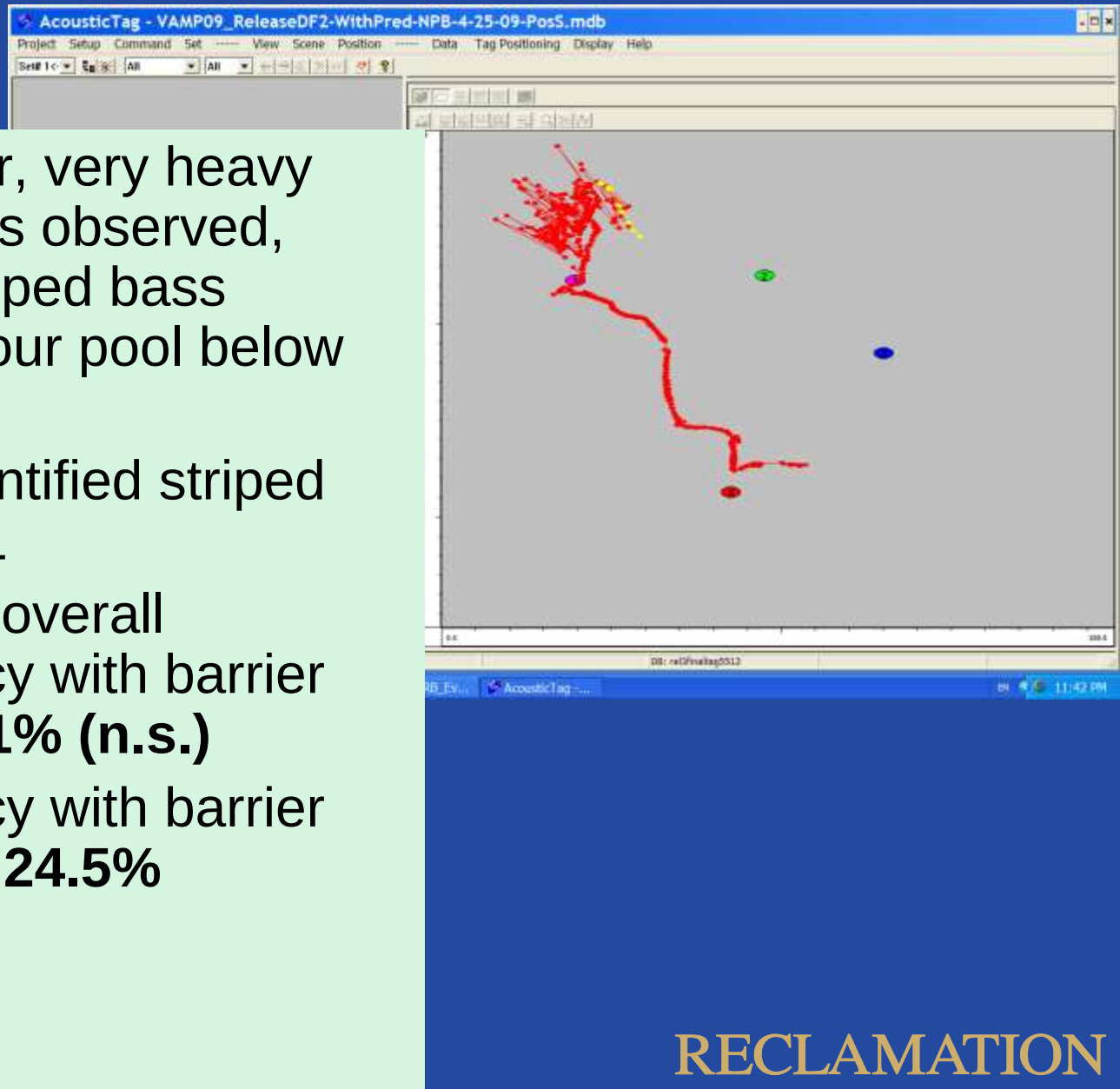
Barrier Deterrence Efficiency

Release No	Percent Deterrence
1	91.7 %
2	90.9 %
3	61.9 %
4	93.8 %
5	100 %
6	60.0 %
7	63.0 %
Grand Efficiency	**81.4 %**

(Kruskal-Wallis X^2 = 9.800, p = 0.0017: ‘highly significant’).

Predation and Its Effects

2009 Effect of Predation Before and After Deterrence



- During this dry year, very heavy smolt predation was observed, associated with striped bass concentrated in scour pool below barrier
- Didson camera identified striped bass 60-140 cm TL
- Predation reduced overall Protection Efficiency with barrier ‘on’ for smolts to **31% (n.s.)**
- Protection Efficiency with barrier ‘off’ for smolts was **24.5%**

RECLAMATION

2009 Smolts Lost or Eaten Before and After Deterrence

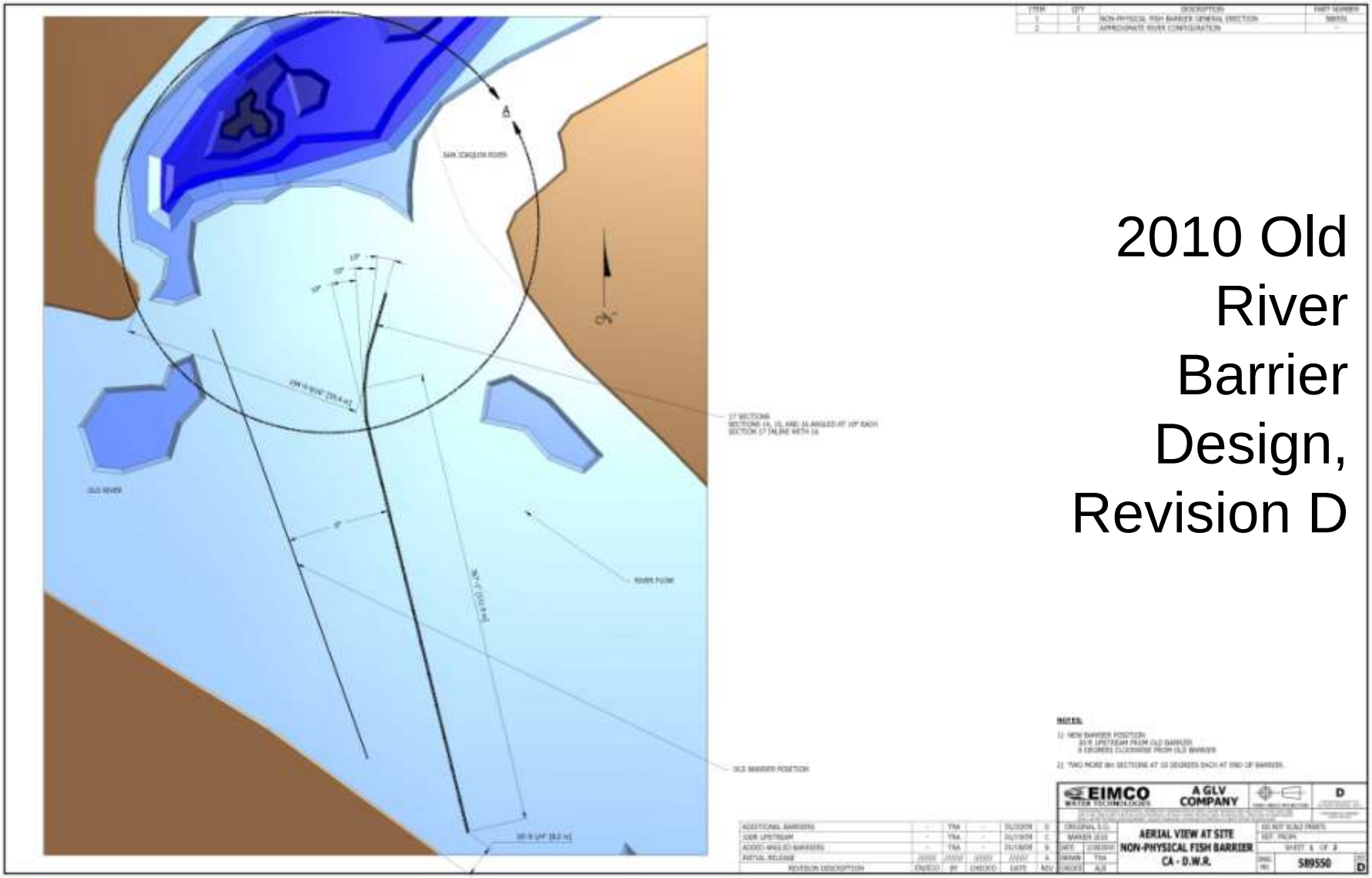
Release	Number Released	Proportion Never Arrived at ORB	Proportion Consumed in ORB area	Total Dead Combined Proportion (before and in ORB area)
1	133	0.466	0.128	0.594
2	134	0.276	0.366	0.642
3	134	0.201	0.478	0.679
4	134	0.455	0.358	0.813
5	132	0.311	0.379	0.689
6	133	0.609	0.143	0.752
7	133	0.368	0.353	0.722

RECLAMATION

San Joaquin/Old River Divergence

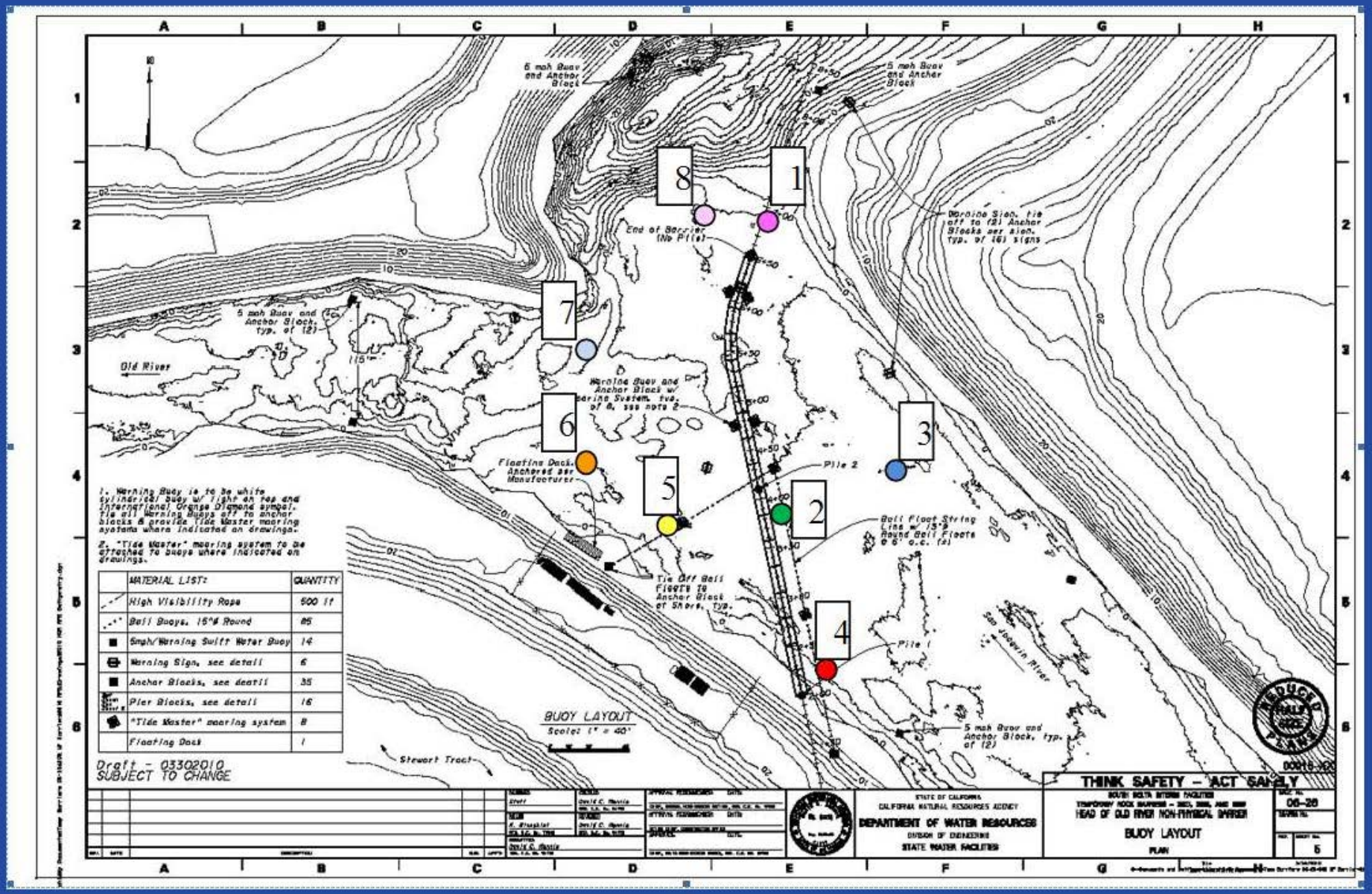
RECLAMATION

Field Evaluation II
Old River Barrier
2010



2010 Old River Barrier Design, Revision D

2010 Hyrophone Arrangement

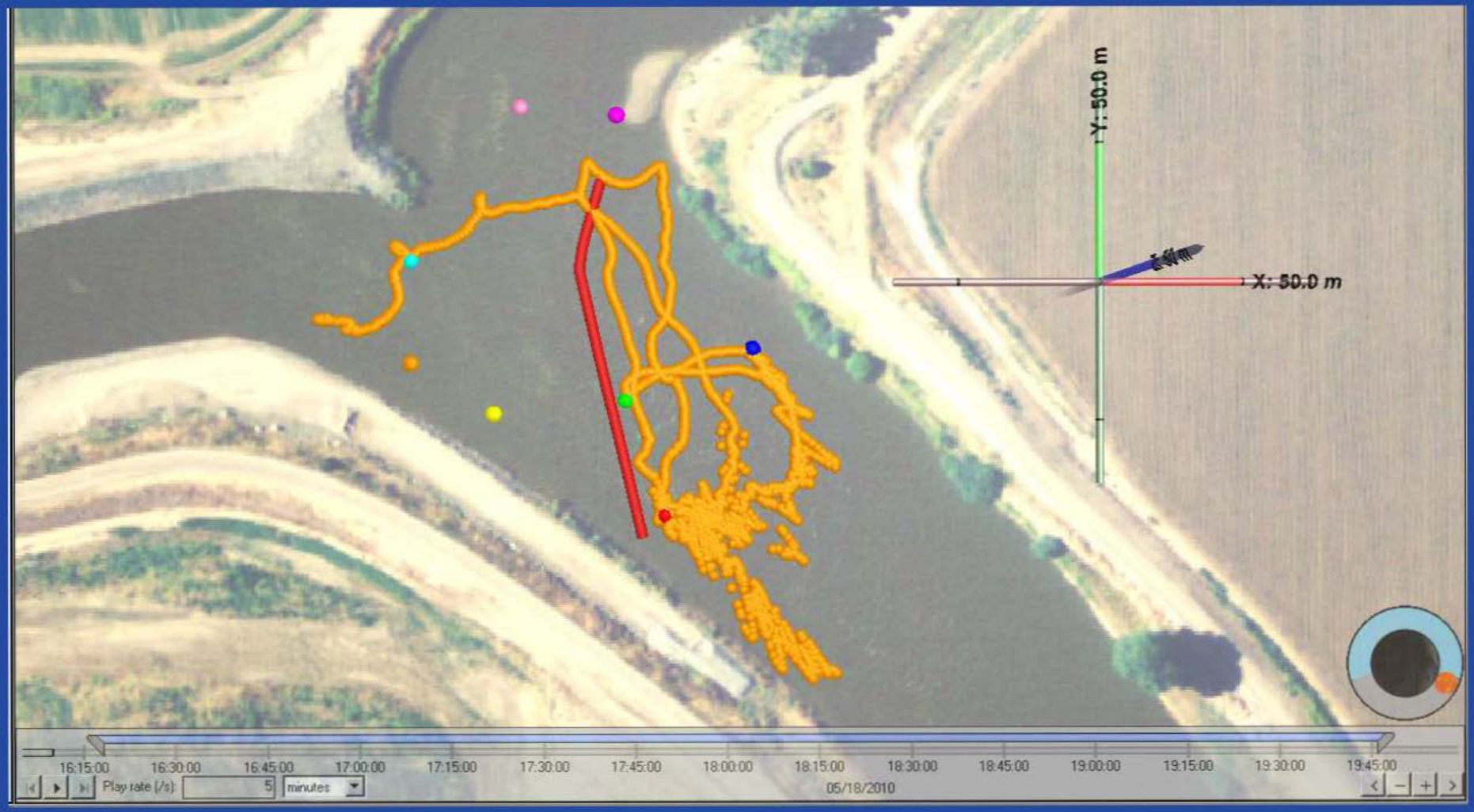


RECLAMATION

2010 BAFF Repairs

Date	Location	Work Performed
5/3/10	Frame 6	Replace bubbler hose
5/6/10	All Frames	Increased intensity of power supplied to sound projectors
5/7/10	Frames 4 and 13	Purged valves to regain consistent bubble curtain
5/13/10	Frame 6	Purged valves to regain consistent bubble curtain
5/19/10	Frame 6	Purged valves to regain consistent bubble curtain
5/26/10	Frame 6	Purged valves to regain consistent bubble curtain
6/1/10	Frame 6	Purged valves to regain consistent bubble curtain
6/7/10	Frame 3	Replace one high intensity LED MIL

2010 Striped Bass 2472



RECLAMATION

2010 Smolts Lost or Eaten Before and After Deterrence

Number Release	Released	Proportion Never Arrived at ORB	Proportion Consumed in ORB area	Total Dead Combined Proportion (before and in ORB area)
1	74	0.081	0.257	0.338
2	71	0.028	0.169	0.197
3	73	0.082	0.205	0.287
4	72	0.042	0.194	0.236
5	71	0.042	0.183	0.225
6	74	0.068	0.270	0.338
7	73	0.205	0.370	0.575

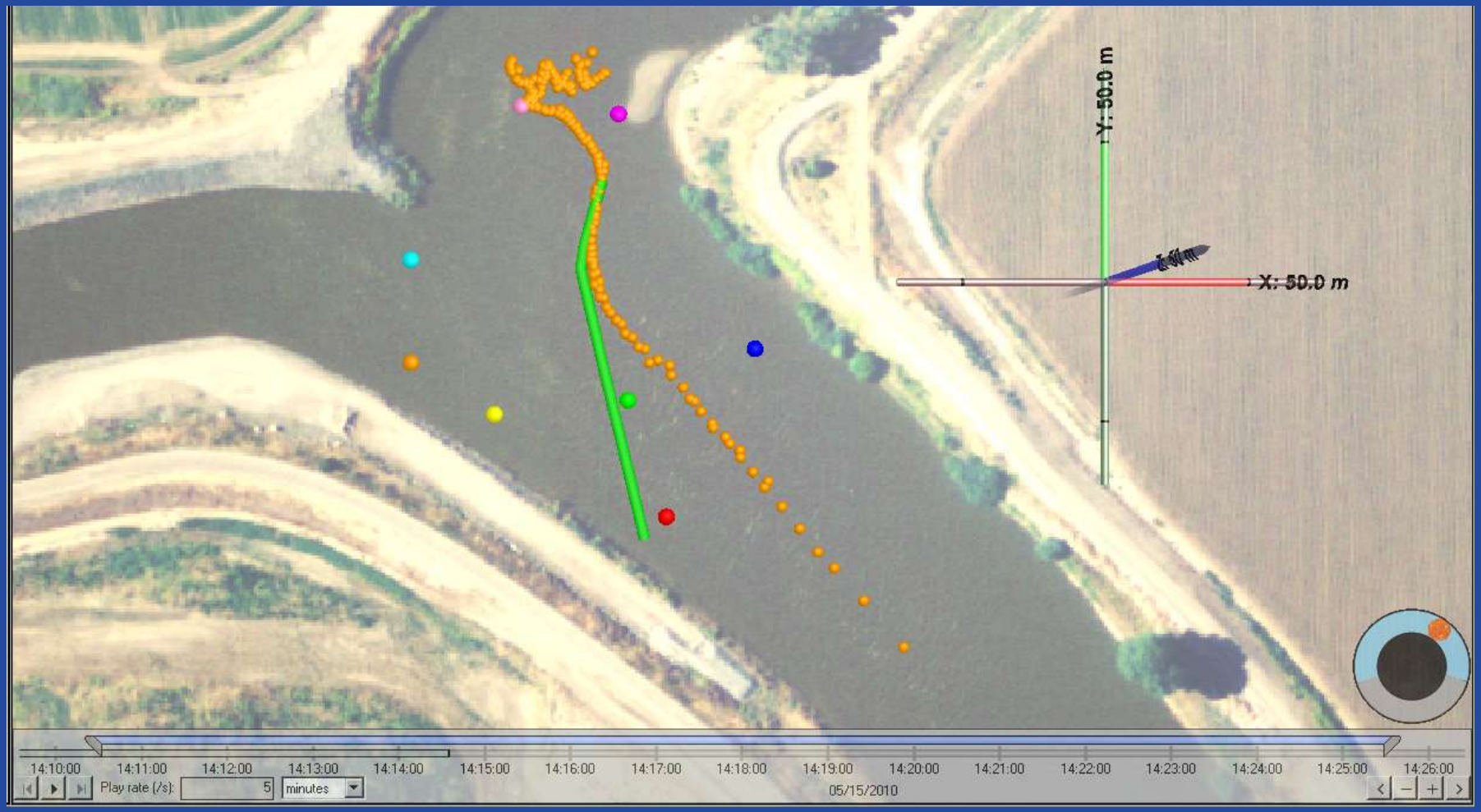
RECLAMATION

2009 and 2010 Smolts Lost or Eaten Before and After Deterrence

	2009 Proportion Eaten at ORB	2010 Proportion Eaten at ORB	2009 Eaten before and at the ORB	2010 Eaten before and at the ORB
	0.118	0.257	0.594	0.338
	0.346	0.169	0.642	0.197
	0.400	0.205	0.679	0.287
	0.279	0.194	0.813	0.236
	0.353	0.197	0.689	0.239
	0.135	0.270	0.752	0.338
	0.296	0.370	0.722	0.575
Mean	0.275	0.238	0.699	0.316

RECLAMATION

Tag 8073. Deterred on 5/15/10 at 14:00 hr.



RECLAMATION

2010 Deterrence Efficiency

Release No	Percent Deterrence
1	7.7 %
2	13.2 %
3	2.6 %
4	23.1 %
5	12.5 %
6	41.2 %
7	66.7 %
Grand Efficiency	**23.0 %**

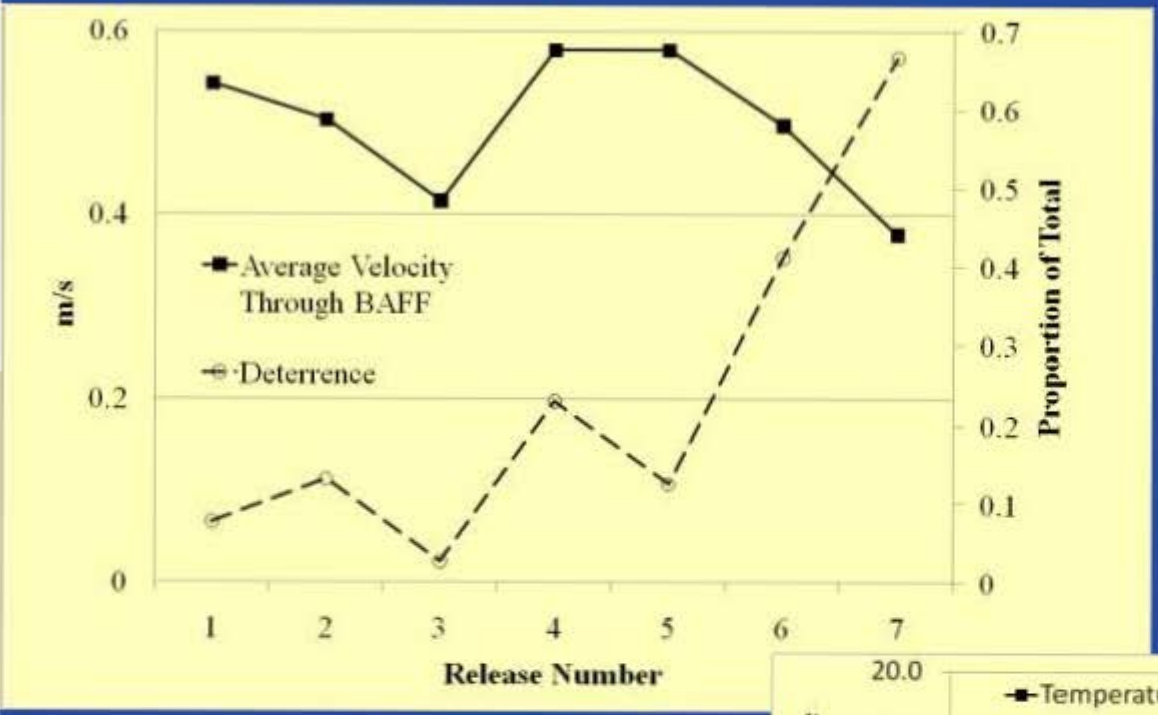
2010 Protection Efficiency

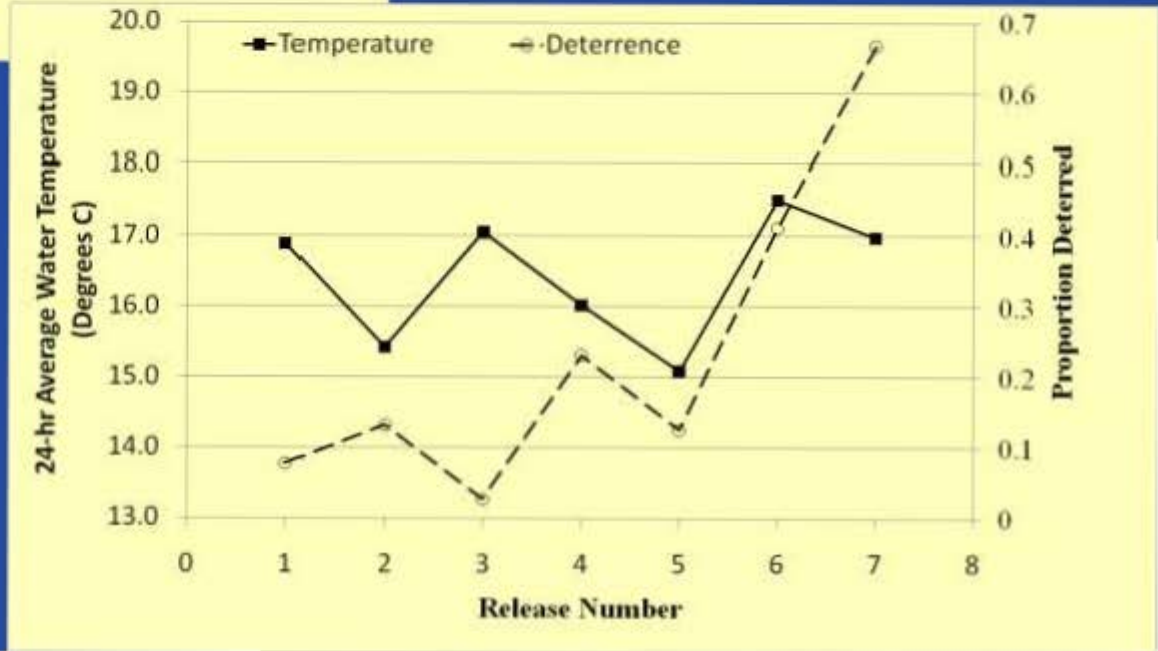
Release No	Percent Protection
1	45.8 %
2	45.2 %
3	31.0 %
4	45.2 %
5	42.1 %
6	42.1 %
7	60.0 %
Grand Efficiency	**43.1 %**

2009 and 2010 Discharge Statistical Moments

	2009(cms)	2009(cfs)	2010(cms)	2010(cfs)
Min	-50.1	-1771	22.2	785
25th Percentile	-17.5	-619	61.7	2179
Median	32.8	1158	77	2721
75th Percentile	44.6	1575	90.2	3186.5
Max	65.1	2300	100.6	3554

2010 Old River Barrier



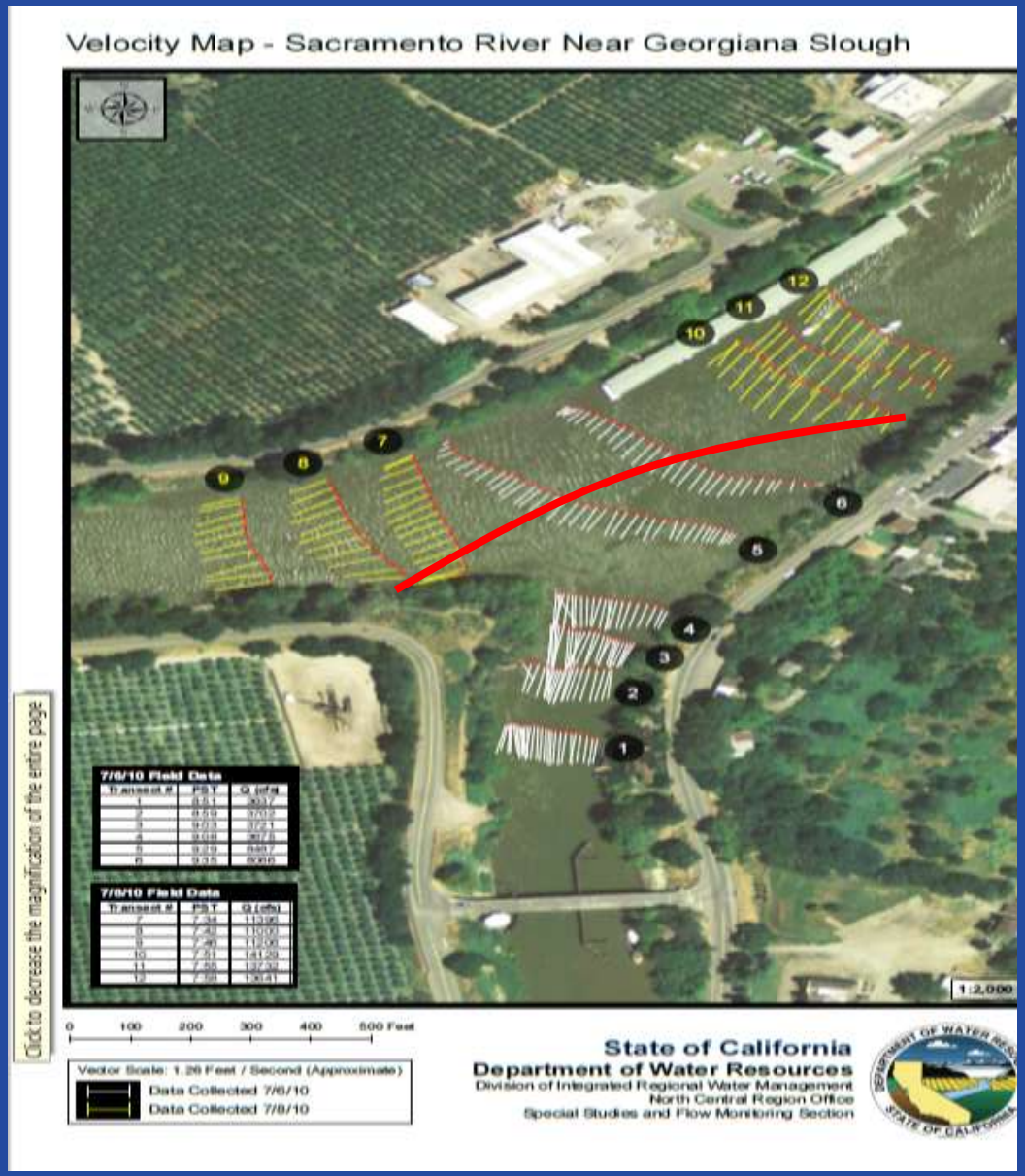


Conclusions I

- In 2009, a dry year, hatchery-reared chinook highly susceptible to predation during river passage
- The multi-stimulus barrier was very effective (81.4%) for diverting chinook smolts
- Benefit of 2009 barrier reduced by predation after deterrence
- 2009 Protection Efficiency was (30.1%)
- A majority of the predation events occurred in or near the scour pool below barrier

Conclusions II

- 2010 deployment used a curved configuration to guide smolts toward San Joaquin River
- The 2010 BAFF was not very effective (23.0%) for deterring chinook smolts
- Poor deterrence probably a function of
  - Higher Q, higher velocities in 2010
  - Steeper BAFF angle (30 degrees)
  - Curved section of BAFF
- Higher flows and BAFF guidance combined to produce significantly higher Protection Efficiency (43.1%)
- Chinook travel speeds are higher in 2010 than in 2009
- Experimental predator relocation while the BAFF operates in 2011 should provide a solution to the predation problem



Georgiana Slough Bio-Acoustic Fish Fence 2011 Deployment

RECLAMATION

Tag 5674. Deterred. No Predation.

RECLAMATION

The End

Special thanks to:

Vernalis Adaptive Management Program (VAMP)

Facility Locations within the UK

RECLAMATION

Backbarrow Power Plant

RECLAMATION

Comparison to Other NPBs

Backbarrow BAFF: 92.7%

RECLAMATION

River Frome NPB and Fish Counter

- Runs of Atlantic salmon and sea trout
- NPB is a Bio-Acoustic Fish Fence (BAFF) like that used in the San Joaquin R., CA

3 Oceans Winter Salmon Adult

~1974

RECLAMATION

RECLAMATION

Comparison to Other NPBs

River Frome BAFF: 80-98%

2009 Dry Year, Calculate Smolt Increase

- A quick calculation to determine smolt increase from BAFF operation
- Suppose 100,000 smolts depart DF
- No Barrier: 3,408 arrive at Chipps Island
- BAFF in operation: 4,706 arrive at Chipps Island
- 1,297 more smolts arriving at Chipps