DRAFT ANNUAL REPORT

2012–2014
Fish Entrainment, Impingement, and Predator Monitoring Results for Freeport Regional Water Authority's New Water Intake Fish Screen

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February 2015

This annual report was prepared by FRWA's environmental consultant, ICF International (ICF). The ICF core team of Gregg Ellis, Monique Briard, and Jeff Kozlowski has led the environmental permitting and regulatory compliance requirements for FRWA since 2006. Since 2011, FRWA has committed over $1M to fund the evaluation of the Freeport water facility intake fish screens and organized a monitoring team consisting of EBMUD, SCWD, and ICF staff to implement an intensive three year entrainment and impingement/predator monitoring program in 2012, 2013 and 2014, and to conduct the hydraulic evaluation in 2014.

ICF International. 2015. *Draft Annual Report: 2012–2014 Fish Entrainment, Impingement, and Predator Monitoring Results for Freeport Regional Water Authority's New Water Intake Fish Screen*. February. (ICF Project 061107.06.) Sacramento, CA. Prepared for Freeport Regional Water Authority and Sacramento County Water Agency, Sacramento, CA.

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Acronyms and Abbreviations

µS/cm	microsiemens per centimeter
AIC	Akaike's information criterion
ARIS	Adaptive Resolution Imaging Sonar
BO	biological opinion
CDEC	California Data Exchange Center
CESA	California Endangered Species Act
cfs	cubic feet per second
CIMIS	California Irrigation Management Information System
DFG	Department of Fish and Game
DFW	Department of Fish and Wildlife
DIDSON	Dual-frequency Identification sonar
DWR	Department of Water Resources
EC	electrical conductivity
ESA	Endangered Species Act
fps	feet per second
FRWA	Freeport Regional Water Authority
GLM	generalized linear modeling
LED	light-emitting diodes
Mgal	million gallons
mgd	million gallons per day
mm	millimeter
msl	mean sea level
NMFS	National Marine Fisheries Service
NTUs	nephelometric turbidity units
PDD	percent discharge diverted
RM	river mile
SCWA	Sacramento County Water Agency
SD	Standard Deviation
sf	square feet
USFWS	U. S. Fish and Wildlife Service
VSWTP	Vineyard Surface Water Treatment Plant
WY	water year

Glossary

Key terms used in this report are defined below.

Detected—term used to indicate that, although no fish were found during sampling, the lack of observed fish does not indicate that fish were not entrained by the water intake facility.

Entrainment— refers to fish that passed through the Freeport water intake facility's fish screen as eggs or young fish (i.e., larvae, post-larvae, pre-juveniles) along with Sacramento River water diverted by the facility.

Entrainment monitoring period—the period that Freeport Regional Water Authority is required to conduct fish entrainment monitoring. In Water Year 2012, the entrainment monitoring period extended from December 1, 2012, through July 31, 2013. In Water Year 2013 and Water Year 2014, the entrainment monitoring period extended from December 1 through June 30 of that water year.

Entrainment monitoring event—each individual 24-hour period that fish entrainment monitoring with the net was conducted.

Sampling interval—each individual period of time the net was fished during a monitoring event.

Water year—the 12-month period beginning on October 1, for any given year, through September 30 of the following year. The water year is designated by the calendar year in which it ends. Thus, the year ending September 30, 2014, is called "water year 2014."

Fish Entrainment, Impingement, and Predator Monitoring Program for Freeport Regional Water Authority's New Water Intake Fish Screen—2012–2014 Annual Report

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1.0 Introduction

This annual report, prepared by the Freeport Regional Water Authority (FRWA)[1], fulfills the monitoring report requirements for the U. S. Fish and Wildlife Service's (USFWS's) biological opinion (BO) for the operation of FRWA's new Freeport water intake structure and pumping facility (water intake facility). This document fulfills the reporting requirement for water year (WY) 2014. Monitoring was previously implemented in WY 2012 and WY 2013, and corresponding annual reports were prepared (ICF International 2012, 2013). The previous annual monitoring reports for WY 2012 and WY 2013 are referenced in this document as the WY 2012 final annual report and WY 2013 final annual report, respectively. Because WY 2014 represented the third year that entrainment, impingement, and predator monitoring were conducted for the Freeport water intake facility, this document also presents a synthesis of results to-date for the entrainment, impingement, and predator monitoring program, so that the monitoring program can be assessed to determine whether the monitoring requirements have been satisfied.

The Freeport water intake structure and pumping facility is located on the east bank of the Sacramento River at Freeport Bend, a short distance upstream from the town of Freeport, California (Figure 1). The water intake facility has a capacity of up to 286 cubic feet per second (cfs), which is equivalent to 185 million gallons per day (mgd). The water intake facility has eight vertical pumps (seven duty pumps and one spare pump) split between two forebay chambers that are hydraulically isolated when the river is below an elevation of approximately 10 feet above mean sea level (msl). Each chamber houses four pumps and eight fish screen bays, two for each pump (Figure 2). All pumps have an equal design flow rate of 40.8 cfs (26.4 mgd), and the maximum design flow rate for each chamber is 163.5 cfs (105.7 mgd).

The water intake facility is designed to minimize fish entrainment losses and provide reliability for FRWA water diversions. The water intake facility uses a fish screen that meets California Department of Fish and Wildlife (DFW; formerly California Department of Fish and Game [DFG]) and National Marine Fisheries Service (NMFS) criteria for adequate screen area, maintenance features, and facility hydraulics for the protection of fish. The fish screen consists of a total of 16 fish screen panels, two for each pump. Each fish screen panel is constructed of stainless steel, vertical profile bar with 1.75-millimeter (mm) (0.069-inch) slot openings; has an effective screening area of 106 square feet (sf); and has been designed to meet a design approach velocity (i.e., velocity

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[1] The Freeport Regional Water Authority was created in February 2002 by a Joint Powers Agreement of Sacramento County Water Agency and East Bay Municipal Utility District. FRWA guides the financing, ownership, development, construction, and operation of the Freeport Regional Water Project.

perpendicular to the fish screen face) of 0.2 foot per second (fps). This approach velocity was chosen specifically because it protects delta smelt, which are weaker swimmers than fry and juvenile steelhead and Chinook salmon. However, because the Sacramento River at Freeport Bend is tidally influenced and subject to reverse flow, it is recognized that the criterion for sweeping velocity (i.e., velocity parallel and adjacent to the fish screen face) will not always be met. NMFS (1997) fish screening criteria require that sweeping velocities be greater than approach velocities, while DFW (DFG 2000) fish screening criteria, which are more stringent, require that sweeping velocities be at least twice approach velocities.

This evaluation of the effectiveness of the water intake facility's fish screen is based on an adopted biological monitoring plan, which was developed by ICF International, on behalf of FRWA, and approved by DFW and the USFWS. The biological monitoring plan was prepared in April 2010 (ICF International 2010; Appendix A) and an addendum to the plan was prepared in October 2011 (ICF International 2011; Appendix A); together, these constitute the adopted biological monitoring plan. Under the adopted monitoring plan, entrainment monitoring, impingement monitoring, and predator monitoring (a component of impingement monitoring) were conducted to meet the terms and conditions of the USFWS BO that was prepared to address the effects of FRWA's Freeport water intake facility on delta smelt, a threatened species under the federal Endangered Species Act (ESA)(U. S. Fish and Wildlife Service 2004) and to meet Provision 8.2 of the California Endangered Species Act (CESA) Incidental Take Permit No. 2081-2010-031-03 for delta smelt and longfin smelt. Delta smelt and longfin smelt are listed as endangered and threatened, respectively, under CESA.

The following is a summary of monitoring activities and events for the WY 2012–2014 monitoring periods.

WY 2012

Entrainment, impingement, and predator monitoring were first conducted from December 2011 through July 2012, in accordance with the adopted biological monitoring plan (Appendix A). During the entrainment monitoring period, sampling was conducted with a hoop net located at the Vineyard Surface Water Treatment Plant (VSWTP) (Figure 1). Impingement and predator monitoring were conducted in late April 2012 using a DIDSON sonar camera. The water intake facility was operated intermittently (nights only and all day Mondays) throughout most of the entrainment monitoring period and the pumping rate was approximately 23 cfs (15 mgd) when the facility was operating.

WY 2013

Based on USFWS-approved recommendations in the WY 2012 final annual report (ICF International 2012), entrainment monitoring was to be conducted from December 2012 through June 2013, with greater flexibility in scheduling entrainment monitoring events to focus monitoring when USFWS in-river fish sampling determined that adult delta smelt or longfin smelt were present in the river and potentially spawning. Because the water intake facility was shut down in December 2012 for required maintenance, pumping and monitoring did not commence until January 2013. In addition, floating larval light traps were added to the monitoring program to determine whether larvae being detected in the net at the VSWTP were representative of fish being entrained. Impingement and predator monitoring were conducted in early April 2013 using an ARIS sonar camera. The water intake facility was operated intermittently (weekdays only) throughout most of the entrainment monitoring period and the pumping rate was approximately (18–23 cfs) 12–15 mgd when the facility was operating. During impingement and predator monitoring, the pumping rate was increased to 46 cfs (30 mgd).

WY 2014

Based on USFWS-approved recommendations in the WY 2013 final annual report (ICF International 2013), a subsample of the WY 2012 entrainment samples were re-sorted after it was determined that some larval fish remained in the sorted WY 2012 samples. The samples were re-sorted in late 2013 and early 2014, and an update to the WY 2012 and WY 2013 final annual reports was prepared (ICF International 2014). Two additional light traps were added to the entrainment monitoring program as part of the recommendations, bringing the total to four, and the duration of their deployment during each monitoring event was increased from 4 hours to up to 12 hours. Entrainment monitoring was conducted in December 2013 and then from March through June 2014; maintenance required that the water intake facility be shut down from mid-December through early to mid-March. Impingement and predator monitoring were conducted in early April 2014 using an ARIS sonar camera and a hydraulic evaluation (measurement of near-screen water velocities) was conducted within days following the impingement and predator monitoring studies. After pumping resumed in early to mid-March, the water intake facility was operated intermittently (weekdays only) through March and the pumping rate was approximately 18–23 cfs (12–15 mgd) when the facility was operating. Beginning in early April, pumping was increased to 139 cfs (90 mgd) to support impingement and predator monitoring studies and the hydraulic evaluation. Pumping was continuous throughout the remainder of the entrainment monitoring period (i.e., June 30); however, the pumping rate varied between 132 and 163 cfs (85–105 mgd).

1.1 Purpose of the Annual Report

The primary purposes of this annual report are to present the results of the third year of fish entrainment, impingement, and predator monitoring for the Freeport water intake facility, and to present a synthesis of results to-date for the entrainment, impingement, and predator monitoring program, so that the monitoring program can be assessed to determine whether monitoring requirements have been satisfied.

The secondary purposes of this annual report are to comply with objectives listed in the Terms and Conditions of USFWS's BO for the effects of the Freeport water intake facility on delta smelt (U.S. Fish and Wildlife Service 2004), to demonstrate fish screen effectiveness for minimizing entrainment of delta smelt, and to evaluate take of delta smelt. In addition, this monitoring provides data on life stages of fish species passing through the fish screen (Meier pers. comm.).

Because this was the third, and potentially final, year that entrainment, impingement, and predator monitoring data were collected, this annual report also integrates and synthesizes all of the monitoring data collected to-date, including monitoring results for WY 2012, which were collected from December 2011 through July 2012 (ICF International 2012), and monitoring results for WY 2013, which were collected from January through June 2013 (ICF International 2013).

1.2 Report Format

This document follows the general format of the previous two annual monitoring reports (ICF International 2012, 2013). Where appropriate, the information for the three separate entrainment monitoring periods has been combined and presented as a single narrative or table; this approach was often used in the "Methods" section and sometimes in the "Results" section. Where combining information for multiple monitoring periods into a single narrative or table was not appropriate or would create an awkward presentation, the information for each water year has been presented separately in narrative and tabular form under a heading for the corresponding water year; this approach was often used in the "Results" section.

2.0 Methods

This section summarizes the methods used to obtain and analyze the environmental and facility operations data and to conduct the fish entrainment, impingement, and predator monitoring during WY 2012–WY 2014. The methods used to gather the environmental data and conduct this biological monitoring followed closely the approach described in the adopted biological monitoring plan prepared for the study (Appendix A). In some cases, methods followed during monitoring differed from the adopted biological monitoring plan based on recommended changes to monitoring methods presented in the previous year's final annual report (ICF International 2012, 2013). This section describes these changes and the methods employed during fish entrainment, impingement, and predator monitoring in WYs 2012–2014.

A list of the personnel who implemented the monitoring program is presented in Appendix B.

2.1 Environmental and Habitat Data and Freeport Water Intake Facility Operations Information

Environmental data were obtained from several sources and were used to provide context for the fish entrainment, impingement, and predator monitoring results. Environmental data presented in this report are Sacramento River conditions, precipitation, and lunar phase.

Sacramento River conditions of most interest are flow, stage, velocity, turbidity, water temperature, and electrical conductivity (EC). These data were obtained from the California Department of Water Resources' (DWR's) California Data Exchange Center (CDEC) for station FPT, which is located on the Sacramento River at Freeport, about 1 mile downstream of the Freeport water intake facility (Figure 1). Hourly river flow, stage, and velocity data and 15-minute turbidity, water temperature, and EC data for the period December 1, 2011, through July 31, 2012, were obtained from the CDEC website on September 13, 2012 (California Data Exchange Center 2012); for the period December 1, 2012, through June 30, 2013, were obtained from the CDEC website on July 18, 2013 (California Data Exchange Center 2013); and for the period December 1, 2013, through June 30, 2014, were obtained from the CDEC website on August 16, 2014 (California Data Exchange Center 2012). All data were entered into Excel spreadsheets and summarized to generate daily minimum, mean, and maximum values, and these daily values for each water year were plotted on graphs.

Precipitation data for the Sacramento region were obtained from DWR's California Irrigation Management Information System (CIMIS) Bryte Station, which is located near the City of West Sacramento. Daily precipitation data for the CIMIS Bryte Station for the period November 1, 2011, through July 31, 2012, were obtained from the CIMIS website on September 21, 2012 (California Irrigation Management Information System 2012); for the period November 1, 2012, through June 30, 2013, were obtained from the CIMIS website on July 20, 2013 (California Irrigation Management Information System 2013); and for the period November 1, 2013, through June 30, 2014, were obtained from the CIMIS website on August 16, 2014 (California Irrigation Management Information System 2014) . The data were entered into an Excel spreadsheet, and daily values for each water year were plotted on graphs.

Information on sunrise, sunset, moonrise, moonset, and lunar phases for the new and full moon for Sacramento during the entrainment monitoring period of December 1 through June 30 (July 31 for WY 2012) for the respective water years was obtained from the website http://www.usno.navy.mil/USNO/astronomical-applications . The information was used to stratify entrainment monitoring samples and to show the lunar phases in relation to the timing of occurrence of adult delta and longfin smelt in the Sacramento River based on the USFWS trawl and beach seine survey data (described in section 2.3, "USFWS Trawl and Beach Seine Data").

In WY 2013, general habitat conditions in the three predator monitoring reaches were visually assessed from the boat and noted. The habitat assessment include measuring water depths in each predator monitoring reach from a boat using a Lowrance model HDS 5X depth finder. A Trimble GPS with submeter accuracy was used to record the location of each water depth measurement point and the data were plotted on an aerial base map of the river that included the three predator monitoring reaches. Water depth data provided a general description of the bathymetry of the Sacramento River within the three predator monitoring reaches and provide context to the predator monitoring results. Because of the lack of major channel forming flows in the Sacramento River during WYs 2012–2014, the data collected in WY 2013 were assumed to be representative of habitat conditions in WY 2012 and WY 2014.

Operations data for the Freeport water intake facility and inflows to the VSWTP were obtained from the Sacramento County Water Agency (SCWA) (Houston pers. comm., Pasterski pers. comm.). Water intake facility operations data are recorded every 15 seconds by the water intake facility's Supervisory Control and Data Acquisition (SCADA) computer system. Continuous monitoring equipment in the pipeline leading to the VSWTP records inflows to the VSWTP. The data were used to evaluate the hourly diversion rates, daily diversion volumes, and total water volumes sampled by the net during each monitoring event. In addition, the proportion of river flow diverted by the water intake facility was calculated by dividing the hourly diversion rates by the hourly flow rates for the Sacramento River at Freeport. The daily volume of water diverted was determined using the continuous diversion rates: SCWA provided an average hourly diversion rate reading for each hour, and these readings were then averaged for each calendar day and for each 24-hour monitoring event. SCWA calculated total water volumes sampled by the net to the minute for each sampling interval (i.e., the duration the net was fished); the totals for each sampling interval were then summed to calculate the total volume of water sampled for each 24-hour monitoring event. These totals were then compared against the total volume of water pumped by the water intake facility over the corresponding time period.

2.2 Entrainment Monitoring

The adopted biological monitoring plan (Appendix A) lays out the methods for entrainment monitoring, including sampling location and gear, sampling procedures, variables measured and recorded, and the procedures for processing the samples, including fish identification and data analysis. Although monitoring was conducted in accordance with the adopted biological monitoring plan, there were slight changes to sampling gear and/or procedures that were implemented each monitoring year in response to facility operations occurring at that time and/or to improve monitoring. Method changes to improve monitoring were based on USFWS-approved recommendations presented in the WY 2012 and WY 2013 final annual monitoring reports (ICF International 2012 and 2013, respectively).

2.2.1 Method Changes

The following is a summary of the changes made to the monitoring activities and events during WYs 2012– 2014.

WY 2012

From December 2011 through May 2012, the Freeport water intake facility typically operated intermittently throughout the week and ceased operations for the weekend. Because of these intermittent operations, sampling intervals for entrainment monitoring were based on debris loading in the net at the time that entrainment monitoring was conducted, rather than stratified to isolate environmental conditions (e.g., day versus night, tidal conditions, river velocity). This change was necessary because the water intake facility was operated for only part of the day and then generally diverted less than 20 million gallons (Mgal) daily, the approximate volume of the pipeline between the water intake facility and the VSWTP. For these reasons, the water in the pipeline frequently represented 2 or more days' worth of diverted water (and entrained fish potentially). This situation precluded stratifying the samples based on environmental conditions. In addition, entrainment monitoring was conducted only on Mondays, rather than other days of the week, because continuous (24-hour) pumping occurred only on Mondays.

WY 2013

The monitoring schedule was changed in WY 2013 to allow for additional and more frequent entrainment monitoring around the time that delta and longfin smelt eggs and larvae were more likely to be present in the river (i.e., March–May) and subject to entrainment by the Freeport water intake facility. To accomplish these changes, the July monitoring event and one of the two monitoring events in June were dropped from the monitoring schedule so that they could be conducted earlier in the monitoring period. In addition, the interval between monitoring events was made flexible so that monitoring could occur more frequently during periods when delta and longfin smelt eggs and larvae were most likely to be present in the river, based on weekly USFWS trawl and beach seine data.

No pumping occurred in December 2012; therefore, no entrainment monitoring occurred during this month. However, this monitoring event was rescheduled for later in the monitoring period.

New sampling gear was also added to the monitoring methods in WY 2013. Floating larval light traps were deployed in the water intake facility's forebay chambers at the same time that entrainment monitoring was conducted in an effort to increase the chance of detecting rare species and to determine whether fish being detected in the net at the VSWTP were representative of the fish that were being entrained. The floating larval light traps and associated methods are discussed below in section 2.2.3, "Entrainment Monitoring using Floating Larval Light Traps".

Lastly, new protocols were put into place to ensure that changing VSWTP operations or turbidity levels in raw water entering VSWTP were communicated to the lead fish biologist so that appropriate measures (e.g., reducing flow through the net, retrieving and cleaning the net more frequently) could be implemented in a timely manner to prevent the net from being damaged by excessive debris volumes.

WY 2014

Although the entrainment monitoring schedule was the same as it was in WY 2013, the lack of pumping in January and February allowed for the entrainment monitoring events that would have occurred during these months had pumping occurred to be rescheduled until later in the entrainment monitoring period. The effect on the entrainment monitoring schedule was that entrainment monitoring events occurred more frequently once pumping resumed in March than they would have had pumping (and entrainment monitoring) not ceased for those two months. The net effect on the entrainment monitoring schedule was that entrainment monitoring occurred weekly from late March through late May.

Two additional floating larval light traps were deployed in WY 2014 to bring the total number of light traps deployed during entrainment monitoring events to four. In addition, the sampling duration for each light trap was increased from 4 hours to as much as 12 hours and a new light source was used in each light trap to maintain a consistent light intensity over the entire period that they were deployed. Additional information about the additional floating larval light traps and new light sources is presented below in section 2.2.3, "Entrainment Monitoring using Floating Larval Light Traps".

The abundance of larval fish in the samples made it impractical to fully sort each sample; therefore, a subsampling approach to sample sorting was employed for most of the samples. The subsampling approach followed closely the methods described by Sebastian et al. (1988), which were developed for subsampling unsorted benthic macroinvertebrates by weight and are especially useful for samples containing large amounts of filamentous algae that preclude the use of conventional subsampling methods. To ensure an equal distribution of larval fish in the sample prior to subsampling, each sample was placed into a 1 Liter container filled with water and the sample was stirred to assist in the separation of fish larvae from debris. The sample was then poured evenly onto a 125-micron sieve and excess water was allowed to drain for 7–10 minutes. The entire sample was weighed (to nearest 0.1 gram) on a tared electronic balance to achieve a total sample weight. Sample material was then removed from different portions of the sieve in a uniform fashion until one-quarter of the sample by weight was removed. The subsample material was placed in a separate sampling jar marked with and containing the sample identification number and preserved in 70% ethyl alcohol for later processing. The sample material remaining on the sieve was returned to its original sample jar and placed in the secured storage cabinet. Prior to applying this subsampling approach to the WY 2014 entrainment samples, the method was applied to several samples to test the appropriateness of applying this subsampling method to all entrainment samples. The results of this test are presented in Appendix C. Given the abundance of detritus and filamentous algae in the samples, the similarity in the size of fish larvae to macroinvertebrates, and the evenness results for the test samples, the subsampling approach described by Sebastian et al. (1988) was determined to be an appropriate method for subsampling WY 2014 entrainment samples (Appendix C).

2.2.2 Monitoring Locations and Schedule

Entrainment monitoring was conducted at two locations using two different methods (except in WY 2012 when entrainment monitoring was conducted at VSWTP only). At the VSWTP, entrainment monitoring was conducted using a plankton net placed on the terminal (discharge) end of the pipeline that delivers water diverted from the Sacramento River by the Freeport water intake facility. The methods and sampling procedures employed to conduct the entrainment monitoring at the VSWTP followed closely the methods and procedures described in the adopted biological monitoring plan (Appendix A) and the method changes discussed above in section 2.3.1, "Method Changes".

At the Freeport water intake facility, floating larval light traps were used to sample fish larvae in the forebay chambers of the water intake facility. The methods and sampling procedures employed to sample fish larvae using the floating larval light traps are described below in section 2.2.3, "Entrainment Monitoring using Floating Larval Light Traps".

Tables 1 and 2 show the dates entrainment monitoring was conducted at VSWTP and in the forebay chambers at the Freeport water intake facility, respectively, during WYs 2012–2014.

Table 1. Dates of Entrainment Monitoring with the Hoop Net at the Vineyard Surface Water Treatment Plant, Water Years 2012–2014

	Monitoring Dates by Water Year		
Monitoring Event	WY 2012	WY 2013[1]	WY 2014[2]
1	December 5–6, 2011	January 24–25, 2013	December 4–5, 2013
2	January 30–31, 2012	February 13–14, 2013	March 20–21, 2014
3	February 21–22, 2012	March 13–14, 2013	March 26–27, 2014
4	March 12–13, 2012	March 20–21, 2013	April 2–3, 2014
5	March 26–27, 2012	April 11, 2013[3]	April 9–10, 2014
6	April 16–17, 2012	April 24–25, 2013	April 16–17, 2014
7	April 30–May 1, 2012	May 2–3, 2013	April 23–24, 2014
8	May 14–15, 2012	May 8–9, 2013	April 30–May 1, 2014
9	May 29–30, 2012	May 16–17, 2013	May 7–8, 2014
10	June 11–12, 2012	May 22–23, 2013	May 14–15, 2014
11	June 25–26, 2012	May 29–30, 2013	May 21–22, 2014
12	July 16–17, 2012	June 19–20, 2013	June 18–19, 2014

[1] No pumping occurred in December 2012; therefore, entrainment monitoring was not conducted in December.

[2] Pumping ceased on December 12, 2013, and resumed on March 11, 2014; therefore, entrainment monitoring was not conducted in January or February.

[3] The net was damaged by debris during the first sampling interval; consequently, entrainment monitoring was postponed until the net could be repaired.

Table 2. Dates of Entrainment Monitoring with the Floating Larval Light Traps at the Freeport Water Intake Facility, Water Years 2012–2014

Monitoring Event	Monitoring Dates by Water Year[1]		
	WY 2012	WY 2013[2]	WY 2014[3]
1	NA	January 24, 2013	December 4 and 5, 2013
2	NA	February 13, 2013	March 20, 2014
3	NA	March 13, 2013	March 26–27, 2014
4	NA	March 20, 2013	April 1–2, 2014
5	NA	April 10 and 11, 2013	April 9–10, 2014
6	NA	April 24, 2013	April 15–16, 2014
7	NA	May 2, 2013	April 23 and 24, 2014
8	NA	May 8, 2013	April 30, 2014
9	NA	May 1, 2013	May 7–8, 2014
10	NA	May 22, 2013	May 14–15, 2014
11	NA	May 29, 2013	May 21–22, 2014
12	NA	June 19, 2013	June 18–19, 2014

NA = Not Applicable (floating larval light traps were added to the entrainment monitoring program beginning with the WY 2013 monitoring period).

[1] Monitoring with larval fish light traps at the Freeport Water Intake Facility was conducted either on a single day, consecutive days, or spanning more than one day (i.e., overnight).

[2] No pumping occurred in December 2012; therefore, entrainment monitoring was not conducted during this month.

[3] Pumping ceased on December 12, 2013, and resumed on March 11, 2014; therefore, entrainment monitoring was not conducted in January or February.

2.2.3 Entrainment Monitoring using Floating Larval Light Traps

Entrainment monitoring using floating larval light traps were added to the monitoring methods at the beginning of WY 2013 and are not described in the adopted monitoring plan (Appendix A). Therefore, the methods and procedures for monitoring larval fish entrainment with the floating larval light traps are summarized below.

Fish larvae occurring in the forebay chambers at the Freeport water intake facility were sampled during each entrainment monitoring event using up to four floating larval light traps. Figure 3 shows the two different types of light traps that were deployed. One type of light trap consisted of a “box” constructed out of clear Plexiglas and measuring approximately 12-inches wide, 12-inches deep, and 8-inches high with 0.25-inch-wide entry slot openings on each side (Figure 3; top photograph). The second type of light trap used was a Quadrafoil type larval light trap with a cloverleaf shaped array measuring approximately 12-inches in diameter and 8-inches high with four 0.25-inch-wide entry slot openings (Figure 3; bottom photograph). Both light traps were equipped with a center tube made of Plexiglas that was open at the top of the trap so a light source could be placed inside the tube; a collection cup with 505-micron mesh nylon netting to facilitate the capture of fish larvae as the light trap was lifted out of the water; and a 2-inch-thick floatation block (e.g., Styrofoam) attached to the top of light trap to allow it to float at the water surface.

In WY 2013, green chemical light sticks were used initially as a light source but after it was observed that chemical luminescence of the light sticks declined relatively quickly (perhaps as a result of being submerged in relatively cold water), a small flashlight equipped with light-emitting diodes (LEDs) was used instead. The LED flashlight was positioned on top of the light trap such that it pointed down directly into the center tube of the trap. To help scatter the light in all directions, small rocks wrapped with foil were placed in the bottom of the center tube to create a reflective surface. In WY 2014, high-intensity LED light sources that were constructed following the methods described by Gyekis et al. (2006) were used to illuminate each of the four deployed light traps. The LED light units used four regular C-cell batteries and a cluster of three LEDs directed outward in a clover-leaf pattern so that light was emitted circularly. These light units emitted bright light consistently for many hours, and permitted the light traps to be deployed for 12 hours duration without any noticeable decrease in light intensity. Two of the light units were constructed with white LEDS, while the other two light units were constructed with green LEDs. In a study of light trap size and color, Marchetti et al. (2004) found that green light appeared to be the strongest attractor for larvae of the five colors evaluated (green, yellow, red, pink, and blue); however, white light was not evaluated as part of the study, which used chemical light sticks as a light source.

In WY 2013, typically two light traps were deployed on the day entrainment monitoring at VSWTP was initiated. When two light traps were deployed, one light trap was placed in the forebay chamber directly behind one of the two screen panels located directly in front of the operating pump, while the second light trap was placed near the operating pump but to the side where it was out of the direct current created by the operating pump. When only one larval light trap was deployed, it was deployed at the pump location as described above. Larval light traps were typically deployed for about 4 hours duration and then retrieved. The light traps were not deployed for more than 4 hours at a time because declining battery power resulted in reduced luminescence of the LEDs.

In WY 2014, four light traps were deployed on the day entrainment monitoring at VSWTP was occurring and were deployed in a manner similar to that described above for WY 2013. When only one forebay chamber was operating, all four of the light traps were deployed in the operating forebay chamber. When both forebay chambers were operating, two light traps were placed in each forebay chamber, although on a few occasions all four light traps were placed in the forebay chamber that was diverting the most water.

The light traps were deployed from, and tethered to, an overhead walkway. Sufficient slack in the tethering line was maintained to allow for changing water surface levels which fluctuated in response to the tides. Dark conditions inside the enclosed forebay chambers permitted the deployment of the light traps at any time of day so long as the overhead lights were turned off; sampling with the light traps was conducted during both daytime and nighttime hours.

2.2.4 Data Analysis

Entrainment data were summarized each year using descriptive statistics (total number, size range and mean length of fish detected) and the data were tabulated by monitoring event. In addition, evidence for the effects of environmental variables on entrainment rate was investigated for WY 2013 and WY 2014 entrainment data; these investigations were precluded from being conducted in WY 2012 because of the intermittent facility operations that occurred that year. Although the approach to these investigations was generally similar for both years, there were some important differences. These differences are described below.

WY 2013

Evidence for the effects of environmental variables on entrainment rate (fish collected per 1 million gallons of diverted water sampled), based on the calculated time when fish passed through the fish screen, was examined using generalized linear modeling (GLM) in SAS/STAT® software, Version 9.3 of the SAS System for Windows[2]. The count of fish collected in each sample was modeled as a function of day/night, river velocity (feet per second), and proportion of discharge diverted (square-root-transformed), as well as all two-way interactions, using a negative binomial error distribution (logarithmic link function) and an offset (million gallons of water sampled, to account for different sampling volumes). GLMs were run separately for all fish combined (n = 38 samples), prickly sculpin (in March–April, n = 20 samples), and Sacramento splittail (in April–May, n = 25 samples).

All possible combinations of predictor variables were examined in a number of candidate models and, following Zeug and Cavallo (2013), an information theoretic approach was used to assess the support for each model (Burnham & Anderson 2002). Akaike's information criterion corrected for small sample size (AIC_c) and was calculated for each candidate model, and model weights (AIC_cw) were calculated using the difference in AIC_c between each candidate model and the best approximating model in the set (ΔAIC_c): $AIC_cw = \exp(-0.5 * \Delta AIC_c)$; AIC_cw for each candidate model was then standardized by dividing by the sum of the AIC_cw for all candidate models. Model weights are interpreted as the probability that a given model is the best relative to all candidate models. Following Zeug and Cavallo (2013), models with a ΔAIC_c value of 0–3 were considered competitors to best explain the data, and the AIC_c values of null (intercept-only) models were compared with the other candidate models as a measure of how well the candidate models fit the data.

WY 2014

Evidence for the effects of environmental variables on entrainment rate (fish collected per 1 million gallons of diverted water sampled), based on the estimated time when fish passed through the fish screen, was examined using generalized linear modeling (GLM) in the R software (Version 3.1.0; R Core Team 2014). The count of fish collected in each sample was modeled as a function of day/night, river velocity (feet per second), proportion of discharge diverted, and water temperature, as well as all two-way interactions, using a negative binomial error distribution (logarithmic link function) and an offset (million gallons of water sampled, to account for different sampling volumes). The proportion of discharge diverted was expressed as an absolute value in order to account for periods when diversions occurred during reversing river flow. GLM was undertaken separately for the three numerically dominant species (prickly sculpin, bigscale logperch, and Sacramento splittail), based on data from March to June 2014. Data from May 14-15 were excluded from the analysis because river flow reversals necessitated pumping to be shut down for several hours during the sampling event.

The R package "glmulti" (Calcagno and de Mazancourt 2010) was used to examine all possible combinations of predictor variables and their interactions in 113 total models. Continuous

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[2] Copyright 2002–2010, SAS Institute Inc. SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc., Cary, NC, USA.

predictors were standardized to zero mean and unit standard deviation prior to analysis. Based on the principle of marginality (Calcagno and de Mazancourt 2010), the interaction term was only included in models including both main effects. An information theoretic /model averaging approach (Burnham & Anderson 2002) was used to assess the support for each model and the relative importance of the environmental variables. The relative level of support for each possible model was estimated in glmulti with the quasi-likelihood equivalent of Akaike's information criterion corrected for small sample sizes (i.e., $QAIC_c$) (Mazerolle 2006). The variance inflation factor, $\hat{c}$, required to compute $QAIC_c$ was estimated by initially running a single, full model with all predictor variables and their interactions included, and then providing $\hat{c}$ (as estimated from the residual deviance divided by the number of degrees of freedom from the full model) to the glmulti package for the automated model-averaging procedure. The difference in QAICc, Δ_i, between each model and the best model (i.e., the model with the lowest $QAIC_c$) was calculated, and Akaike weights (w_i) were calculated based on the Δ_i. Model averaging of the predictor variable coefficients was undertaken based on w_i for each model, and unconditional confidence intervals were calculated for each coefficient (Mazerolle 2006). The importance of each predictor variable was assessed by summing the w_i of all models in which the variable appeared. Following Calcagno and de Mazancourt (2010), importance of 0.8 or greater was used to infer support for a variable's potential influence on entrainment rate, in addition to unconditional 95% confidence intervals for variable coefficients not overlapping zero (per Zeug and Cavallo 2013). Models within 3.0 $QAIC_c$ units of the best models were considered candidates for best explaining the patterns in entrainment rate (Zeug and Cavallo 2013). Models including predictors were assessed to provide a better fit to the data than null (intercept-only) models if the $QAIC_c$ of the full models (with all predictors included) was 3.0 or more units greater than the $QAIC_c$ of the intercept-only models (Zeug and Cavallo 2013).

2.3 USFWS Trawl and Beach Seine Data

Trawl and beach seine survey data for the Sacramento River were obtained from the USFWS's Lodi Field Office (Speegle pers. comm.). USFWS conducts weekly trawl (Kodiak or mid-water) and beach seine surveys of the Sacramento River at Sherwood Harbor (river mile [RM] 55) and the boat ramp at Garcia Bend (RM 49), respectively, in addition to other river and delta locations, as part of its Delta Juvenile Fish Monitoring Program. Sherwood Harbor and Garcia Bend are located on the Sacramento River 7.5 miles and 2 miles, respectively, upstream of the Freeport water intake facility (RM 47) (Figure 4). The purpose of the USFWS surveys is to collect abundance, distribution, and survival data on juvenile fish in the delta. Although species of management concern (e.g., delta and longfin smelt, Chinook salmon, steelhead, and Sacramento splittail) are the primary species targeted by these surveys, USFWS also collects and reports information on all other species captured in the trawls and beach seines. USFWS uses a Kodiak trawl at Sherwood Harbor from December through March and switches to a mid-water trawl beginning in April. The USFWS trawl and beach seine surveys coincided with the WY 2012, WY 2013, and WY 2014 entrainment, impingement, and predator monitoring periods.

In addition to collecting data on the relative number and timing of occurrence of delta and longfin smelt, USFWS also collects information on the maturation status of adult smelt (i.e., individuals are physically examined at the time of capture to determine their readiness to spawn based on whether eggs or milt can be manually expressed). Maturation status provides information on the potential timing of spawning and, therefore, the potential occurrence of the species' eggs and larvae in the river. This information was then used to determine the timing of monitoring events.

The data were received from USFWS as Excel files and were subsequently sorted by species for Sherwood Harbor (trawl data) and Garcia Bend (beach seine data). Catch and size data for delta and longfin smelt and fish species detected in the net were compiled and, when appropriate, graphed to show the timing of occurrence, relative abundance, and fish size over the entrainment monitoring period (i.e., December through June [through July in WY 2012], which is the period that FRWA is required to conduct fish entrainment monitoring). The data were used to compare the fish detections in the net at the VSWTP and in the light traps at the Freeport water intake facility with the timing of their occurrence, relative abundance, and size in the river. It should be noted that USFWS does not identify and measure fish in the field that are less than 25 mm fork length; except for Sacramento splittail, which are identified and measured in the field down to 20 mm fork length. Nonetheless, this information is useful for identifying the presence of adults and the potential timing of spawning in the river, as well as the presence of juveniles in the river which can be used to estimate the general timing of larvae in the vicinity of the Freeport water intake facility.

2.4 Impingement and Predator Monitoring

Impingement and predator monitoring were conducted using high-definition imaging sonar and visual observation (impingement only). Impingement on the fish screen was monitored using a fixed close-range, DIDSON (WY 2012) or ARIS (WY 2013 and WY 2014) sonar camera and visual observation by divers using scuba. Predator- and prey-size fish in the vicinity of the Freeport water intake facility and its fish screen and adjacent shoreline areas of the Sacramento River not influenced by the water intake facility were also monitored using mobile DIDSON/ARIS monitoring from a boat. The approach and equipment used to conduct this monitoring are described below.

2.4.1 Impingement Monitoring Using a Fixed DIDSON/ARIS Sonar Camera

DIDSON/ARIS Sonar Camera Description and Operating Mode

A standard DIDSON 300 M sonar camera was used in WY 2012 and an ARIS Explorer 3000 sonar camera (Sound Metrics Corporation) was used in WYs 2013 and 2014 to conduct close-range monitoring for fish impingement on the fish screen. The DIDSON is a high-definition sonar camera that uses acoustic lenses to give imaging of underwater objects. The ARIS is the new generation of forward-looking sonar that generates high-resolution acoustic images at a near-video rate. Both sonar cameras allow for imaging of underwater objects where underwater optical cameras would be limited by low light or turbid conditions. The DIDSON/ARIS sonar camera operates by sending out high-frequency sound which is then synthesized to form acoustic images with greater detail than found in conventional sonars.

The DIDSON/ARIS sonar camera can be operated in either a high-frequency mode or a low-frequency mode. High-frequency mode provides high-resolution imaging, while low-frequency mode allows for a greater operating range (i.e., greater viewing distance) but with lower image resolution because of fewer number of beams and beam spread at greater distances. Table 3 lists a side-by-side comparison of operating specifications for the DIDSON and ARIS sonar cameras.

Table 3. DIDSON and ARIS Sonar Camera Operating Specifications

Sonar Camera/Frequency Mode	Number of Beams	Field of View	Range
DIDSON			
High-Frequency (1.8 megahertz)	96	29 degrees in the horizontal plane and 14 degrees in the vertical plane	3–49 feet (1–15 meters)
Low-Frequency (1.1 megahertz)	48	29 degrees in the horizontal plane and 14 degrees in the vertical plane	3–114 feet (1–35 meters)
ARIS			
High-Frequency (3.0 megahertz)	128	30 degrees in the horizontal plane and 14 degrees in the vertical plane	2.3–20 feet (0.7–6.0 meters)
Low-Frequency (1.8 megahertz)	64	30 degrees in the horizontal plane and 14 degrees in the vertical plane	3–49 feet (1–15 meters)

The DIDSON/ARIS sonar camera, which consisted of a transducer array, an acoustic lens, and electronics contained in a waterproof housing, was operated per the manufacturer's specifications. Data were transmitted to a laptop computer via a 163-foot-long (50-meter-long) waterproof data cable and a topside control box. The laptop computer was used to control the DIDSON/ARIS sonar camera settings, operate the X2 rotator (described below), display the sonar images in real-time, record all sonar video, and capture stills of select images.

DIDSON/ARIS Sonar Camera Mounting Apparatus and Positioning

The DIDSON/ARIS sonar camera was mounted to a custom-made, adjustable pole mount that attached to the traveling arm of the water intake facility's fish screen cleaner assembly via a horizontal boom and steel pipe tapping tee (Figure 5). In general, the entire mounting apparatus consisted of the steel pipe tapping tee; a two-piece, 15.5-foot-long horizontal boom pipe with a pipe fitting on the end; and a 20-foot-long vertical pole that slipped into the pipe fitting on the boom. In WY 2012 when the DIDSON sonar camera was used, a flat plate (transducer mount) welded to a short section of pipe that slipped inside the bottom end of the vertical pole was used, and the DIDSON sonar camera was mounted to the underside of the transducer plate with screws. In WYs 2013 and 2014 when the ARIS sonar camera was used, a short, solid section of pipe that slipped inside the end of the hollow vertical pole was used, and a pan and tilt rotator (X2 Rotator) was attached to the end of the short solid pipe section. The ARIS sonar camera was then mounted to the X2 rotator with the supplied mounting hardware.

All components of the mounting apparatus, with the exception of the steel pipe tapping tee, were constructed of aluminum to minimize the overall weight of the mounting apparatus. The mounting apparatus design permitted manual adjustment of the DIDSON/ARIS sonar camera's depth below the water surface and distance from the fish screen, while the X2 rotator permitted the ARIS sonar camera to be panned and tilted remotely by the laptop computer (panning and tilting was not an option with the DIDSON sonar camera because the X2 rotator was not used). The horizontal distance of the DIDSON/ARIS sonar camera from the fish screen was controlled by adjusting the angle of the boom relative to parallel with the fish screen. A chain mounted to the end of the boom and secured to the fish screen cleaner assembly provided stability to the mounting apparatus while ensuring that the boom (fully loaded with the pole mount, X2 Rotator [when used], and DIDSON/ARIS sonar camera) was level relative to the water surface. Guy ropes tied to the vertical pole immediately above the DIDSON/ARIS sonar camera were secured to the railing of the deck of the water intake facility upstream and downstream of the DIDSON/ARIS sonar camera to minimize camera movement (vibration) caused by river current.

Table 4 lists the positioning of the DIDSON/ARIS sonar camera in front of the fish screen panels during impingement monitoring in WYs 2012–2014. In general, the DIDSON/ARIS sonar camera was aimed at the face of the fish screen perpendicular to flow but angled upstream from perpendicular to minimize crosstalk[3] interference by the fish screen. These settings were arrived at after testing different distances and aiming angles to determine the best position to achieve minimal interference from the fish screen, while balancing the need for observing small fish and maintaining a sufficient sample volume (i.e., viewing area in front of the fish screen). During initial setup and testing of the DIDSON/ARIS sonar camera, small targets (fishing jigs) suspended on monofilament line were used to determine the optimal settings for positioning and aiming of the ARIS sonar camera. A spreader lens was used to “double” the sample volume by increasing the field of view in the vertical plane from 14 to 28 degrees.

Table 4. Positioning of the DIDSON/ARIS Sonar Camera during Impingement Monitoring, WYs 2012–2014

Monitoring Year (sonar camera used)	Screen Panel Monitored	Horizontal Distance Sonar Camera from Fish Screen Panel (feet)	Depth of Sonar Camera (distance [feet] from top of fish screen panel)	Aiming Angle (degrees upstream relative to perpendicular)	Total Viewing Area (sf)
WY 2012 (DIDSON)	1	11.4 (3.5 meters)	3.5 (1.1 meters)	10	31.5
WY 2013 (ARIS)	11	8.0 (2.44 meters)	3 (0.9 meter)	27.5	26
WY 2014 (ARIS)	14	7.4 (2.25 meters)	3 (0.9 meter)	27.5	24

ARIS Sonar Camera Resolution Settings

To provide high-resolution images, the DIDSON sonar camera (WY 2012) was set to record at 15–18 frames per second and the ARIS sonar camera (WYs 2013 and 2014) was set to record at approximately 14 frames per second. To maintain manageable file sizes and facilitate data review, the data files were saved every hour on the hour, resulting in data files of 1-hour duration or less; initial and ending sampling intervals that did not start at the top of the hour resulted in data files that were a fraction of an hour long. Data were saved to the laptop’s hard drive and backed up daily to a removable storage drive. The removable storage drive was also used to transfer the data to a

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[3] Crosstalk occurs when objects send back bright echoes that are picked up not only in the main lobes of the beams aimed at the object, but also in the side lobes of beams not aimed at the object. The display will show an arc of “crosstalk spots” about the object. The shape is an arc because the returns are picked up at the same time in the adjacent beams and thus the mapping will show the same range for these returns. (Sound Metrics Corporation website [www.soundmetrics.com].)

network drive for permanent data file storage and archiving following completion of impingement monitoring.

Monitoring Location and Schedule

WY 2012

Impingement monitoring was conducted during two 4-hour periods each day on April 25 and 26, 2012. The first 4-hour monitoring period occurred during daylight and the second 4-hour monitoring period occurred at night. Impingement monitoring was conducted with pump 1 operating and with the DIDSON camera aimed at fish screen panel 1 (Table 4) (Figure 2). The diversion rate was 15 mgd on the days that impingement monitoring was conducted. However, SCWA was able to temporarily operate a second pump and increase the pumping rate from 15 mgd to 60 mgd on the second day of impingement monitoring for the final 1.5 hours of the nighttime monitoring period. The DIDSON sonar camera was deployed at fish screen panel 1 for the duration of impingement monitoring, and the fish screen cleaner remained off on both days. However, normal fish screen cleaning operations resumed at the conclusion of each monitoring day.

Water velocity was measured in front of the fish screen at the midpoint of the water intake facility (i.e., between pumps 4 and 5) at the start of impingement monitoring and every ½ hour thereafter while impingement monitoring with the DIDSON sonar camera was being conducted. In addition, longitudinal profiles of water velocities along the face of the entire water intake facility were also measured periodically by taking measurements in front of each pump's pair of fish screen panels. A Marsh-McBirney Flowmate Model 2000 flow meter with a 6-foot-long top-setting rod was used to measure water velocity. The Marsh-McBirney flow meter has an accuracy of ±2% of the reading and ±0.05 fps (zero stability). Measurements were taken 3 feet below the water surface at a distance of 6 feet from the water intake facility.

WY 2013

Impingement monitoring was conducted during two 4-hour periods each day on April 10 and 11, 2013. On both days, the first 4-hour monitoring period occurred during daylight and the second 4-hour monitoring period occurred at night. Although the Freeport water intake facility was operating at minimal capacity during the WY 2013 monitoring period because of limited demand for water, SCWA was able to temporarily increase the pumping rate from 15 mgd to 30 mgd and operate two pumps at a time on the days that impingement monitoring was conducted.

Impingement monitoring was conducted with pumps 5 and 6 operating in the downstream forebay chamber and with the ARIS sonar camera aimed at fish screen panel 11 (Table 4) (Figure 2). The ARIS sonar camera was deployed at fish screen panel 11 for the duration of impingement monitoring, and the fish screen cleaner remained off on both days. However, normal fish screen cleaning operations resumed at the conclusion of each monitoring day.

Water velocity was measured in front of the fish screen panels located in front of pumps 5 and 6 at the start of impingement monitoring and every ½ hour thereafter while impingement monitoring with the ARIS sonar camera was being conducted, using similar methods employed during WY 2012 impingement monitoring.

WY 2014

Impingement monitoring was conducted during two 4-hour periods each day on April 9 and 10, 2014. The first 4-hour monitoring period occurred during daylight and the second 4-hour monitoring period occurred at night. Impingement monitoring was conducted with pumps 6, 7, and 8 operating and with the ARIS camera aimed at fish screen panel 14 (Table 4) (Figure 2). The diversion rate was 90 mgd on the days that impingement monitoring was conducted. The ARIS sonar camera was deployed at fish screen panel 14 for the duration of impingement monitoring, and the fish screen cleaner remained off on both days. However, normal fish screen cleaning operations resumed at the conclusion of each monitoring day.

Water velocity was measured in front of the fish screen panels using the same methods and equipment discussed above.

2.4.2 Impingement Monitoring Using Scuba

Impingement monitoring using scuba was conducted in WYs 2012–2014, and the same methods were used each year. The only difference among the monitoring years was the location that monitoring was conducted. The methods used and the locations where impingement monitoring using scuba were conducted are discussed below.

Prior to the start of impingement monitoring each year, scuba divers visually inspected all 16 fish screen panels on the day preceding the first day of impingement monitoring, to determine the general condition of the fish screen facility, to assess the cleaning efficiency of the screen cleaner brush system, to estimate the degree of sediment accumulation at the base of the fish screen panels, and to confirm the absence of any damage or debris that might otherwise influence the results of impingement monitoring. As part of this inspection, the divers also visually inspected the fish screen panels for any impinged fish. For safety reasons, the fish screen cleaner system was turned off during the diver inspection.

To determine whether fish are being impinged on the fish screens and to provide context to the DIDSON/ARIS monitoring results, scuba divers visually inspected the screens for impinged fish three times on each day impingement monitoring was conducted with the DIDSON/ARIS sonar camera:

- immediately prior to the start of the daylight DIDSON/ARIS monitoring period.
- immediately after the daylight DIDSON/ARIS monitoring period concluded and before the start of the nighttime DIDSON/ARIS monitoring period (i.e., during twilight).
- immediately after the conclusion of the nighttime DIDSON/ARIS monitoring period.

The fish screen cleaner system was turned off several hours before the first diver inspection was conducted and remained off until after the day's third and final diver inspection.

On days that impingement monitoring was conducted, divers inspected only the screens in front of the forebay chamber that was operating[4]. In WY 2012, divers inspected fish screen panels 1–8 (in

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[4] At the river stages that occurred during impingement monitoring in WYs 2012–2014, the two forebay chambers were hydraulically isolated from each other. Therefore, operation of pumps in the downstream forebay chamber did not result in any water being drawn through the fish screen panels located in front of the upstream forebay chamber, and vice-versa (Figure 2).

front of pumps 1–4) of the upstream forebay chamber because pumps 1 and 2 were the only pumps that operated on the days that impingement monitoring was conducted. In WY 2013, divers inspected fish screen panels 9–16 (in front of pumps 5–8) of the downstream forebay chamber because pumps 5 and 6 in the downstream forebay chamber were the only pumps that operated on the days that impingement monitoring was conducted. In WY 2014, divers inspected fish screen panels 9–16 (in front of pumps 5–8) of the downstream forebay chamber because pumps 6, 7, and 8 in the downstream forebay chamber were the only pumps that operated on the days that impingement monitoring was conducted.

To facilitate divers being able to maintain their position against the river current while performing a thorough inspection of each fish screen panel, a safety line was attached to the facility's log boom at the upstream end of the water intake facility. The safety line was deployed so that it trailed downstream in front of, but away from, all of the fish screen panels. Divers used powerful underwater lights to illuminate the fish screen panels, even during daylight surveys, because relatively high turbidity levels and low light conditions limited underwater visibility to approximately 1–2 feet.

Visual inspection of the fish screen panels was performed by two divers working in tandem; a third diver and boat operator remained topside in a boat to assist the divers as needed. A small boat was used to ferry the divers inside the log boom and upstream of the most upstream fish screen panel to be inspected. The divers entered the water directly upstream of the fish screen panel and, while holding onto the safety line, submerged to the top of first fish screen panel to be inspected, which was approximately 2–3 feet below the water surface. Starting side-by-side at the top of the fish screen panel, the divers moved outward to opposite edges of the fish screen panel while observing as much of the fish screen as visibility would allow (about 18 inches). Once the divers reached the outer edge of their side of the fish screen panel, they submerged 1 to 2 feet further and inspected a new section of the fish screen panel while they moved back toward the center of the screen. Once the divers met in the center of the fish screen panel, they submerged 1 to 2 feet further and moved outward toward their edge of the screen panel. This process was repeated until the divers reached the bottom of the fish screen panel. In this manner, the divers were able to systematically observe the entire surface of the fish screen panel, even in the reduced visibility. Once the first screen panel was thoroughly inspected, the divers moved downstream to the top center of the adjacent fish screen panel and the process was repeated until all fish screen panels were visually inspected for impinged fish.

2.4.3 Predator Monitoring Using a Mobile DIDSON/ARIS Sonar Camera

The predator monitoring component consisted of using long-range DIDSON/ARIS monitoring to survey for predator- and prey-size fish in front and within the vicinity of the Freeport water intake facility. In addition to these mobile surveys of the facility and adjacent shoreline areas, in WY 2013 the ARIS sonar camera was used to conduct a drifting[5] survey in a low velocity area located immediately downstream of the water intake facility after numerous juvenile Chinook salmon using this area for feeding were incidentally observed from the boat and shore. The approach and equipment used to conduct this monitoring are described below.

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[5] Drifting refers to letting the boat move with the current (i.e., the boat motor was turned off)

DIDSON/ARIS Sonar Camera Description and Operation Mode

The same DIDSON/ARIS sonar camera and electronic equipment used to monitor for impingement of fish on the fish screen was used for the predator monitoring. As with the impingement monitoring, data were transmitted to a topside control box and laptop computer via a waterproof data cable. The DIDSON/ARIS sonar camera and laptop were powered by a 12-volt, deep cycle car battery connected to a 120-volt AC/DC power inverter.

DIDSON/ARIS Sonar Camera Mounting Apparatus and Positioning

A custom-made, adjustable pole mount was used to secure the DIDSON/ARIS sonar camera to the side of the boat. The pole mount consisted of a flat plate (transducer mount), a main vertical pole, an adjustment rod, and an adjustment handle (Figure 6). All of the components were constructed of aluminum to minimize weight. The DIDSON/ARIS sonar camera was mounted to the underside of the transducer plate with screws[6], and the pole mount (with DIDSON/ARIS sonar camera attached) was secured to the boat via a standard trolling-motor mount. Hinged connections between the components of the pole mount permitted manual tilt adjustment of the DIDSON/ARIS sonar camera once it was secured to the trolling-motor mount. Depth of the DIDSON/ARIS sonar camera was controlled by loosening the motor-mount clamp on the trolling-motor mount and raising or lowering the main vertical pole of the pole mount until the desired depth of the DIDSON/ARIS sonar camera was achieved. Once the desired depth was achieved, the trolling-motor mount clamp holding the main vertical pole was secured.

The DIDSON/ARIS sonar camera was positioned horizontally (i.e., in landscape orientation) at a depth of 2.8 feet (0.85 meter) and 1.5 feet (0.46 meter) below the water surface and with a tilt (17 degrees) downward relative to horizontal to avoid interference from the water surface. The DIDSON/ARIS sonar camera was operated in low-frequency mode, and a standard lens, rather than the spreader lens, was used to minimize beam size. A narrower beam size improved resolution of the images at long range while reducing the potential for interference from the water surface and river bottom. Horizontal positioning and operation of the DIDSON/ARIS sonar camera in low-frequency mode with the standard lens resulted in a field of view of 30 degrees horizontal and 14 degrees vertical and provided information on target (fish) size and distance (range) from the camera. Table 5 presents the positioning of the DIDSON/ARIS sonar camera during predator monitoring in WYs 2012–2014.

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[6] The X2 Rotator was not used with the ARIS sonar camera during predator monitoring in WYs 2013 and 2014 as it was for impingement monitoring with the fixed ARIS sonar camera because panning and tilting of the ARIS sonar camera during predator monitoring was not needed or desired.

Table 5. Positioning and Operating Specifications for the DIDSON/ARIS Sonar Camera during Predator Monitoring, WYs 2012–2014

Monitoring Year (sonar camera used)	Depth Below Water Surface (feet)	Downward Tilt (degrees)	Frequency Mode	Number of Beams
WY 2012 (DIDSON)	2.8 (0.85 meter)	14	Low Frequency (1.1 MHz)	48
WY 2013 (ARIS)	1.5 (0.46 meter)	17	Low Frequency (1.8 MHz)	64
WY 2014 (ARIS)	1.5 (0.46 meter)	17	Low Frequency (1.8 MHz)	64

DIDSON/ARIS Sonar Camera Resolution Settings

The DIDSON/ARIS sonar camera was set to record in auto mode; consequently, the frame rate setting varied. The data files were saved every hour on the hour as discussed for impingement monitoring. Data were saved to the laptop's hard drive and backed up to a removable storage drive at the conclusion of the predator monitoring surveys and transferred to a network drive for permanent storage.

Monitoring Location and Schedule

Monitoring for predator- and prey-size fish[7] in the nearshore area of the Sacramento River adjacent to and in the vicinity of the Freeport water intake structure was conducted by mounting the DIDSON/ARIS sonar camera to the starboard side of a 16-foot-long aluminum boat outfitted with an outboard jet motor. For purposes of this monitoring study, fish 12 inches long [305 mm long] and larger were classified as predators, while fish smaller than 12 inches long were classified as prey.

Three contiguous reaches of the Sacramento River were surveyed for predator- and prey-size fish with the boat-mounted DIDSON/ARIS sonar camera (Figure 7).

- The Downstream Control Reach was 2,281 feet long and unaffected by the water intake facility.
- The Facility Reach was 1,295 feet long and was centered on the water intake facility. The Facility Reach consisted of the water intake facility and adjacent sections of shoreline upstream and downstream of the facility. This reach was affected by the water intake facility.
- The Upstream Control Reach was 1,744 feet long and unaffected by the water intake facility.

The same reaches were surveyed each year, except that in WY 2012 the upstream and downstream control reaches were not contiguous with the facility reach (i.e., short distances separated each of the three reaches) and, therefore, were slightly shorter than the upstream and downstream control reaches in WYs 2013 and 2014..

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[7] Because the DIDSON sonar camera settings were chosen to maximize observing predator-size fish, the resulting resolution of the sonar images was not sufficient to simultaneously observe, enumerate, and measure predator- and prey-size fish. Therefore, predator monitoring in WY 2012 focused solely on quantifying the presence of predator-size fish.

During predator monitoring, each reach was surveyed four times with the DIDSON/ARIS sonar camera, and each survey included one pass through each reach. Two of the surveys were conducted during daylight (daytime surveys), one survey was conducted from approximately ½ hour before to ½ hour after sunset (twilight survey), and one survey was conducted at night, except in WY 2012 when two surveys were conducted during daylight and two surveys were conducted at night. Each pass through the reach was conducted from downstream to upstream while the boat was from 50–100 feet (15–30 meters) from shore. During each pass, the boat was operated at a slow, steady speed to ensure maximum detection of targets and the highest resolution of images possible. A Trimble GPS unit with submeter accuracy was used to create a track log of the boat's path and to record GPS coordinates of reach boundaries. In combination with the range data of each target, the GPS track log was used to estimate the location of each target identified as a predator- or prey-sized fish (see below). Software used to operate the DIDSON/ARIS sonar camera did not support direct integration with a GPS unit; therefore, the laptop's clock was synchronized to the GPS's clock so that target (i.e., fish) locations could be determined (see additional discussion below in section 2.4.4, "Data Processing, Review, and Analysis".

In WY 2013, a drifting survey of a low velocity area (backwater eddy) located immediately downstream of the water intake facility was also conducted with the ARIS sonar camera (Figure 7). Numerous juvenile Chinook salmon were visually observed feeding in this backwater eddy, especially during twilight and at nighttime.

2.4.4 Data Processing, Review, and Analysis

Raw data files were processed and reviewed using DIDSON v5.25.41 (WY 2012) and ARISFish v1.5 software (WYs 2013 and 2014) (Sound Metrics Corporation). To aid in the identification and measurement of targets (fish), raw image files were processed to display echograms. Conversion of the raw image files to echograms permitted rapid review of each file in their entirety for echo returns. All data files were processed and reviewed by a skilled technician familiar with DIDSON/ARIS imaging.

During review of the echograms, targets were identified and motion images of targets were examined for swimming motion and shape to confirm the target was a fish. Once a target was confirmed as a fish, the line measurement tool in the DIDSON or ARISFish software was used to measure fish length to the nearest millimeter; length measurements were made when the fish was parallel to the DIDSON/ARIS sonar camera lens. The DIDSON and ARISFish software was also used to measure the range of each fish (i.e., the distance the fish was from the DIDSON/ARIS sonar camera). Fish heading (i.e., upstream or downstream direction the fish was swimming) and the time fish were observed were also recorded. Display thresholds and intensity settings were manually adjusted to optimize the contrast of the targets. All data were entered into Excel spreadsheets for synthesis and evaluation.

Each data file collected during impingement monitoring was reviewed three times to obtain key information on fish passing the fish screen panel being monitored. The information collected with each pass through the image files is described below.

Pass 1—all of the image files were reviewed to determine the smallest target that could be identified as a fish, based on swimming motion, shape, and direction (targets moving upstream against the current invariably were fish).

Pass 2—all of the image files were reviewed for fish that appeared to be influenced by the diversion. To be considered influenced by the diversion, the fish had to first be within 6 feet (2 meters) of the fish screen and exhibit a trajectory (greater than 5 degrees from parallel) toward the fish screen. All fish meeting these criteria were measured, and their direction of travel (upstream or downstream) and time of occurrence (computer time and video frame) were recorded.

Pass 3—all targets observed and identified as fish that passed between the DIDSON/ARIS sonar camera and the viewable area of the fish screen panel being monitored were measured, and their direction of travel (up- or downstream) and time of occurrence were recorded.

Each data file collected during predator monitoring was reviewed once for targets, and all targets identified as predator-size and prey-size fish were measured for length and range (distance from DIDSON/ARIS sonar camera), and the time of each observation was recorded, as described above. The location of predator-size fish observed with the DIDSON sonar camera and predator-size and prey-size fish observed with the ARIS sonar camera was determined by matching the time fish were observed with the DIDSON/ARIS sonar camera against the time stamps of the track logs recorded by the GPS unit. CAD/GIS was then used to plot fish location on aerial photos using the range data determined by the DIDSON/ARIS sonar camera and the boat's location at that time based on the GPS track log.

3.0 Results

3.1 Environmental Conditions and Freeport Water Intake Facility Operations

To provide context for the fish entrainment, impingement, and predator monitoring results, this section describes the environmental conditions of the Sacramento River and the facility operations during the three entrainment monitoring periods: December 1, 2011, through July 31, 2012; December 1, 2012, through June 30, 2013; and December 1, 2013, through June 30, 2014. Additional information on environmental conditions of the Sacramento River and the facility operations are provided for the impingement and predator monitoring periods in section 3.3.1, "Environmental Conditions during Impingement and Predator Monitoring," because the temporal scale of this monitoring was much less than it was for entrainment monitoring. Figures showing environmental conditions and water intake facility operations during the entrainment, impingement, and predator monitoring periods are presented in relation to when monitoring was conducted.

3.1.1 Environmental Conditions

Sacramento River Flow, Stage, and Velocity and Regional Precipitation

Sacramento River flow, stage, and velocity are measured hourly at the Freeport bridge, located approximately 1 mile downstream of the Freeport Water Intake Facility (Figure 4). These measurements are assumed to be representative of conditions at the Freeport water intake facility because of the proximity of the water intake facility to the water quality monitoring station. Precipitation data are measured daily at the Bryte CIMIS Station near the City of West Sacramento and provide the daily rainfall amounts for the Sacramento region.

It should be noted that river flow, stage, and velocity measurements generally track one another because of the positive relationship between each of these parameters (i.e., as flows increase, stage and velocity also increase). Although these three parameters are linked to one another, each has its own implication with respect to entrainment (e.g., depth of the fish screens [stage] and sweeping velocity [velocity]).

Figure 8 shows the daily minimum, maximum, and mean values for Sacramento River flow during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Mean daily flows levels are most representative of general conditions in the Sacramento River. During the entrainment monitoring period, mean daily flow levels in the Sacramento River generally were 10,000–20,000 cubic feet per second (cfs) in WY 2012 and WY 2013, and 5,000–10,000 cfs in WY 2014. Storm events (Figure 9) during the three entrainment monitoring periods often caused river flows to increase, sometimes substantially, including the days when entrainment monitoring was conducted (Figure 8). Unlike that which occurred in WY 2012, storm events and ensuing high flows in WY 2013 and WY 2014 tended to occur during periods when no pumping (and, therefore, no entrainment monitoring) occurred (Figure 8; middle and bottom graphs). In WY 2013, high spring tides combined with relatively low river discharges to result in reverse flow conditions on several occasions in late April and early May, as indicated by the negative flow values (Figure 8; middle graph). Reverse flows were quite common during WY 2014 entrainment monitoring as a result of relatively low river levels (Figure 8; bottom graph). By contrast, river flows were sufficiently high in WY 2012 to prevent reverse flows from occurring (Figure 8; top graph). Flows fluctuated daily throughout each entrainment monitoring period. Daily fluctuations in flow, as indicated on Figure 8 (all graphs) by the substantial difference between daily maximum and minimum flows, were most notable at low to moderate flow levels and least notable when flows were high. These daily fluctuations in flow reflect the influence of the twice-daily tidal cycles on river flow, which often caused the difference between the daily minimum and maximum flows to be 10,000 cfs or more, including the days when entrainment monitoring was conducted. In addition to facility operations (i.e., pumping rate), river flow can be an important determinant of entrainment because it relates to the percentage of river flow that is diverted. For example, under constant pumping rate, the percentage of river flow diverted increases or decreases in proportion to the change in river flow (section 3.1.2, “Freeport Water Intake Facility Operations”). The data show that entrainment monitoring over the three water years was conducted under a wide range of river flows.

Figure 10 shows the daily minimum, maximum, and mean values for Sacramento River stage readings during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. As with flow, mean daily river stage is most representative of general conditions in the Sacramento River. During the entrainment monitoring period, mean daily stage in the Sacramento River generally was 2–4 feet in WY 2012 and WY 2013 (Figure 10; top and middle graphs) and 2–3 feet in WY 2014 (Figure 10, bottom graph), except during periods when flows were high in response to storm events. Stage fluctuated daily throughout the entrainment monitoring period, for the same reasons discussed above for flow. River stage is hypothesized to have important implications for entrainment with respect to the depth at which the water intake facility’s fish screens are submerged. Higher river stage results in the fish screens being submerged at greater depths, potentially reducing the risk of entrainment for surface dwelling fish, and vice-versa. The data show that entrainment monitoring over the three water years was conducted under a wide range of river stages.

Figure 11 shows the daily minimum, maximum, and mean values for Sacramento River velocities during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. As with flow and stage, mean daily river velocity is most representative of general conditions in the Sacramento River. During the entrainment monitoring period, mean daily river velocity in the Sacramento River generally was 1–2 fps in WY 2012 and WY 2013 (Figure 11; top and middle graph) and 1 fps or less in WY 2014 (Figure 11; bottom graph), except during periods when flows were elevated in response to storm events. As with flow, high spring tides in combination with relatively low river discharges resulted in negative velocities (i.e., reverse flows) in WY 2013 and WY 2014 (Figure 11; middle and bottom graphs). Velocities fluctuated daily throughout the entrainment monitoring period, for the same reasons discussed above for flow and stage. River velocity can have important implications for entrainment with respect to sweeping velocities (i.e., velocities parallel to the screen face); higher river velocity results in higher sweeping velocity, which reduces the time fish are exposed to the fish screen as they are transported across the face of the fish screen. The data show that entrainment monitoring over the three water years was conducted under a wide range of river velocities (and, therefore, sweeping velocities).

Sacramento River Turbidity, Water Temperature, and Electrical Conductivity

Sacramento River turbidity, water temperature, and EC are measured every 15 minutes at the Freeport bridge, located approximately 1 mile downstream of the Freeport water intake facility (Figure 4). These measurements are assumed to be representative of conditions at the Freeport water intake facility because of the proximity of the water intake facility to the monitoring station.

Figure 12 shows the daily minimum, maximum, and mean turbidity levels for the Sacramento River at Freeport during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Mean turbidity levels are most representative of general conditions in the Sacramento River. During the three entrainment monitoring periods, turbidity levels in the Sacramento River generally followed flow trends and occasionally exceeded 50 nephelometric turbidity units (NTUs) during periods of elevated flows (Figure 12). At relatively low flows, turbidity levels typically were below 15 NTU. Turbidity fluctuated daily during the entrainment monitoring period and appeared to do so in response to the daily fluctuations in flow. Turbidity can have implications for entrainment; higher turbidities may increase entrainment risk by making the fish screen less visible to fish. The data show that entrainment monitoring over the three water years was conducted under a wide range of turbidity levels.

Figure 13 shows the daily minimum, maximum, and mean water temperatures for the Sacramento River at Freeport during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Water temperatures showed minimal daily fluctuation throughout most of the entrainment monitoring period; daily fluctuations of about 1–2°F occurred after late April. During the three entrainment monitoring periods, minimum average water temperatures ranged from about 43°F in winter (December–January) to as much as 75–80°F by late May to mid-June. Water temperature influences the timing of migration and spawning and the suitability of habitats for fish in the Sacramento River. The data show that entrainment monitoring over the three water years was conducted under a wide range of temperature conditions.

Figure 14 shows the daily minimum, maximum, and mean EC levels for the Sacramento River at Freeport during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Mean EC levels are most representative of general conditions in the Sacramento River. During the entrainment monitoring period, EC ranged from approximately 100–250 microsiemens per centimeter (μS/cm) in WY 2012, 100–200 (μS/cm) in WY 2013, and 150–300 (μS/cm) in WY 2014 (Figure 14; top, middle, and bottom graphs, respectively). EC levels in the Sacramento River generally followed the reverse of flow trends (i.e., as river flow increased, EC decreased). EC levels can have implications on delta and longfin smelt spawning, and, therefore, the occurrence of eggs and larvae in the river. Delta smelt are considered a semi-anadromous species and longfin smelt are considered an anadromous species, spawning in the freshwater reaches of the San Francisco Estuary and primarily in the Delta. Some spawning occurs in the Sacramento River each year by both species and the EC levels (fresh water) found during this study would support spawning by each species. The data show that entrainment monitoring over the three water years was conducted under a wide range of EC conditions.

3.1.2 Freeport Water Intake Facility Operations

The parameters used to monitor Freeport water intake facility operations are hourly diversion rates, daily diversion volumes, and hourly percent discharge diverted (PDD).

Hourly Diversion Rates

Figure 15 shows the hourly flow rate for the Freeport water intake facility during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Operations were substantially different across monitoring years, ranging from intermittent pumping at instantaneous pumping rates of 23 cfs (15 mgd) in WY 2012 to continuous pumping at instantaneous pumping rates of 139–163 cfs (90–105 mgd) in WY 2014. The higher pumping rates in WY 2014 were in response to East Bay Municipal Utility District (EBMUD) taking its dry year deliveries and to support the hydraulic evaluation (ICF International 2015) that was conducted in April. Differences in hourly flow rates and facility operations during the monitoring periods for each of the three monitoring years are discussed in greater detail below.

WY 2012

From December through May, the Freeport water intake facility typically operated intermittently throughout the week and ceased operations for the weekend (Figure 15; top graph). Intermittent operations used off peak (i.e., nighttime) electrical rates, which are lower. To make up for lack of pumping over the weekend, the facility would commence pumping on Monday morning and pump continuously for approximately 24 hours. By early June, demand for water required that pumping occur continuously over the weekends, although pumping still occurred intermittently during the weekdays (i.e., only at night).

Typically, instantaneous diversion rates were about 23 cfs (15 mgd) when the water intake facility was operating. However, pumping rates were often increased to as much as 93 cfs (60 mgd) for a few hours overnight to flush the pipeline of accumulated sediment. By early May, instantaneous diversion rates of about 35 cfs (23 mgd) occurred more frequently to meet increased water demand. At low pumping rates (e.g., 23 cfs), operations required that only one pump be operated to meet water demand. Although the operating pump would remain the same over the course of the day, FRWA would operate a different pump on a daily basis. When it was necessary to increase pumping to 93 cfs (60 mgd) for a couple of hours to flush sediment from the pipeline, FRWA would start up a second pump and increase the speed of both pumps until the target pumping rate was achieved. The secondary pump selected was also varied on a daily basis. Pumping occurred either from one or both forebay chambers, depending on which two pumps were selected.

When 23 cfs was being diverted by one pump, water theoretically was being drawn through all eight fish screen panels covering the forebay chamber where the pump was located. Because each fish screen panel has an effective screen area of 106 sf, the total screen area for each chamber totaled 850 sf. At 23 cfs, the calculated average approach velocity across all eight fish screen panels was 0.03 fps, assuming that water was being drawn equally through all fish screen panels. Similarly, when a total of 93 cfs was being diverted by two pumps located in the same forebay chamber, the calculated average approach velocity across all eight fish screen panels was 0.11 fps if water was being drawn equally through all fish screen panels. When operating pumps were located in different forebay chambers, calculated average approach velocities for both forebay chambers would have been about 0.05 fps, assuming that flow was being split equally between forebay chambers.

WY 2013

No pumping occurred in December and during the first week of January; operations commenced on January 8th and continued throughout the remainder of the entrainment monitoring period (Figure

15; middle graph). From early January through early April, the Freeport water intake facility typically operated continuously throughout the week, ceasing operations for the weekend. By mid-April, demand for water required that pumping occur continuously, including during the weekends.

Typically, instantaneous diversion rates were about 20–25 cfs (13–16 mgd) when the water intake facility was operating. Instantaneous diversion rates peaked at about 46 cfs (30 mgd) during the second week of April as part of fish impingement monitoring studies. As in WY 2012, at low pumping rates only one pump was required to be operated to meet water demand. Although the operating pump typically would remain the same over the course of the day, FRWA would often operate a different pump on a daily or near-daily basis. When it was necessary to increase pumping to 46 cfs (30 mgd) for the week in early April to support the impingement and predator monitoring studies, FRWA operated a second pump to meet the target pumping rate of 30 mgd; this second pump also was operated in the same forebay chamber as the first operating pump in order to meet the objectives of the impingement and predator monitoring studies. Over the course of the monitoring period, pumping occurred from either of the two forebay chambers, depending on which pump was selected. Unlike during the WY 2012 monitoring period, FRWA did not periodically increase flows to 93 cfs (60 mgd) for a couple of hours to flush sediment from the pipeline. Based on these operations, the calculated average approach velocity across all eight fish screen panels of a single forebay chamber ranged from 0.02 to 0.05 fps during the monitoring period.

WY 2014

Pumping occurred in early December and then operations ceased on December 12th; operations resumed on March 11th and continued throughout the remainder of the entrainment monitoring period (Figure 15; bottom graph). The Freeport water intake facility typically operated continuously, although intermittent operations occurred in March, April, and May when reverse flows required that the water intake facility cease pumping temporarily (i.e., for several hours each of the days when reverse flows occurred).

From December through March, instantaneous diversion rates were about 17–23 cfs (11–15 mgd) when the water intake facility was operating (Figure 15, bottom graph). Beginning in early April, instantaneous diversion rates increased incrementally as EBMUD prepared to take their dry-year deliveries, which commenced on April 7. During the next two weeks, operations were held constant at 139 cfs (90 mgd) to meet the objectives of the impingement and predator monitoring studies (this report) and the hydraulic evaluation (ICF International 2015). Instantaneous diversion rates peaked at 163 cfs (105 mgd) through mid-May and then were 120–132 cfs (78–85 mgd) throughout the remainder of the entrainment monitoring period. As in previous years, at low pumping rates only one pump was required to be operated to meet water demand. At higher pumping rates, up to 3 pumps were operated simultaneously to meet EBMUD delivery needs, although diversions typically were split at a ratio of 2:1 between forebay chambers (i.e., two pumps were operated in one forebay chamber and the third pump was operated in the other forebay chamber, with all pumps being operated equally). The only exception occurred during the nine days in April when all three pumps were being operated in the same forebay chamber to support the objectives of the impingement and predator monitoring studies and the hydraulic evaluation. Based on these operations, the calculated average approach velocity across all eight fish screen panels of a single forebay chamber ranged from 0.02 to 0.16 fps during the monitoring period. It should be noted that the calculated average approach velocity of 0.16 fps occurred only during the nine days in April when the impingement and predator monitoring studies and the hydraulic evaluation were being conducted. Because FRWA split the flow between forebay chambers during other periods when EBMUD was taking its dry-year deliveries, the maximum calculated average approach velocity for either forebay was approximately 0.13 fps based on a maximum diversion of 109 cfs (two-thirds of 163 cfs) through a single forebay chamber.

Diversion Volumes

Figure 16 shows the daily volume of water diverted by the Freeport water intake facility during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. In WY 2012 and WY 2013, daily diversions were less than 20 million gallons (Mgal), except for two days in April 2013 when daily diversions of 24 and 30 Mgal occurred during impingement monitoring (Figure 16; top and middle graph). By contrast, daily diversions in WY 2014 were less than 20 Mgal in December–March on the days when FRWA was operating to meet local water demand only and as much as 105 Mgal while EBMUD was taking its dry-year deliveries (Figure 16; bottom graph). Daily diversion volumes were less than 10% of the water intake facility's daily design capacity of 185 mgd in WY 2012 and WY 2013 (Figure 17; top and middle graphs). By contrast, daily diversion volumes in WY 2014 peaked at nearly 60% of the water intake facility's overall daily design capacity of 185 mgd (Figure 17; bottom graph). It should be noted, however, that instantaneous diversion rates of 90 mgd with all three pumps operating in the same forebay chamber during impingement and predator monitoring studies and the hydraulic evaluation was 85% of the design flow rate (105.7 mgd) for each forebay chamber. The data show that entrainment monitoring over the three water years was conducted over a wide range of diversion conditions.

Percent Discharge Diverted

Figure 18 shows the daily minimum, maximum, and mean PDD (i.e., the proportion of Sacramento River flow diverted) by the Freeport water intake facility during each of the three entrainment monitoring periods and in relation to their respective entrainment monitoring dates. Mean PDD is most representative of general conditions in the Sacramento River. In WY 2012 and WY 2013, the proportion of Sacramento River flow diverted by the Freeport water intake facility typically was less than 0.5% (Figure 18; top and middle graphs). By contrast, the proportion of Sacramento River flow diverted by the Freeport water intake facility was much greater and more variable in WY 2014 than during WY 2012 and WY 2013 (Figure 18; bottom graph). The much larger percent diversions observed in WY 2014 were caused by the intermittent very low or negative hourly river flows (Figure 8; bottom graph) resulting from the combination of unseasonable low river levels caused by the drought and seasonable high tides, as well as the higher pumping rates. The data show that entrainment monitoring over the three water years was conducted under a wide range of PDD conditions.

3.2 Entrainment Monitoring

3.2.1 Overview of Monitoring Activities

A combined total of 759 hours of sampling with the hoop net at the VSWTP and a combined total of 676 trap-hours of sampling with the floating larval light traps behind the fish screens at the Freeport water intake facility were conducted over the course of the WY 2012–2014 entrainment monitoring periods. Freeport water intake facility operations and results of entrainment monitoring for monitoring events during each of the three entrainment monitoring periods are summarized below.

WY 2012

Table 6 summarizes the Freeport water intake facility operations and results of fish entrainment monitoring based on detection of fish in the hoop net at the VSWTP during WY 2012. Entrainment was monitored from December 2011 through July 2012. During each monitoring event, the net was operated from facility startup on Monday morning to facility shutdown on Tuesday morning to take advantage of the 24-hour continuous operation of the facility. A total of 212.2 Mgal of diverted water was passed through the net during 266 hours of sampling during the monitoring period (Table 6). This sample volume represented 11% (212.2 of 1,955 Mgal) of the total volume of water diverted by the Freeport water intake facility from December 1, 2011, through July 31, 2012. Operation of the pumps varied across monitoring events, while PDD ranged from approximately 0.08% to 0.44% for the 12 monitoring events (Table 6). Entrainment monitoring with floating larval light traps did not commence until WY 2013; consequently, there are no monitoring results for larval fish sampling in the forebay chambers

WY 2013

Table 7 summarizes the Freeport water intake facility operations and results of fish entrainment monitoring based on detection of fish in the hoop net at the VSWTP during WY 2013. Entrainment was monitored from January through June 2013. Entrainment monitoring did not occur during December 2012 because no pumping occurred (the water intake facility was offline for maintenance). During each monitoring event, the net was operated continuously over a 24-hour period, with the exception of brief periods when the net was out of the water to retrieve samples. A total of 150 Mgal of diverted water was passed through the net during 247 hours of sampling during the monitoring period (Table 7). This sample volume represented approximately 8% (150 of 1,923 Mgal) of the total volume of water diverted by the Freeport water intake facility during the WY 2013 entrainment monitoring period (i.e., December 1, 2012, through June 30, 2013). Operation of the pumps varied across monitoring events, while PDD ranged from approximately 0.09% to 36.2% across the 12 monitoring events (Table 7).

Table 8 summarizes the results of larval fish sampling in the forebay chambers at the Freeport water intake facility using the floating larval light traps during WY 2013. Larval fish sampling in the forebay chambers occurred concurrently with entrainment monitoring to determine whether the fish species detected in the net at the VSWTP were representative of species present in the forebay chamber and to assist in detecting rare species. The floating larval light traps were deployed on 13 days for a total of 115 trap-hours over the course of the WY 2013 entrainment monitoring period.

Table 6. Summary of WY 2012 (December 2011–July 2012) Facility Operations and Fish Entrainment Monitoring Results Using the Hoop Net

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Average Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Pumped/ Volume Passing through Net)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
1	December 5–6, 2011	19:39	5 (2)	20.4	0.22	17.0	83.2	5	Striped bass—1 (142 mm) Prickly sculpin—2 (95–98 mm) White catfish—2 (50–90 mm)
2	January 30–31, 2012	20:18	2 (8)	18.1	0.16	15.6	86.0	22	Chinook salmon—1 (32 mm) Prickly sculpin—2 (74–80 mm) Lamprey ammocoete—19 (21–46 mm)
3	February 21–22, 2012	22:04	1 (8)	17.8	0.22	15.5	87.3	1	Prickly sculpin—1 (NA[2]) Prickly sculpin eggs—NA[3]
4	March 12–13, 2012	23:29	5 (3)	18.2	0.44	16.5	90.6	1	Prickly sculpin—1 (NA[2])
5	March 26–27, 2012	22:20	7 (2)	16.9	0.14	15.2	89.9	1	Sacramento sucker—1 (13 mm)
6	April 16–17, 2012	22:50	8 (1)	17.6	0.08	15.3	87.0	31	Prickly sculpin—30 (4.5–31 mm) Sacramento sucker—1 (16.3 mm) Prickly sculpin eggs—>400

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Average Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Pumped/ Volume Passing through Net)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
7	April 30–May 1, 2012	21:52	**2 (3)**	14.8	0.08	13.4	90.7	13	Striped bass—1 (165 mm) Prickly sculpin—6 (20.5–37 mm) Sacramento sucker—6 (13.6–15.9 mm) Prickly sculpin eggs—5
8	May 14–15, 2012	22:45	2 (7)	22.3	0.33	19.6	87.7	21	Sacramento splittail—5 (14.5–16.2 mm) Prickly sculpin—11 (26–139 mm) Sacramento sucker—5 (14.1–16.3 mm)
9	May 29–30, 2012	22:02	**5 (7)**	22.1	0.44	19.4	87.7	6	Prickly sculpin—5 (33–153 mm) Threadfin shad—1 (10.6 mm)
10	June 11–12, 2012	22:22	**2 (4)**	24.1	0.44	21.7	90.0	10[4]	Sacramento sucker—3 (9.3–25 mm) Prickly sculpin—2 (30–103 mm) Striped bass—4 (168–182 mm) Common carp—1 (7.6 mm)

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Average Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Pumped/ Volume Passing through Net)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
11	June 25–26, 2012	23:12	6 (3)	22.8	0.24	19.6	86.1	1	Prickly sculpin—1 (35 mm)
12	July 16–17, 2012	23:14	3 (8)	26.2	0.19	23.5	89.6	1[5]	Prickly sculpin—1 (60 mm)
TOTALS		266		241.3		212.2		113[6]	

Note: See report text for discussion regarding which sampling intervals were re-examined for fish larvae overlooked during initial sample sorting in 2012.

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2). Pumps 1–4 are located in the upstream forebay chamber, while pumps 5–8 are located in the downstream forebay chamber. The primary pump that was operating over the duration of the monitoring event is listed first, followed by the secondary pump ( ) that was placed into service for about 2 hours when additional pumping was needed to flush the pipeline of sediment. Pump combinations in **bold** indicate that both operating pumps are located in the same forebay chamber.

[2] NA = Measurement was not possible because the individual was not intact.

[3] NA = Eggs in tight clustered formation and could not be counted.

[4] The net was found with tear at the conclusion of the final sampling interval and may have affected the number of fish detected in the net. The net was repaired prior to the next (11th) monitoring event.

[5] The net was found with tear at the conclusion of the final sampling interval and may have affected the number of fish detected in the net.

[6] 61 of the 113 fish were larvae.

Table 7. Summary of WY 2013 (2012–2013) Facility Operations and Fish Entrainment Monitoring using the Hoop Net

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal)	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
1	January 24–25, 2013	21:48	7	14.6	0.11 (0.09–0.17)	13.3	0.91	1	Prickly sculpin—1 (5.5 mm)
2	February 13–14, 2013	22:55	7	15.5	0.11 (0.09–0.14)	14.7	0.95	10	Prickly sculpin—10 (5.5–6.4 mm)
3	March 13–14, 2013	22:11	3, 4	14.7	0.14 (0.12–0.26)	13.6	0.92	16	Prickly sculpin—11 (4.8–6.0 mm) Bigscale logperch—3 (5.3–5.7 mm)[2] Striped bass—1 (2.8 mm) Unknown—1 (NA)[3]
4	March 20–21, 2013	21:23	2, 3, 4	12.1	0.12 (0.11–0.17)	10.9	0.90	147	Prickly sculpin—145 (4.3–7.2 mm) Striped bass—1 (4.8 mm) Unknown—1 (NA)[3]
5[4]	April 11, 2013	2:36	(5 and 6)	29.0	0.24	3.1	0.11	1	Lamprey ammocoete—1 (41 mm)

Table 7. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal)	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
6	April 24–25, 2013	22:11	7	10.9	0.17 (0.14–15.2)	6.0[5]	0.92	222	Sacramento splittail—117 (6.1–9.0 mm) Bigscale logperch—48 (3.1–8.0 mm) Prickly sculpin—38 (4.1–6.4 mm) Unknown—12 (NA)[3] Striped bass—3 (4.9–5.6 mm) Sacramento sucker—2 (16.9–17.1 mm) Wakasagi—2 (13.0–17.1 mm) Eggs[5]—2 (2.5–2.6 mm)[6]
7	May 2–3, 2013	22:12	7	14.9	0.19 (0.13–0.41)	13.8	0.92	5	Sacramento splittail—4 (7.4–15.0 mm) Sacramento blackfish—1 (10.5 mm) Eggs (Prickly sculpin)—>1,000 (1.1–1.2 mm)[6]

Table 7. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal)	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
8	May 8–9, 2013	22:19	4	16.1	0.37 (0.18–36.2)	14.8	0.92	23	Sacramento splittail—9 (6.4–14.3 mm) Sacramento sucker—4 (15.7–19.0 mm) Sacramento blackfish—2 (6.9–7.8 mm) Bigscale logperch—2 (10.5–11.5 mm) Common carp—2 (6.4–7.1 mm) Largemouth bass—2 (9.4–10.2 mm) Wakasagi—1 (15.2 mm) Unknown—1 (NA)[3]
9	May 16–17, 2013	22:13	2	16.0	0.21 (0.16–0.47)	14.7	0.92	4	Bigscale logperch—3 (9.5–12.1 mm) Sacramento splittail—1 (13.8 mm)

Table 7. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal)	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Total Number of Fish Detected in Net	Number and Size Range (millimeters) of Fish Species Detected in Net
10	May 22–23, 2013	22:38	4	16.5	0.19 (0.16–0.64)	15.3	0.93	4	Prickly sculpin—1 (18.0 mm) Common carp—1 (6.6 mm) Threadfin shad—1 (10.9 mm) Micropterus spp.—1 (6.8 mm)
11	May 29–30, 2013	22:27	5	16.8	0.19 (0.15–0.51)	15.8	0.94	1	Threadfin shad—1 (10.9 mm) Eggs[6]—3 (2.5–2.7 mm)[7]
12	June 19–20, 2013	22:30	3	15.0	0.16 (0.12-0.47)	14.0	0.93	1	Western mosquitofish—1 (12.7 mm)
TOTALS		247:23		192.2		150.0		435	

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2). Pumps 1–4 are located in the upstream forebay chamber, while pumps 5–8 are located in the downstream forebay chamber. Only one pump was operated at a time during each entrainment monitoring event, except on April 11 when two pumps operated simultaneously to achieve the target pumping rate of 30 mgd (both pumps are listed inside the parenthesis). In cases where multiple pumps were operated in succession over the course of the entrainment monitoring event, each pump is listed and separated by a comma.

[2] Does not include partial fish.

[3] Identification and precise length measurement not possible because individual was not intact.

[4] The net was found with tear at the conclusion of the first sampling interval and may have affected the number of fish detected in the net. No further sampling during this monitoring event was possible.

[5] Flow was split between north and south weir boxes, therefore less than 100% of flow sampled.

[6] Possibly Sacramento sucker (Wang pers. comm.).

[7] Diameter (millimeters).

Table 8. Summary of WY 2013 (2012–2013) Fish Entrainment Monitoring using the Floating Larval Light Traps

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Approximate Pumping Rate (mgd)	Start Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins)	Total Number of Fish Detected in Light Trap	Number and Size Range (millimeters) of Fish Species Detected in Net
1	January 24, 2013	7	15	09:30	12:40	0	
2	February 13, 2013	7	16	10:05	10:20	5	Prickly sculpin—5 (5.2–5.4 mm)
3	March 13, 2013	3, 4	15	10:15	9:45	0	
4	March 20, 2013	2, 3, 4	12	11:34	9:04	8	Prickly sculpin—8 (5.2–6.6 mm)
5[2]	April 10, 2013	(5 and 6)	30	14:11 20:02	7:56 7:49	4 2	Prickly sculpin—4 (5.5–6.3 mm) Prickly sculpin—1 (5.7 mm) Sacramento sucker—1 (14.2 mm)
	April 11, 2013	(5 and 6)	30	15:00 20:00	8:04 7:26	0 21	Prickly sculpin—20 (5.0–5.8 mm) Sacramento sucker–1 (14.6 mm)
6	April 24, 2013	7	11	10:33	8:56	1	Sacramento splittail—1 (7.7 mm)
7	May 2, 2013	7	15	11:07	8:07	0	
8	May 8, 2013	4	16	11:03	8:24	0	
9	May 16, 2013	2	16	10:47	3:53	0	
10	May 22, 2013	4	17	11:38	3:52	0	

Table 8. Continued

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Approximate Pumping Rate (mgd)	Start Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins)	Total Number of Fish Detected in Light Trap	Number and Size Range (millimeters) of Fish Species Detected in Net
11	May 29, 2013	5	17	12:28	4:47	0	
12	June 19, 2013	3	15	11:16	4:12	0	
TOTALS					115:15	41	

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2). Pumps 1–4 are located in the upstream forebay chamber, while pumps 5–8 are located in the downstream forebay chamber. Only one pump was operated at a time during each entrainment monitoring event, except on April 11 when two pumps operated simultaneously to achieve the target pumping rate of 30 mgd (both pumps are listed inside the parenthesis). In cases where multiple pumps were operated in succession over the course of the entrainment monitoring event, each pump is listed and separated by a comma.

[2] Pumping was increased to 30 mgd to facilitate implementing impingement and predator monitoring studies.

WY 2014

Table 9 summarizes the Freeport water intake facility operations and results of fish entrainment monitoring based on detection of fish in the hoop net at the VSWTP during WY 2014. Entrainment was monitored from December 2013 through June 2014; however, entrainment monitoring did not occur during January and February 2014 because no pumping occurred (the water intake facility was offline for maintenance). During each monitoring event, the net was operated continuously over a 24-hour period, with the exception of brief periods when the net was out of the water to retrieve samples. A total of 121 Mgal of diverted water was passed through the net during 246 hours of sampling during the monitoring period (Table 9). This sample volume represented approximately 1.6% (121 of 7,603 Mgal) of the total volume of water diverted by the Freeport water intake facility during the WY 2014 entrainment monitoring period (i.e., December 1, 2013, through June 30, 2014). Operation of the pumps varied across monitoring events, while PDD ranged from approximately -290% to 88.7% across the 12 monitoring events (Table 9).

Table 10 summarizes the results of larval fish sampling in the forebay chambers at the Freeport water intake facility using the floating larval light traps during WY 2014. Larval fish sampling in the forebay chambers occurred concurrently with entrainment monitoring for the same reasons as discussed above. The floating larval light traps were deployed on 14 days for a total of 561 trap-hours over the course of the WY 2014 entrainment monitoring period.

Table 9. Summary of WY 2014 (December 2013– June 2014) Facility Operations and Fish Entrainment Monitoring Results using the Hoop Net

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
1	December 4–5, 2013	22:03	6	12.5	0.18 (-9.10 to 1.62)	10.3	0.82	0	
2	March 20–21, 2014	22:11	4	12.8	0.18 (0.03 to 1.25)	10.4	0.81	993	Prickly sculpin—978 (3.6–8.8 mm) Bigscale logperch—13 (5.4–6.8 mm) Eggs (prickly sculpin)—4 (1.0-1.1 mm) Sacramento splittail—1 (7.7 mm) Unknown—1 (NA)[3] Juvenile prickly sculpin—1 (45 mm)
3	March 26–27, 2013	22:38	7	11.2	0.19 (-2.21 to 3.33)	10.5	0.94	258	Prickly sculpin—248 (3.3–8.5 mm) Sacramento sucker—6 (13.9–15.3) Sacramento splittail—2 (7.4–8.2 mm) Bigscale logperch—1 (6.3 mm) Unknown—1 (NA)[3]

Table 9. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
4	April 2–3, 2014	20:32	(2, 3, 5)	49.9	0.11 (0.09 to 0.23)	5.3	0.11	94	Prickly sculpin—80 (4.5–10.7 mm) Unknown—6 (NA)[3] Sacramento sucker—4 (13.6–13.8 mm) Sacramento splittail—4 (7.3–7.5 mm)
5[4]	April 9–10, 2014	20:37	(6, 7, 8)	90.0	1.25 (0.99 to 5.33)	15.0	0.17	28,125	Unknown—18,039 (NA)[3] Prickly sculpin—9,781 (4.3–7.2 mm) Eggs (prickly sculpin)—208 (0.2–1.6 mm) Sacramento splittail—170 (5.0–7.6 mm) Bigscale logperch—103 (4.7–5.8 mm) Sacramento sucker—20 (11.7–15.9 mm) Smelt[5]—12 (6.3 mm)

Table 9. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
6	April 16–17, 2014	21:31	(5, 6, 7)	90.8	1.37 (-14.87 to 88.68)	15.0	0.17	26,704	Unknown—21,244 (NA)[3] Prickly sculpin—4,652 (4.3–7.6 mm) Bigscale logperch—664 (5.0–9.7 mm) Sacramento splittail—84 (7.5–7.8 mm) Striped bass—32 (2.5–4.9 mm) Common carp—20 (6.4–7.9 mm) Eggs (prickly sculpin [8], Cyprinid [4], Sacramento sucker [4])—16 (0.6–2.4 mm) Sacramento sucker—4 (NA) Inland silverside—4 (NA) Juvenile prickly sculpin—1 (52 mm) Lamprey ammocoete—1 (105 mm)

Table 9. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
7	April 23–24, 2014	21:47	(1, 4, 7)	101.0	1.54 (1.26 to 22.16)	10.0	0.10	634	Sacramento splittail—260 (2.1–8.1 mm) Unknown—258 (NA)[3] Prickly sculpin—72 (4.2–6.1 mm) Bigscale logperch—39 (5.4–11.3 mm) Eggs (Cyprinid, possibly common carp)—4 (2.0–2.4 mm) Striped bass—4 (4.5 mm) Inland silverside—1 (7.1 mm) Adult prickly sculpin—2 (65–73 mm)
8	April 30–May 1, 2014	21:17	(1, 4, 7)6 (3, 4, 6)7	100.8	1.30 (-55.99 to 23.25)	10.3	0.10	720	Unknown—280 (NA)[3] Bigscale logperch—236 (5.3–15.0 mm) Sacramento splittail—132 (6.7–9.3 mm) Prickly sculpin—68 (4.7–11.7 mm) Largemouth bass—4 (7.0 mm)

Table 9. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
									Juvenile prickly sculpin—1 (63 mm)
9	May 7–8, 2014	22:03	(1, 3, 6)	104.3	1.84 (-290.09 to 22.94)	15.5	0.15	1,012	Unknown—716 (NA)[3] Bigscale logperch—140 (5.5–14.5 mm) Sacramento splittail—64 (8.8–12.4mm) Common carp—36 (6.2–7.6 mm) Inland silverside—36 (4.4–7.8 mm) Prickly sculpin—16 (5.3–5.4 mm) Largemouth bass—4 (10.8 mm)
10	May 14–15, 2014	19:48	(1, 2, 7)	100.1	1.39 (-19.84 to 14.97)	8.9	0.09	96	Bigscale logperch—40 (5.7–14.6 mm) Unknown—36 (NA)[3] Sacramento splittail—8 (8.8–8.9 mm) Inland silverside—8 (6.1–6.4 mm) Prickly sculpin—4 (NA) Juvenile prickly sculpin—1 (42 mm)

Table 9. Continued

Monitoring Event	Monitoring Dates	Elapsed Time Net Was Fished (Hrs:Mins)	Operating Pump Number[1]	Volume of Water Pumped by Diversion (Mgal) during Monitoring	Median (Range)Percent River Flow Diverted during Monitoring Event	Volume of Water Passing through Net (Mgal)	Proportion of Pumped Water Passing through Net (Volume Passing through Net /Volume Pumped)	Estimated Total Number of Fish Detected in Net[2]	Estimated Number and Size Range (millimeters) of Fish and Eggs Detected in Net
11	May 21–22, 2014	10:10	(1, 2, 7)	37.5	1.13 (-11.49 to 27.16)	5.1	0.14	76	Unknown—52 (NA)[3] Bigscale logperch—20 (6.4–12.6 mm) Prickly sculpin—4 (NA) Juvenile prickly sculpin—2 (47–64 mm)
12	June 18–19, 2014	21:50	(2, 3, 5)	77.8	1.20 (0.76 to 8.80)	5.1	0.07	4	Inland silverside—4 (4.7 mm)
TOTALS		246:27		788.6		121.3		58,716	

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2). Pumps 1–4 are located in the upstream forebay chamber, while pumps 5–8 are located in the downstream forebay chamber. Only one pump was operated at a time during the December and March entrainment monitoring events; when more than one pump was operated simultaneously to achieve the target pumping rate (both pumps are listed inside the parenthesis). In cases where multiple pumps were operated in succession over the course of the entrainment monitoring event, each pump is listed and separated by a comma.

[2] Includes expanded numbers of fish to account for subsampling of samples associated with monitoring events 5–12. A total of 18,519 larvae were sorted from all samples that were sorted completely (primarily the December, March, and early April samples) and the subsamples.

[3] Identification and precise length measurement not possible because individual was not intact.

[4] The net was found with tear at the conclusion of the first sampling interval and may have affected the number of fish detected in the net. No further sampling during this monitoring event was possible.

[5] Identification to species not possible because of poor condition of specimens.

[6] First 7 hours

[7] Latter 17 hours

Table 10. Summary of WY 2014 (2013–2014) Fish Entrainment Monitoring Results using the Floating Larval Light Traps

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Average Pumping Rate (mgd)	Start/End Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins) (Forebay Chamber)	Total Number of Fish Detected in Light Traps	Number and Size Range (millimeters) of Fish Species Detected in Net
1	December 4, 2013	6	12.5	08:30/16:45	16:30 (D)	0	
	December 5, 2013	6	12.5	08:35/16:40	16:10 (D)	0	
2	March 20, 2014	4	12.8	09:30/16:30	28:00 (U)	0	
3	March 25–26, 2014	2	11.2	18:30/07:00	50:00 (U)	91	Prickly sculpin—91 (4.2–8.1 mm)
4	April 1–2, 2014	2	49.9	16:50/08:30	62:40 (U)	82	Prickly sculpin—80 (4.2–5.7 mm) Unknown—2 (NA)
5[2]	April 9–10, 2014	(6, 7, 8)	90.0	20:45/12:25	62:40 (D)	67	Prickly sculpin—44 (4.1–6.1 mm) Sacramento splittail—14 (6.5–7.9 mm) Sacramento sucker—4 (11.1–14.9 mm) Unknown—4 (NA) Bigscale logperch—1 (5.9 mm)
6	April 15–16, 2014	(6, 7, 8)	90.8	19:00/08:55	55:40 (D)	128	Prickly sculpin—128 (1.6–5.9 mm)
7	April 23–24, 2014	(1, 4, 7)	101.0	19:52/08:52	26:00 (U)	39	Prickly sculpin—30 (4.5–5.9 mm) Sacramento splittail—8 (7.4-8.5 mm) Bigscale logperch—1 (4.8 mm)

Table 10. Continued

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Average Pumping Rate (mgd)	Start/End Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins) (Forebay Chamber)	Total Number of Fish Detected in Light Traps	Number and Size Range (millimeters) of Fish Species Detected in Net
7 (Continued)	April 24, 2014	(1, 4, 7)	101.0	09:23/18:05	17:24 (U)	28	Prickly sculpin—23 (4.0–8.7 mm) Bigscale logperch—3 (5.1–5.9 mm) Sacramento splittail—1 (7.4 mm) Largemouth bass—1 (9.4 mm)
8	April 30, 2014	(1, 4, 7) (3, 4, 6)	100.8	08:30/16:30	32:00 (U)	2	Prickly sculpin—1 (3.9 mm) Inland silverside—1 (5.4 mm)
9	May 7–8, 2014	(1, 3, 6)	104.3	20:30/07:20	21:40 (U)	87	Inland silverside—61 (4.0–9.6 mm) Prickly sculpin—15 (4.4–5.6 mm) Common carp—5 (7.0–8.0 mm) Sacramento splittail—4 (7.0–10.3 mm) Wakasagi—1 (18.3 mm) Unknown—1 (4.9 mm)
				20:40/07:28	21:36 (D)	29	Prickly sculpin—16 (4.6 mm) Inland silverside—6 (5.9–7.6 mm) Unknown—6 (NA) Wakasagi—1 (15.9 mm)

Table 10. Continued

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Average Pumping Rate (mgd)	Start/End Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins) (Forebay Chamber)	Total Number of Fish Detected in Light Traps	Number and Size Range (millimeters) of Fish Species Detected in Net
10	May 14–15, 2014	(1, 2, 7)	100.1	19:34/08:23	25:38 (U)	24	Inland silverside—13 (4.6–15.8 mm) Prickly sculpin—10 (5.0–5.8 mm) Bigscale logperch—1 (8.2 mm)
				19:43/08:50	26:14 (D)	26	Prickly sculpin—12 (4.2–6.8 mm) Inland silverside—10 (3.9–7.4 mm) Unknown—2 (NA) Sacramento sucker—1 (14.0 mm) Largemouth bass—1 (12.7 mm)
11	May 21–22, 2014	(1, 2, 7)	75.0	19:27/08:25	25:56 (U)	13	Inland silverside—13 (8.7–8.8 mm)
				19:35/08:30	25:50 (D)	36	Inland silverside—29 (5.0–11.5 mm) Unknown—3 (NA) Prickly sculpin—2 (7.7—11.4 mm) Sacramento splittail—1 (22.6 mm) Common carp—1 (17.9 mm)

Table 10. Continued

Monitoring Event	Monitoring Date	Operating Pump Number[1]	Average Pumping Rate (mgd)	Start/End Time Light Traps were Deployed (Hrs:Mins)	Combined Total Elapsed Time Light Traps Were Deployed (Hrs:Mins) (Forebay Chamber)	Total Number of Fish Detected in Light Traps	Number and Size Range (millimeters) of Fish Species Detected in Net
12	June 18, 2014	(2, 3, 5)	77.8	19:42/07:12	23:00	0	
				19:48/07:36	23:36	0	
TOTALS					560:34	652	

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2). Pumps 1–4 are located in the upstream forebay chamber, while pumps 5–8 are located in the downstream forebay chamber. Only one pump was operated at a time during each entrainment monitoring event, except on April 11 when two pumps operated simultaneously to achieve the target pumping rate of 30 mgd (both pumps are listed inside the parenthesis). In cases where multiple pumps were operated in succession over the course of the entrainment monitoring event, each pump is listed and separated by a comma.

[2] Pumping was increased to 90 mgd to facilitate implementing impingement and predator monitoring studies.

3.2.2 Fish Entrained by Diversion of Sacramento River Flow

Fish entrained by the Freeport water intake facility and later detected in the net at the VSWTP and the floating larval light traps at the water intake facility were entrained with flow diverted from the Sacramento River. After passing through the facility's fish screen, these fish entered and traveled across the forebay chamber, became entrained by one of the operating pumps, and were transported through the pipeline before being detected in the hoop net attached to the outlet of the pipeline at the VWSTP. The light traps passively captured entrained fish while they were in the forebay chamber (i.e., behind the fish screen but in front of the pumps).

In this section, general results of entrainment monitoring for each of the three monitoring years are discussed first, followed by a species-based discussion that integrates and synthesizes the WY 2012–WY 2014 entrainment monitoring results.

WY 2012

One hundred and thirteen (113) fish, comprising 9 species, were detected in the net at the VSWTP (Tables 6 and 11). All fish were identified to species. Of the 113 fish detected in the net at the VSWTP, 61 were larvae, while the remaining 52 fish were classified as juveniles or adults (primarily prickly sculpin and striped bass) that had reared (and grew) for an indeterminate amount of time in the forebay chamber before being detected in the net at the VSWTP. Prickly sculpin were the most abundant species detected in the net and accounted for 55% of the catch. Lamprey ammocoete (17%), Sacramento sucker (14%), juvenile striped bass (5%), Sacramento splittail (4%), and white catfish (1.8%) were the next most common fish species detected. Common carp, threadfin shad, and Chinook salmon each accounted for less than 1% of the total catch. Prickly sculpin, lamprey ammocoete, Sacramento sucker, and Sacramento splittail were the only native species detected in the net.

Table 11. Species, Number Detected, and Size of Fish Detected in the Net, WY 2012 (December 2011 to July 2012)

Species (Common /Scientific Name)	Number Collected	Average (SD) Fork Length (millimeters)	Size Range (millimeters)
Prickly sculpin* *Cottus asper*	62[1]	33.9 (31.0)[2]	4.5–153[2]
Lamprey ammocoete* *Entosphenus/Lampetra* spp.	19	29.8 (5.6)	21–46
Striped bass *Marone saxatilis*	6	169.5 (15.2)	142–182
Sacramento splittail* *Pogonichthys macrolepidotus*	5	15.2 (0.6)	14.5–16.2
Sacramento sucker* *Catostomus occidentalis*	16	14.9 (3.3)	9.3–25
White catfish *Ameiurus catus*	2	70 (28.3)	50–90
Common carp *Cyprinus carpio*	1	7.6	7.6
Threadfin shad *Dorosoma petenense*	1	10.6	10.6
Chinook salmon* *Oncorhynchus tshawytscha*	1	32	32

* = Native species

[1] 19 were larvae; numerous eggs also were collected.

[2] Two individuals were not intact and could not be measured.

Overall, the median size of fish detected in the net was 31 mm fork length (range: 4.5–182 mm); the largest individual (182 mm) detected in the net was a juvenile striped bass, while the smallest (4.5 mm) was a pro-larval[8] prickly sculpin (Table 11). Most of the fish detected in the net were larvae and juveniles; the only adult fish detected in the net were prickly sculpin. The larger fish detected in the net are assumed to have passed through the fish screen as eggs or larvae weeks or months prior to being captured in the net (section 4, "Discussion").

With the exception of two prickly sculpin, all the fish captured in the net were intact and could be measured, and lacked obvious marks or injuries that would indicate trauma as a result of being entrained by the operating pump, being transported through the pipeline and associated valves, or being captured by the net. Likewise, an overwhelming majority of the fish that were recovered from the net and observed in the field prior to sample preservation were found to be alive and in good condition. In the few instances where dead individuals were recovered from the net, there was visual evidence (e.g., partial decomposition) to suggest that the fish may have died in the forebay

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[8] A larval fish that has undeveloped mouth parts and relies on a yolk-sac for nutrition.

prior to being entrained by the pump, where it was then transported through the pipeline before being detected in the net at the VWSTP.

The total number of fish detected in the net varied from one to 31 fish per monitoring event and the estimated average catch rate[9] was 0.46 larval fish per 1 million gallons of diverted water sampled over the course of the 12 monitoring events; however, it should be noted that the intermittent facility operations during the entrainment monitoring period may have affected fish densities in the forebay chambers and pipeline and, therefore, the true catch rate.

In addition to fish, aquatic invertebrates, one amphibian, and more than 321 prickly sculpin eggs were also detected in the net at the VSWTP. Invertebrates detected included an abundance of amphipods (*Corophium* spp.), cladocera (*daphnia* spp.), snails (family Physidae), and clams (*Corbicula* spp.), and at least one freshwater shrimp (likely *Exopalaemon modestus* [Siberian prawn]). The amphibian detected in the net was a bullfrog tadpole (*Lithobates catesbeiana*, formerly *Rana catesbeiana*) that was 127 mm long.

WY 2013

Hoop Net

Four hundred and thirty-five (435) fish, comprising 12 species, were detected in the net at the VSWTP (Tables 7 and 12). All fish, with the exception of 16 individuals, were identified to species: one unidentified individual belonged to the Centrarchidae family (i.e., black bass and sunfish family) and could only be identified to genus (i.e., *Micropterus* [black bass]), while 15 unidentified individuals ("Unknown spp.") were too badly damaged to be identified. Prickly sculpin were the most abundant species detected and accounted for 47% of the catch. Sacramento splittail (30%), bigscale logperch (13%), Unknown species (3%), Sacramento sucker (1%), and striped bass (1%) were the next most common fish species detected. Sacramento blackfish, Wakasagi, common carp, largemouth bass, threadfin shad, lamprey ammocoete, Western mosquitofish, and the unknown Centrarchid each accounted for less than 1% of the total catch. Prickly sculpin, Sacramento splittail, Sacramento sucker, Sacramento blackfish, and the lamprey ammocoete were the only native fish species detected in the net.

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[9] The catch rate is an estimate because the total number of larval fish (i.e., 97) reported in the update to the WY 2012 and WY 2013 final annual reports (ICF International 2014) was an estimated maximum number based on a re-examination of a portion of the WY 2012 samples.

Table 12. Species, Number, and Size of Fish Detected in the Hoop Net, WY 2013 (January–June 2013)

Species (Common/Scientific Name)	Number Collected	Average (SD) Total Length (millimeters)	Size Range (millimeters)
Prickly sculpin* *Cottus asper*	206	5.7 (1.0)[1]	4.1–18.0
Sacramento splittail* *Pogonichthys macrolepidotus*	131	7.9 (1.3)[2]	6.1–15.0
Bigscale logperch *Percina macrolepida*	56	6.5 (1.6)[3]	3.1–12.1
Unknown spp.	15	NA[4]	NA[4]
Sacramento sucker* *Catostomus occidentalis*	6	17.6 (1.3)	15.7–19.0
Striped bass *Marone saxatilis*	5	4.7 (1.1)	2.8–5.6
Sacramento blackfish* *Orthodon microlepidotus*	3	8.4 (1.9)	6.9–10.5
Wakasagi *Hypomesus nipponensis*	3	15.1 (2.1)	13.0–17.1
Common carp *Cyprinus carpio*	3	6.7 (0.4)	6.4–7.1
Largemouth bass *Micropterus salmoides*	2	9.8 (0.6)	9.4–10.2
Threadfin shad *Dorosoma petenense*	2	10.8 (0.2)	10.6–10.9
Lamprey ammocoete* *Entosphenus/Lampetra* spp.	1	41	41
Western mosquitofish *Gambusia affinis*	1	12.7	12.7
Micropterus spp.	1	6.8	6.8
Eggs (Sacramento sucker)	5	2.6 (0.1)	2.5–2.7
Eggs (Prickly sculpin)	>1,000	1.2[5]	1.1–1.2

* = Native species

[1] Seven individuals were not intact and could not be measured.

[2] Three individuals were not intact and could not be measured.

[3] One individual was not intact and could not be measured.

[4] NA = Not Available. Individuals were not intact, which precluded obtaining length measurements.

[5] Only a few eggs were measured.

The total number of fish detected in the net varied from one to 222 fish per monitoring event (Table 7). Overall, the median size of fish detected in the net was 6.1 mm total length (range: 2.8–41.0 mm); the largest individual (41 mm) detected in the net was a lamprey ammocoete, while the smallest (2.8 mm) was a pro-larval[10] striped bass (Table 12). All of the fish detected in the net were pro-larvae, larvae, or post-larvae ; no adult fish were detected in the net. Based on the small size of all of the fish, it is assumed that the fish detected in the net had passed through the fish screen shortly before being captured in the net (section 4, "Discussion").

With the exception of 15 individuals, all the fish captured in the net were intact and lacked obvious marks or injuries that would indicate trauma as a result of being entrained by the operating pump, being transported through the pipeline and associated valves, and being captured by the net.

In addition to fish, aquatic invertebrates, 5 eggs believed to be Sacramento sucker, and more than 1,000 prickly sculpin eggs were also detected in the net at the VSWTP. Invertebrates detected included an abundance of amphipods (*Corophium* spp.), cladocera (*daphnia* spp.), snails (family Physidae), and clams (*Corbicula* spp.), and at least one freshwater shrimp (likely *Exopalaemon modestus* [Siberian prawn]).

The detection of 435 fish in 150 Mgal of diverted water sampled by the net at the VSWTP corresponded to an average catch rate of 2.9 fish per 1 million gallons of diverted water sampled over the course of the 12 monitoring events (Table 7).

In contrast to WY 2012 entrainment monitoring results, no large juvenile or adult fish (e.g., juvenile striped bass, adult prickly sculpin) were detected in the net at the VSWTP during WY 2013 entrainment monitoring.

Floating Larval Light Traps

A total of 41 larval fish were collected in the light traps that were placed in the operating forebay chamber during each monitoring event (Tables 8 and 13). Thirty-eight (38) prickly sculpin (93% of the total catch), 2 Sacramento sucker (5% of the total catch) and 1 Sacramento splittail (2% of the total catch) were detected in the light traps. All of the larval fish detected in the light traps were observed during entrainment monitoring events in February, March, and April, with a total of 27 larval fish (66%) being detected in the light traps during the expanded sampling on April 10 and 11. No larval fish were detected in the light traps after the April 24 monitoring event. Prickly sculpin detected in the light traps averaged 5.5 mm total length (range: 5.0–6.3 mm), Sacramento sucker averaged 14.4 mm total length (range: 14.2–14.6 mm), and Sacramento splittail was 7.7 mm long (Table 13).

The temporal occurrence of prickly sculpin, Sacramento sucker, and Sacramento splittail in the light traps overlapped their detection in the hoop net during February through late April (Tables 7 and 8). While prickly sculpin and/or Sacramento splittail continued to be detected in the hoop net during the late April through late May monitoring events, they were not detected in the light traps during this same period (no larval fish were detected in the light traps during the May through June monitoring events). The greater abundance and greater frequency of detection of prickly sculpin in the catch for the light traps was consistent with the abundance and frequency trends observed for the hoop net (Tables 12 and 13).

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[10] A larval fish that has undeveloped mouth parts and relies on a yolk-sac for nutrition.

Table 13. Species, Number, and Size of Fish Detected in the Floating Larval Light Traps, WY 2013 (January–June 2013)

Species Common Name	Number Collected	Average (SD) Total Length (millimeters)	Size Range (millimeters)
Prickly sculpin	38	5.5 (0.3)	5.0 –6.6
Sacramento sucker	2	14.4(0.2)	14.2–14.6
Sacramento splittail	1	7.7	7.7

Note: all species are native.

WY 2014

Hoop Net

An estimated total of 58,716 larval fish and a total of nine juvenile and adult fish, comprising a minimum of 10 species, were detected in the net at the VSWTP (Tables 9 and 14). Of all the larval fish sorted from the samples and counted, only 34% were identified to species. Most of the fish larvae were too badly damaged to be identified or measured. Prickly sculpin were the most abundant species detected and accounted for 27% of the catch. Bigscale logperch (2%) and Sacramento splittail (1.2%) were the next most common fish species detected. Sacramento sucker, common carp, inland silverside, striped bass, unidentified smelt, and largemouth bass each accounted for less than 0.1% of the total catch. In addition, a total of eight juvenile and adult prickly sculpin and one lamprey ammocoete was detected in the net based on a full examination of all samples. Prickly sculpin, Sacramento splittail, Sacramento sucker, and the lamprey ammocoete were the only native fish species detected in the net.

Table 14. Species, Number, and Size of Fish Detected in the Hoop Net, WY 2014 (December 2013 and March–June 2014)

Species (Common/Scientific Name)	Estimated Number Collected	Average (SD) Total Length (millimeters)	Size Range (millimeters)
Unknown spp.	40,633	NA[1]	NA[1]
Prickly sculpin* *Cottus asper*	15,903	5.4 (0.8)	3.3–11.7
Bigscale logperch *Percina macrolepida*	1,256	7.0 (1.9)	4.7–15.0
Sacramento splittail* *Pogonichthys macrolepidotus*	725	7.4 (0.8)	5.0–12.4
Common carp *Cyprinus carpio*	56	6.9 (0.7)	6.2–7.9
Inland silverside *Menidia beryllina*	53	5.7 (1.1)	4.4–7.8

Species (Common/Scientific Name)	Estimated Number Collected	Average (SD) Total Length (millimeters)	Size Range (millimeters)
Striped bass *Marone saxatilis*	36	4.1 (0.8)	2.5–4.9
Sacramento sucker* *Catostomus occidentalis*	34	14.1 (1.1)	11.7–15.9
Unidentified smelt *Hypomesus/Spirinchus* spp.	12	NA[1]	NA[1]
Largemouth bass *Micropterus salmoides*	8	8.9 (2.7)	7.0–10.8
Lamprey ammocoete* *Entosphenus/Lampetra* spp.	1	105	105
Prickly sculpin (juv/ad)* *Cottus asper*	8	56.4 (11.3)	42–73
*Eggs (Prickly sculpin)**	220	NA	(0.2–1.6) [2]
*Eggs (Cyprinid)**	8	NA	(2.0–2.4)
*Eggs (Sacramento sucker)**	4	NA	(2.4)

* = Native species

NA = Not Available.

[1] Individuals were not intact, which precluded obtaining length measurements.

[2] Only a few eggs were measured.

The estimate total number of fish detected in the net varied from zero to 28,125 fish per monitoring event (Table 9). Overall, the median size of fish detected in the net was 6.6 mm total length (range: 2.1–105 mm); the largest individual (105 mm) detected in the net was a lamprey ammocoete, while the smallest (2.5 mm) was a pro-larval[11] striped bass (Table 14). An overwhelming majority of the fish detected in the net were pro-larvae, larvae, or post-larvae; several large juvenile and adult fish (prickly sculpin) were detected in the net. Based on the small size of the larval fish, it is assumed that the fish detected in the net had passed through the fish screen shortly before being captured in the net (section 4, "Discussion").

Two-thirds of all the fish sorted from the samples were damaged and could not be identified or measured. Fish that have been sampled by the net have traveled from the Freeport water intake facility to the VSWTP and have been entrained by the operating pump, transported through the pipeline and associated valves, and captured by the net. The most likely source for the damage is the sleeve valve located at the VSWTP. This type of valve dissipates excess pressure and controls the flow rate to the treatment plant. The valve has an interior cylinder with one inch holes and an outer solid cylinder that moves to cover the holes, as required, to control the flow. Flow control is necessary especially when EBMUD is taking water because the EBMUD discharge point is at a higher elevation than the elevation of the weir where water enters VSWTP. In WYs 2012 and 2013 when water was only going to VSWTP the sleeve valve was completely open and no excess pressure was required to be dissipated. In WY 2014 when EBMUD and SCWA both were taking water the sleeve

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[11] A larval fish that has undeveloped mouth parts and relies on a yolk-sac for nutrition.

valve was partially closed to control the flow entering VSWTP and the water and fish went through the holes at a higher velocity than in previous years. A greater percentage of fish were damaged when pumping rates were high and the sleeve valve was controlling the flow to the VSWTP.

In addition to fish and aquatic invertebrates, an estimated total of 220 prickly sculpin eggs, 8 Cyprinid (minnow) eggs, and 4 Sacramento sucker eggs also were detected in the net at the VSWTP. Invertebrates detected included an abundance of amphipods (*Corophium* spp.), cladocera (*Daphnia* spp.), snails (family Physidae), and clams (*Corbicula* spp.), and at least one freshwater shrimp (likely *Exopalaemon modestus* [Siberian prawn]).

The detection of an estimated 58,716 larval fish in 121 Mgal of diverted water sampled by the net at the VSWTP corresponded to an average catch rate of 485 fish per 1 million gallons of diverted water sampled over the course of the 12 monitoring events (Table 9).

Floating Larval Light Traps

A total of 652 larval fish, comprising a minimum of 8 species, were collected in the light traps that were placed in the operating forebay chamber during each monitoring event (Tables 10 and 15). All but 18 of the larvae were identified to species. The unidentified larvae were too damaged to be identified or accurately measured. Macro-invertebrates, which also were captured in the light traps, were suspected as the cause for the damage to the larval fish in the light traps. Prickly sculpin (69% of the total catch) was the most abundant species detected in the light traps, followed by inland silverside (20% of the total catch) and Sacramento splittail (4% of the total catch). Bigscale logperch, common carp, Sacramento sucker, largemouth bass, and Wakasagi each accounted for less than 1% of the total catch. Prickly sculpin, Sacramento splittail, and Sacramento sucker were the only native fish species detected in the light traps. All of the larval fish detected in the light traps were observed during entrainment monitoring events in March, April, and May with a total of 435 larval fish (67%) being detected in the light traps in a one month period from late March through late April (Table 10). No larval fish were detected in the light traps in December or June..

Eight of the 10 species of larval fish detected in the hoop net also were detected in the larval light traps (Tables 14 and 15). Striped bass and lamprey were the two species detected in the hoop that were not detected in the larval light traps. The temporal occurrence of prickly sculpin, Sacramento splittail, and Sacramento sucker in the light traps overlapped their detection in the hoop net (Tables 9 and 10). Prickly sculpin were the most abundance and most frequently detected larval fish in the light traps and this trend was consistent with the trends observed for the hoop net (Tables 14 and 15).

Table 15. Species, Number, and Size of Fish Detected in the Floating Larval Light Traps, WY 2014 (December 2013 and March–June 2014)

Species Common Name	Number Collected	Average (SD) Total Length (millimeters)	Size Range (millimeters)
Prickly sculpin*	452	5.3 (0.6)	4.0 –11.4
Inland silverside	133	6.2 (2.0)	3.9–15.8
Sacramento splittail*	28	8.3 (2.9)	6.5–22.6
Unknown	18	NA	NA
Bigscale logperch	6	5.9 (1.2)	4.8–8.2
Common carp	6	9.4 (4.8)	7.0–17.9
Sacramento sucker*	5	13.5 (1.6)	11.1–14.9
Largemouth bass	2	11.0 (2.3)	9.4–12.7
Wakasagi	2	17.1 (1.7)	15.9–18.3

* = Native species
NA = Not Applicable

Protected Species and Species of Management Concern

Delta and Longfin Smelt

No delta smelt (*Hypomesus transpacificus*) or longfin smelt (*Spirinchus thaleichthys*) larvae were detected in the net at the VSWTP or in the light traps at the Freeport water intake facility during the WY 2012–2014 entrainment monitoring periods, which included the period when adult delta smelt and longfin smelt were present in the Sacramento River and may have been spawning, and any eggs and larvae subject to entrainment by the Freeport water intake facility. However, not all fish sorted from the samples could be identified to species, including three smelt[12] that were subsampled from the WY 2014 hoop net samples. It is therefore possible that a portion of these unknown fish and the three unknown smelt may have been delta smelt, longfin smelt, and/or Wakasagi, the introduced Japanese pond smelt that is similar to delta smelt. Wakasagi were the only confirmed smelt species detected in the net and floating larval light traps during entrainment monitoring (see the additional discussion below regarding Wakasagi).

The occurrence of adult delta smelt in the Sacramento River during the three entrainment monitoring periods was confirmed by the USFWS trawl and beach seine surveys of the Sacramento River at Sherwood Harbor and Garcia Bend, respectively. Adult delta smelt were detected in the USFWS trawls and/or beach seine surveys during each of the three entrainment monitoring periods, although the number captured in the trawls and beach seine surveys varied widely among the three entrainment monitoring years (Figure 19). By contrast, only one longfin smelt was captured by USFWS during this same period; the single adult longfin smelt was captured in the Kodiak trawl on December 30, 2011 (Speegle pers. comm.). The USFWS trawl and beach seine survey data suggest

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[12] Because of the subsampling approach that was applied to sample sorting in WY 2014, the total number of unidentified smelt was reported in Table 14 as 12 individuals (i.e., the three unknown smelt that were sorted from the subsamples was expanded by a factor of four).

that adult delta smelt abundance in the vicinity of the Freeport water intake facility, while highly variable from year-to-year, probably is low. The USFWS trawl and beach seine data also suggest that adult longfin smelt are less abundant than delta smelt in the vicinity of the Freeport water intake facility. While adult delta smelt in spawning condition have been caught by the USFWS trawls and beach seine surveys, there is no confirmation whether delta smelt and/or longfin smelt spawned in the Sacramento River and produced viable offspring in the vicinity of the Freeport water intake facility during the WY 2012–2014 entrainment monitoring periods. No juvenile delta smelt or longfin smelt were detected by the USFWS trawls or beach seine surveys over the course of the three entrainment monitoring periods; however, their absence in the USFWS catch may be because young smelt may not be vulnerable to capture by the USFWS trawls and beach seines or, if they are captured, not identified and counted if they are smaller than 20 mm (this is the minimum size fish that USFWS identifies and includes in the weekly survey counts).

Sacramento Splittail

Sacramento splittail were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility in each of the three entrainment monitoring periods. Typically, they were one of the more abundant species detected in the net and in the floating light traps. Substantially more Sacramento splittail were detected in WY 2014 (estimated total=753) than in WY 2012 (total=5) and WY 2013 (total=131) (Tables 11–15). Overall, Sacramento splittail were detected in the net and larval light traps from late March through late May, which is consistent with the known splittail spawning season (typically March and April; Moyle [2002]). Across all monitoring events, splittail detected in the net and larval light traps ranged in size from 5.0 to 22.6 mm (Tables 11–15, Figure 20). Sacramento splittail in this size range consist of pro-larvae, larvae, and post-larvae; the largest (22.6 mm) was a juvenile (Wang and Reyes 2007).

The occurrence of Sacramento splittail in the net and in the larval light traps generally coincided with the catch of juvenile Sacramento splittail in the USFWS trawl and beach seine surveys (Figure 21). However, the initial detection of splittail in the net and in the larval light traps always preceded the catch in the river, but this is expected given differences in gear used between the two studies and because USFWS does not report the catch of Sacramento splittail smaller than 20 mm. Juvenile Sacramento splittail were always detected by the USFWS trawl and beach seine surveys beyond the last dates they were detected in the net and larval light traps, presumably because splittail in the Sacramento River became large enough to be physically excluded by the fish screen by these dates (Figure 22).

Chinook Salmon

One unmarked Chinook salmon (i.e., those lacking an adipose fin clip) was detected in the net at the VSWTP over the course of the WY 2012–2014 entrainment monitoring periods. This salmon was detected in the net during the monitoring event on January 30–31, 2012, (Table 6) and was a 32-mm-long (fork length) pre-juvenile. Based on its size at the time it was detected in the net at the VSWTP, it was classified by USFWS as a fall-run (Speegle pers. comm.). Generally, juvenile Chinook salmon are too large to be captured in larval light traps.

Based on the USFWS trawl and beach seine survey data for WYs 2012–2014, Chinook salmon 32 mm and smaller were typically present in the Sacramento River from late December into early April (Figure 23) and presumably were subject to entrainment by the Freeport water intake facility based on the observed entrainment of the 32-mm-long pre-juvenile. However, the USFWS trawl and beach seine survey data indicate that most Chinook salmon passing the Freeport water intake facility are much larger than 32 mm and, therefore, unlikely to be at risk of entrainment (Figure 23).

Steelhead

No juvenile steelhead (*Oncorhynchus mykiss*) were detected in the net at the VSWTP over the course of the WY 2-12–2014 entrainment monitoring periods. Generally, juvenile steelhead are too large to be captured in larval light traps.

All but three steelhead captured by the USFWS trawl and beach seine surveys during the WY 2012–2014 entrainment monitoring period ranged in size from 111 to 350 mm; the three smaller juvenile steelhead were 36mm, 45mm, and 46 mm long (Speegle pers. comm.). Because juvenile steelhead remain in their natal streams for one or more years before emigrating to the ocean, it is unlikely that pre-juvenile steelhead are at risk of entrainment by the Freeport water intake facility. Based on the size data from the USFWS trawl and beach seine surveys, juvenile steelhead that occur in the Sacramento River are too large to pass through the 1.75 mm slot openings of the fish screen panels.

Green Sturgeon

No larval or juvenile green sturgeon (*Acipenser medirostris*) were detected in the net at the VSWTP or in the floating larval light traps over the course of the WY 2012–2014 monitoring periods. In addition, no green sturgeon eggs were detected in the net at the VSWTP; however, green sturgeon eggs are not likely to be present in the Sacramento River in the vicinity of the Freeport water intake facility because adult green sturgeon spawn well upstream of the Freeport water intake facility. Because of the distance separating green sturgeon spawning areas from the Freeport water intake facility, it is likely that larval and juvenile green sturgeon grow to a sufficient size to be physically excluded by the water intake facility’s fish screens by the time they pass the Freeport water intake facility. No green sturgeon were reported in the catch by the weekly USFWS trawl and beach seine surveys during the WY 2012–WY 2014 entrainment periods (Speegle pers. comm.); however, their absence in the catch may be a result of gear selectivity.

Other Native and Introduced Fish Species

Other native fish species entrained by the Freeport water intake facility and detected in the net at the VSWTP and in the larval light traps Freeport water intake facility included prickly sculpin, Sacramento sucker, Sacramento blackfish, and lamprey ammocoete. Introduced fish species entrained by the Freeport water intake facility and detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility included bigscale logperch, striped bass, Wakasagi, common carp, threadfin shad, largemouth bass, inland silverside, white catfish, and Western mosquitofish. This section presents the results of entrainment monitoring for these thirteen species and, where appropriate, the results of the concurrent trawl and beach seine surveys for the Sacramento River conducted by USFWS.

Native Species

Prickly Sculpin

Prickly sculpin were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during all three entrainment monitoring periods. They were the most numerous and frequently detected species in the net and in the light traps during each of the three entrainment monitoring periods. Substantially more prickly sculpin were detected in WY 2014 (estimated total=16,355) than in WY 2012 (total=19) and WY 2013 (total=244) (Tables 11–15). Overall, prickly sculpin were detected in the net and in the larval light traps from late January through May, which is consistent with their known spawning season (typically February through mid-June [Moyle 2002]). Across all monitoring events and periods, larval prickly sculpin detected in the net and in the larval light traps ranged in size from 3.3 to 21 mm (Figure 24). Prickly sculpin in this size range consist of pro-larvae, larvae, and post-larvae (Wang 2010).

No prickly sculpin were collected by USFWS during trawl surveys of the Sacramento River at Sherwood Harbor during the WY 2012–2014 entrainment monitoring periods. The several prickly sculpin collected by the USFWS during beach seining of the Sacramento River at Garcia Bend during the WY 2012–2014 entrainment monitoring periods were adults. Consequently, concurrent information is not available with respect to the occurrence of small juvenile prickly sculpin that were present in the Sacramento River at the time larvae were detected in the net and in the larval light traps.

Sacramento Sucker

Sacramento sucker were detected in the net at the VSWTP and in the larval light traps in the forebay chambers during all three entrainment monitoring periods. They were detected in about one-third of the monitoring events (Tables 6-10). More Sacramento sucker were detected in WY 2014 (estimated total=39) than in WY 2012 (total=14) and WY 2013 (total=8) (Tables 11–15). Overall, Sacramento sucker were detected in the net and in the larval light traps from late March to mid-June, which is consistent with their known spawning season (typically late February through early June [Moyle 2002]). Across all monitoring events and periods, larval Sacramento sucker detected in the net and in the larval light traps ranged in size from 4.5 to 21 mm (Tables 11–15). Sacramento sucker in this size range consist of pro-larvae, larvae, and post-larvae (Wang 2010).

Based on the weekly USFWS trawl and beach seine surveys at Sherwood Harbor and Garcia Bend, respectively, juvenile Sacramento sucker can occur in the Sacramento River during each month of the entrainment monitoring period and juveniles at least as small as 21 mm have been reported from the Sacramento River in the vicinity of the Freeport water intake facility in December, April, May, and June (Speegle pers. comm.). The timing of their detection in the net and in the larval light traps was consistent with the detection of young juvenile Sacramento sucker in the USFWS trawl and beach seine surveys during the WY 2012–WY 2014 entrainment monitoring periods.

Sacramento Blackfish

Sacramento blackfish (*Orthodon microlepidotus*) were detected in the net at the VSWTP during WY 2013 only (Table 7). No Sacramento blackfish were detected in the light traps. A total of three Sacramento blackfish were detected in the net in early May, which is consistent with their spawning season (typically between April and July, and sometimes as early as March; Moyle [2002]). The three Sacramento blackfish detected in the net ranged in size from 6.9 to 10.5 mm (Table 12). Sacramento blackfish in this size range consist of pro-larvae, larvae, and post-larvae (Wang and Reyes 2007).

No Sacramento blackfish were reported by the weekly USFWS trawl and beach seine surveys of the Sacramento River at Sherwood Harbor and Garcia Bend, respectively, during the WY 2012–WY 2014 entrainment monitoring periods (Speegle pers. comm.). Consequently, concurrent information is not available on the occurrence of young Sacramento blackfish in the Sacramento River at the time larvae were detected in the net at the VSWTP.

Lamprey Ammocoete

Lamprey (*Entosphenus/Lampetra* spp.) ammocoete (i.e., larvae) were detected in the net at the VSWTP during all three entrainment monitoring periods. No lamprey ammocoetes were detected in the light traps. Overall, lamprey ammocoete were not very abundant in the catch: 19 were detected in the net at the VSWTP during WY 2012, one was detected in the net during WY 2013, and one was detected in the net during WY 2014 (Tables 6, 7, and 9). Over the course of the three entrainment monitoring periods, lamprey ammocoete were detected in the net in the months of January and April. The 19 lamprey ammocoetes detected in January (WY 2012) ranged in size from 21 to 46 mm total length, while two detected in the net in April were 41 mm total length (WY 2013) and 105 mm total length (WY 2014) (Tables 6, 7, and 9, respectively). Three species of lamprey occur in the Sacramento River: Pacific lamprey (*Entosphenus tridentata*, formerly *Lampetra tridentata*), river lamprey (*Lampetra ayresi*), and Western brook lamprey (*Lampetra richardsoni*) (Moyle 2002). Lamprey ammocoetes of the size detected in the net at VSWTP cannot be distinguished from one another by visual examination; therefore, species identification of these ammocoetes was not possible.

All of these lamprey sizes, with the exception of the 105-mm-long ammocoete, are consistent with the range of ammocoete sizes found to be vulnerable to entrainment based on laboratory studies of the effectiveness of 1.75-mm vertical bar fish screen material to protect lamprey ammocoetes (Rose and Mesa 2012).

The detection of lamprey ammocoete in the net at the VSWTP during the three entrainment monitoring periods coincided with the catch of lamprey ammocoetes in the USFWS trawl and beach seine surveys, which occurred from December to April (Speegle pers. comm.). Overall, a total of 88 lamprey, ammocoetes ranging in size from 66 to 158 mm were collected by the weekly USFWS trawl and beach seine surveys during the WY 2012–WY 2014 entrainment monitoring periods(Speegle pers. comm.). All but one of the lamprey ammocoetes detected in the net at the VSWTP were smaller than those detected in the USFWS trawl and beach seine surveys over the course of the WY 2012–WY 2014 entrainment monitoring periods. Concurrent information is not available on the occurrence of lamprey ammocoetes smaller than 66 mm in the Sacramento River at the time lamprey ammocoetes were detected in the net at the VSWTP.

Introduced Species

Wakasagi

Larval Wakasagi were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during the WY 2013 and WY 2014 entrainment monitoring periods; no larval Wakasagi were detected in the net during the WY 2012 entrainment monitoring period. Overall, Wakasagi were not very abundant in the catch: three were detected in the net at the VSWTP during WY 2013 and two were detected in the larval light trap during WY 2014 (Tables 7 and 10). Over the course of the three entrainment monitoring periods, larval Wakasagi were detected in April and May, which is consistent with their spawning season (April and May; Moyle [2002]). Across all monitoring events and monitoring periods, the larval Wakasagi ranged in size from 13.0 to 18.3 mm (Tables 12 and 15). Wakasagi in this size range consist of pro-larvae, larvae, post-larvae, and pre-juveniles (Wang et al. 2005).

The occurrence of larval Wakasagi in the net and in the larval light traps coincided with the catch of juvenile or adult Wakasagi in the USFWS trawl and beach seine surveys, which over the course of the three entrainment monitoring periods occurred in every month of the entrainment monitoring period with the exception of May (Figure 25). Over the course of the three entrainment monitoring periods, a total of 178 juvenile and adult Wakasagi, ranging in size from 26 mm to 89 mm, were collected in the Sacramento River at Sherwood Harbor by the USFWS trawl surveys and at Garcia Bend by the USFWS beach seine survey (Figure 26). Because no Wakasagi smaller than 26 mm were reported by the USFWS trawl and beach seine surveys, concurrent information on the occurrence of young Wakasagi in the Sacramento River at the time that larvae were detected in the net at the VSWTP is not available.

Bigscale Logperch

Larval bigscale logperch were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during the WY 2013 and WY 2014 entrainment monitoring periods; no larval bigscale logperch were detected in the net during the WY 2012 entrainment monitoring period. Overall, bigscale logperch were relatively abundant in the catch and were the most numerous non-native species detected in the net at the VSWTP. Substantially more bigscale logperch were detected in WY 2014 (estimate total = 1,262) than in WY 2013 (total=56) (Tables 7, 9, and 10). Overall, bigscale logperch were detected in the net and in the larval light traps from March to May, which is consistent with the known bigscale logperch spawning season (typically from late February through mid-July, depending on water temperature; Moyle [2002]). Across all monitoring events and monitoring periods, bigscale logperch detected in the net and in the larval light traps ranged in size from 3.1 mm to 15.0 mm (Tables 12, 14, and 15). Bigscale logperch in this size range consist of pro-larvae, larvae, and post-larvae (Wang 2010).

Bigscale logperch were rarely caught by the USFWS trawl and beach seine surveys at Sherwood Harbor and Garcia Bend, respectively. Over the course of the three entrainment monitoring periods, a total of 3 adult bigscale logperch were captured in the USFWS beach seine surveys. These adults ranged in size from 74 mm to 89 mm fork length and were caught in February and March. Consequently, concurrent information is not available on the occurrence of young bigscale logperch in the Sacramento River at the time larvae were detected in the net at the VSWTP and in the larval light traps in the Freeport water intake facility.

Striped Bass

Juvenile striped bass were detected in the net at the VSWTP during the WY 2012 entrainment monitoring period, while larval striped bass were detected in the net at the VSWTP during the WY 2013 and WY 2014 entrainment monitoring periods. No striped bass were detected in the larval light traps. Overall, striped bass were not very abundant in the catch. In WY 2012, six juvenile striped bass, ranging in size from 142 mm to 182 mm, were detected in the net (Tables 6 and 11). Based on their size at time of capture, it is hypothesized that these juvenile striped bass had passed through the fish screen as eggs or larvae and reared for an indeterminate amount of time in the water intake's forebay chambers before they were transported by the pipeline and detected in the net at the VSWTP. Larval striped bass were more abundant in the catch in WY 2014 (estimated total=36) than in WY 2013 (total=5) (Tables 14 and 12, respectively). Larval striped bass were detected in the net in March and April, which is consistent with the known striped bass spawning season (between April and early June; Moyle [2002]). Larval striped bass detected in the net ranged in size from 2.5 mm to 5.6 mm total length (Tables 12 and 14) and were all pro-larvae (Wang 2010).

Striped bass were rarely caught by the USFWS trawl surveys—one individual was detected during the WY 2012 entrainment monitoring period and two individuals were detected in the WY 2013 entrainment monitoring period. However, all three of these individuals were adults (300–475 mm fork length). No striped bass were detected by the USFWS beach seine surveys. Consequently, concurrent information is not available on the occurrence of young striped bass in the Sacramento River at the time larvae were detected in the net at the VSWTP.

Common Carp

Larval common carp were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during all three entrainment monitoring periods. Overall, carp were moderately abundant in the catch. Substantially more carp were detected in WY 2014 (estimated total=62) than in WY 2012 (total=1) and WY 2013 (total=3) (Tables 11–15). Overall, carp were detected in the net and in the larval light traps from April to June, which is consistent with the known carp spawning season (spring to early summer; Moyle [2002]). Carp detected in the net and in the larval light traps ranged in size from 6.2 mm to 7.9 mm total length, although one pre-juvenile at 17.9 mm total length also was detected (Tables 11–15). Common carp in the 6.2–7.9 mm size range consist of pro-larvae and post-larvae (Wang and Reyes 2007).

Carp were not commonly caught by the weekly USFWS trawl surveys during the WY 2012–WY 2014 entrainment monitoring periods; no carp were caught by the beach seine surveys during any of the entrainment monitoring periods. Over the course of the three entrainment monitoring periods, a total of 22 carp were caught in December through March and in August, and ranged in size from 31 mm to 90 mm fork length. Because of the limited numbers and relatively large size range of carp reported by the USFWS trawl and beach seine surveys, concurrent information is not available on the occurrence of young carp in the Sacramento River at the time larvae were detected in the net at the VSWTP.

Threadfin Shad

Larval threadfin shad were detected in the net at the VSWTP during the WY 2012 and WY 2013 entrainment monitoring periods (Tables 6 and 7, respectively); no threadfin shad were detected in the net during the WY 2014 entrainment monitoring period. No threadfin shad were detected in the larval light traps. Overall, the abundance of threadfin shad in the catch was very low; only three larvae were detected in the net. The threadfin shad were detected in the net in May, which is consistent with the known threadfin shad spawning season (April through August; Moyle [2002]). Threadfin shad detected in the net ranged in size from 10.6 mm to 10.9 mm (Tables 11 and 12), and were pro-larvae, larvae, and post-larvae (Wang 2010).

Juvenile and adult threadfin shad were frequently caught by the USFWS trawl and beach seine surveys. Over the course of the WY 2012–WY 2014 entrainment monitoring periods, a combined total of 419 threadfin shad were caught from December through early March, and in June, and ranged in size from 32 mm to 134 mm fork length. Because no threadfin shad smaller than 32 mm were reported by the USFWS trawl and beach seine surveys, concurrent information is not available on the occurrence of young threadfin shad in the Sacramento River at the time larvae were detected in the net at the VSWTP.

Largemouth Bass

Larval largemouth bass were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during the WY 2013 and WY 2014 entrainment monitoring periods (Tables 7, 9, and 10); no largemouth bass were detected in the net during the WY 2012 entrainment monitoring period. Overall, the abundance of largemouth bass in the catch was low; a combined total of 10 largemouth bass were detected in the net and two largemouth bass were detected in the larval light traps (Tables 12, 14, and 15). The largemouth bass were detected in the net and in the larval light traps in April and May, which is consistent with the known largemouth bass spawning season (March or April through June; Moyle [2002]). Across all monitoring events and periods, largemouth bass detected in the net and larval light traps ranged in size from 7.0 mm to 12.7 mm (Tables 12, 14, and 15), and were pro-larvae, larvae, and post-larvae (Wang 2008).

Juvenile largemouth bass were infrequently observed by the USFWS trawl and beach seine surveys. Over the course of the WY 2012–WY 2014 entrainment monitoring periods, a combined total of 36 juvenile largemouth bass were caught from December through June, although most were caught in May and June. The largemouth bass ranged in size from 25 mm to 124 mm fork length, with the smaller size classes occurring in the spring. Because no largemouth bass smaller than 25 mm were reported by the USFWS trawl and beach seine surveys, concurrent information is not available on the occurrence of young largemouth bass in the Sacramento River at the time larvae were detected in the net at the VSWTP.

Inland Silverside

Larval inland silverside were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility during the WY 2014 entrainment monitoring period only (Tables 9 and 10); no inland silversides were detected in the net during the WY 2012 and WY 2013 entrainment monitoring periods or in the larval light traps during the WY 2013 entrainment monitoring period. The abundance of inland silverside in the catch in WY 2014 was moderate: an estimated 53 inland silverside were detected in the net and 133 were detected in the larval light traps (Tables 14 and 15, respectively). Inland silverside were detected in the net and in the larval light traps in April, May, and June, although most occurred in April and May. Their timing in the catch is consistent with the known timing of larval presence in the Central Valley (March through August, with a strong peak in April and May; Moyle [2002]). Inland silverside detected in the net and larval light traps ranged in size from 3.9 mm to 15.8 mm (Tables 14 and 15), and were pro-larvae, larvae, and post-larvae (Wang 2008).

Juvenile and adult inland silverside were the most abundant non-native species in the USFWS trawl and beach seine catches. Over the course of the WY 2012–WY 2014 entrainment monitoring periods, a combined total of 6,560 inland silverside were caught from December through June: 526 were caught in WY 2012; 1,305 in WY 2013; and 4,729 in WY 2014 (Figure 27). Overall, inland silverside caught in the USFWS trawls and beach seine surveys ranged in size from 25 mm to 105 mm fork length (Figure 28). Because no inland silverside smaller than 25 mm were reported by the USFWS trawl and beach seine surveys, concurrent information is not available on the occurrence of young inland silverside in the Sacramento River at the time larvae were detected in the net at the VSWTP and in the larval light traps at the Freeport water intake facility.

White Catfish

Juvenile white catfish were detected in the net at the VSWTP during the WY 2012 entrainment monitoring period; no white catfish were detected in the net during either the WY 2013 or WY 2014 entrainment monitoring periods. No white catfish larvae were detected in the larval light traps. The two juvenile white catfish were detected in the net in December and ranged in size from 50 mm to 90 mm fork length (Tables 6 and 11). Based on their size at the time they were detected in the net, both juvenile white catfish undoubtedly passed through the fish screen as eggs or larvae and reared for an indeterminate amount of time before they were detected in the net. Adult white catfish spawn in June and July, but can occur as late as September (Moyle 2002); therefore, it is likely that these individuals passed through the fish screen during the previous summer or early fall.

White catfish were rarely caught by the USFWS trawl surveys during the WY 2012–WY 2014 entrainment monitoring periods; no white catfish were caught by the USFWS beach seine surveys. Two individuals were caught in the trawl survey during the WY 2013 entrainment monitoring period and two individuals were caught in the WY 2014 entrainment monitoring period. However, all four of these individuals were large juveniles (134–225 mm, fork length). Consequently, information is not available on the timing of occurrence of young white catfish in the Sacramento River.

Western Mosquitofish

A single Western mosquitofish was detected in the net at the VSWTP during the WY 2013 entrainment monitoring period (Table 7); no mosquitofish were detected in the net during the WY 2012 or WY 2014 entrainment monitoring periods. No mosquitofish were detected in the larval light traps. The single mosquitofish was detected in the net during June, which is consistent with their spawning season (April through September; Moyle [2002]). The mosquitofish was a juvenile (Wang 2010) and was 12.7 mm long, total length (Table 11).

Western mosquitofish were infrequently observed by the USFWS trawl and beach seine surveys. Over the course of the WY 2012–WY 2014 entrainment monitoring periods, a combined total of 25 adult mosquitofish were caught from December through May. Collectively, the mosquitofish ranged in size from 23 mm to 44 mm total length. Because no mosquitofish smaller than 23 mm were reported by the USFWS trawl and beach seine surveys, concurrent information is not available on the occurrence of young mosquitofish in the Sacramento River at the time the mosquitofish juvenile was detected in the net at the VSWTP.

Eggs

WY 2012

More than 321 prickly sculpin eggs entrained by the Freeport water intake facility were detected in the net at the VSWTP during the WY 2012 monitoring period. They were detected during the monitoring events on February 21–22 and April 16–17, 2012 (Table 6). No eggs from any other fish species were detected in the net.

WY 2013

More than 1,000 prickly sculpin eggs entrained by the Freeport water intake facility were detected in the net at the VSWTP during the WY 2013 entrainment monitoring period. They were detected during the monitoring event on May 2–3, 2013 (Table 7). In addition, a total of 5 eggs believed to be

Sacramento sucker (Wang pers. comm.) were detected in the net during two of the 12 entrainment monitoring events: April 24–25 and May 29–30, 2013 (Table 7). No eggs from any other fish species were detected in the net.

WY 2014

An estimated 220 prickly sculpin eggs, 8 Cyprinid eggs, and 4 Sacramento sucker eggs entrained by the Freeport water intake facility were detected in the net at the VSWTP during the WY 2014 entrainment monitoring period. Prickly sculpin eggs were detected during the monitoring events on March 20, April 10, and April 16, 2014; Cyprinid eggs were detected during the monitoring events on April 16 and April 23, 2014; and Sacramento sucker eggs were detected during the monitoring event on April 16, 2014 (Table 9). No eggs from any other fish species were detected in the net. In addition to eggs, ova and related connective tissue were also observed in the sorted samples (Wang pers. comm.) and their occurrence in the samples presumably was a result of gravid females being damaged during transport from the Freeport water intake facility to the VSWTP.

3.2.3 Correlation of Entrainment to Environmental Conditions

This section presents the results of investigating whether any of the environmental variables were appreciable predictors of entrainment rate. Results are presented for WY 2013 and WY 2014; facility operations in WY 2012 precluded the ability to relate entrainment rate with environmental variables.

WY 2013

The results of the GLM and information theoretic approach indicated that there was limited support for any of the environmental variables being appreciable predictors of entrainment rate for all fishes (Table 16), prickly sculpin (Table 17), or Sacramento splittail (Table 18). The null (intercept-only) models were among the mostly likely models in all 3 cases, and for Sacramento splittail the null model was the most likely of the candidate models. That is, in all 3 cases the addition of environmental variables did not give a more likely explanation of the patterns observed in the data than use of an overall average entrainment rate (as represented by the null models). Among the environmental variables, there was some evidence that entrainment rate of prickly sculpin was greater during the day than by night ($P = 0.07$ from Type III Test of Fixed Effects in the model including only this variable), as reflected by this variable's appearance in several candidate models within 3 AIC_c units of the best model (Table 17).

Table 16. Results of Generalized Linear Modeling of Entrainment Rate of All Fishes

Model	AIC_c	ΔAIC_c	$AIC_c w$
D	245.62	0.00	0.26
Null (Intercept only)	245.66	0.04	0.26
V	247.45	1.83	0.11
D + V	247.53	1.91	0.10
P	248.04	2.42	0.08
D + P	248.12	2.50	0.08
V + P	249.16	3.54	0.05
D + V + D*V	249.74	4.12	0.03
D + P + D*P	250.55	4.93	0.02
V + P + V*P	251.84	6.22	0.01
Full (D + V + P + D*V + D*P + V*P)	257.80	12.18	0.00

Note: All Months, n = 38 Samples as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), and Interactions, with Comparisons Between Candidate Models from Akaike's Information Criterion Corrected For Small Sample Sizes (AICc), Differences Between Each Candidate Model and the Best Model (ΔAICc), and Model Weights (AICcw).

Table 17. Results of Generalized Linear Modeling of Entrainment Rate of Prickly Sculpin

Model	AIC_c	ΔAIC_c	$AIC_c w$
D	131.36	0.00	0.35
Null (Intercept only)	131.84	0.48	0.28
D + P	134.28	2.92	0.08
D + V	134.31	2.95	0.08
P	134.38	3.02	0.08
V	134.65	3.29	0.07
V + P + V*P	137.39	6.03	0.02
V + P	137.41	6.05	0.02
D + P + D*P	138.01	6.65	0.01
D + V + D*V	138.07	6.71	0.01
Full (D + V + P + D*V + D*P + V*P)	151.31	19.95	0.00

Note: March-April, n = 19 Samples as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), and Interactions, with Comparisons Between Candidate Models from Akaike's Information Criterion Corrected For Small Sample Sizes (AIC_c), Differences Between Each Candidate Model and the Best Model (ΔAIC_c), and Model Weights ($AIC_c w$).

Table 18. Results of Generalized Linear Modeling of Entrainment Rate of Sacramento Splittail

Model	AIC_c	ΔAIC_c	$AIC_c w$
Null (Intercept only)	119.99	0.00	0.40
D	121.54	1.55	0.19
V	122.48	2.49	0.12
P	122.58	2.59	0.11
D + V	124.13	4.14	0.05
D + P	124.34	4.35	0.05
D + V + D*V	124.72	4.73	0.04
V + P	124.95	4.96	0.03
D + P + D*P	127.52	7.53	0.01
V + P + V*P	128.17	8.18	0.01
Full (D + V + P + D*V + D*P + V*P)	133.54	13.55	0.00

Note: April-May, n = 24 Samples as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), and Interactions, with Comparisons Between Candidate Models from Akaike's Information Criterion Corrected For Small Sample Sizes (AIC_c), Differences Between Each Candidate Model and the Best Model (ΔAIC_c), and Model Weights ($AIC_c w$).

WY 2014

The results of the GLM and information theoretic approach generally indicated that there was limited support for the environmental variables being appreciable predictors of entrainment rate for prickly sculpin (Table 19), bigscale logperch (Table 20), or Sacramento splittail (Table 21). For prickly sculpin the null (intercept-only) model was the most likely of the candidate models, i.e., the addition of environmental variables did not give a more likely explanation of the patterns observed in the data than use of an overall average entrainment rate (as represented by the null model).

For Sacramento splittail, the null model ($QAIC_c$ = 278.73) was more than 3.0 $QAIC_c$ units greater than the best model, but the null model was more likely than the full model with all predictors included ($QAIC_c$ = 283.02), suggesting that the models including predictors were not a better fit to the data. This was confirmed by the model-averaged unconditional 95% confidence intervals for all predictors overlapping zero.

The only evidence of an environmental variable being a predictor of entrainment rate was for bigscale logperch. Over 40 candidate models were within 3.0 $QAIC_c$ units of the best model (Table 20), including the full model ($QAIC_c$ = 293.41) which was more than 3.0 $QAIC_c$ units less than the null model ($QAIC_c$ = 311.70); this suggested that models including predictors were a better fit to the data than the null model (Zeug and Cavallo 2013). Among the predictors, only water temperature had importance >0.8 and a coefficient unconditional 95% confidence interval not overlapping zero (1.38 ± 0.60). This suggested that entrainment rate of prickly sculpin was positively related to water temperature.

Table 19. Results of Generalized Linear Modeling of Entrainment Rate of Prickly Sculpin

Model	$QAIC_c$	w_i
Null (Intercept only)	420.75	0.21
T	422.90	0.07
P	422.91	0.07
D	422.93	0.07
V	422.94	0.07
D + P + D*P	423.47	0.05

Note: n = 56 Samples as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), Water Temperature (D) and Interactions, with Comparisons Between Candidate Models Within 3 Units of the Best Model (Based on the Quasi-likelihood Equivalent to Akaike's Information Criterion Corrected For Small Sample Sizes, $QAIC_c$) and Model Weights (w_i).

Table 20. Results of Generalized Linear Modeling of Entrainment Rate of Bigscale Logperch

Model	$QAIC_c$	w_i
V + P + T + P*V	291.83	0.05
D + T	292.37	0.03
T	293.02	0.03
D + V + P + T + P*V	293.41	0.02
D + V + P + T + P*V + T*V	293.41	0.02
D + V + P + T + P*V + T*P	293.41	0.02
D + V + P + T + P*V + T*V + T*P	293.41	0.02
D + V + P + T + P*V + D*P	293.41	0.02
D + V + P + T + P*V + T*V + D*P	293.41	0.02
D + V + P + T + P*V + T*P + D*P	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*P	293.41	0.02
D + V + P + T + P*V + D*T	293.41	0.02
D + V + P + T + P*V + T*V + D*T	293.41	0.02
D + V + P + T + P*V + T*P + D*T	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*T	293.41	0.02
D + V + P + T + P*V + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*V + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*P + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*P + D*T	293.41	0.02
D + V + P + T + P*V + D*V	293.41	0.02
D + V + P + T + P*V + T*V + D*V	293.41	0.02
D + V + P + T + P*V + T*P + D*V	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*V	293.41	0.02

Model	QAIC$_c$	w_i
D + V + P + T + P*V + D*V + D*P	293.41	0.02
D + V + P + T + P*V + T*V + D*V + D*P	293.41	0.02
D + V + P + T + P*V + T*P + D*V + D*P	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*V + D*P	293.41	0.02
D + V + P + T + P*V + D*V + D*T	293.41	0.02
D + V + P + T + P*V + T*V + D*V + D*T	293.41	0.02
D + V + P + T + P*V + T*P + D*V + D*T	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*V + D*T	293.41	0.02
D + V + P + T + P*V + D*V + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*V + D*V + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*P + D*V + D*P + D*T	293.41	0.02
D + V + P + T + P*V + T*V + T*P + D*V + D*P + D*T	293.41	0.02
V + P + T + P*V + T*V	294.41	0.01
V + P + T + P*V + T*V + T*P	294.41	0.01
D + P + T	294.42	0.01
V + P + T + P*V + T*P	294.43	0.01
D + V + T	294.61	0.01
D + T + D*T	294.64	0.01

Note: n = 56 Samples) as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), Water Temperature (D) and Interactions, with Comparisons Between Candidate Models Within 3 Units of the Best Model (Based on the Quasi-likelihood Equivalent to Akaike's Information Criterion Corrected For Small Sample Sizes, QAIC$_c$) and Model Weights (w_i).

Table 21. Results of Generalized Linear Modeling of Entrainment Rate of Sacramento Splittail

Model	$QAIC_c$	w_i
D + P + T + T*P + D*T	275.40	0.09
P + T + T*P	275.54	0.08
D + P + T + T*P	276.73	0.05
V + P + T + T*V + T*P	276.77	0.05
V + P + T + T*P	277.20	0.04
T	277.54	0.03
D + T + D*T	277.77	0.03
P	277.92	0.03
D + V + P + T + T*P	278.09	0.02
D + V + P + T + T*P + D*P	278.09	0.02
D + V + P + T + T*P + D*T	278.09	0.02
D + V + P + T + T*P + D*P + D*T	278.09	0.02
D + V + P + T + T*P + D*V	278.09	0.02
D + V + P + T + T*P + D*V + D*P	278.09	0.02
D + V + P + T + T*P + D*V + D*T	278.09	0.02
D + V + P + T + T*P + D*V + D*P + D*T	278.09	0.02
D + P + T + T*P + D*P	278.11	0.02
D + P + T + T*P + D*P + D*T	278.11	0.02
V	278.31	0.02
D + P	278.35	0.02

Note: n = 56 Samples) as a Function of Day/Night (D), River Velocity (V), Proportion of Discharge Diverted (D), Water Temperature (D) and Interactions, with Comparisons Between Candidate Models Within 3 Units of the Best Model (Based on the Quasi-likelihood Equivalent to Akaike's Information Criterion Corrected For Small Sample Sizes, QAICc) and Model Weights (w^i).

3.2.4 Problems Encountered

WY 2012

On two occasions, the net was found with a large tear running lengthwise along the tapered section of the net. In both cases, it was unknown at what time the net tore and whether it affected the number of fish capable of being detected in the net.

On the first occasion, the net tore sometime during the final sampling interval of the June 11–12, 2012, monitoring event and was discovered on the morning of June 12, 2012, when the net was being retrieved for a final time (Table 6). When the tear was discovered, the net was found with a considerable amount of detritus coating the inside of the net, which was impeding the flow of water through the net openings (i.e., mesh). A total of 10.1 Mgal of water was discharged from the pipeline during that final set of the net (Table 6). The net was repaired and used for the next two monitoring events.

On the second occasion, the net tore during the final sampling interval of the July 16–17, 2012, monitoring event and was discovered on the morning of July 17, 2012, when the net was being retrieved for a final time (Table 6). As before, the net was found with a considerable amount of detritus coating the inside of the net. A total of 11.0 Mgal of water was discharged from the pipeline during that final set of the net (Table 6).

Based on an evaluation of the operations data, it was determined that much more water than anticipated was discharged from the pipeline and sent through the net during the final set of the net, which typically extended from around midnight to 6:00 a.m. or 7:00 a.m. (Table 6).

WY 2013

On one occasion, the net was found with a large tear running lengthwise along the tapered section of the net. The net tore sometime during the first sampling interval of the April 11–12, 2013, monitoring event and was discovered at 8:36 a.m. when the net was being retrieved for the first time (Table 7). When the tear was discovered, the net was found with a considerable amount of detritus coating the inside of the net, which was impeding the flow of water through the net openings (i.e., mesh). A total of 3.23 Mgal of water was discharged from the pipeline during that first set of the net (Table 7). The net was removed from service and sampling was discontinued for the remainder of that monitoring event.

Based on discussions with SCWA treatment plant operators, it was determined that WY 2013 operations, specifically the absence of high pumping rates to flush sediment and debris from the pipeline, had resulted in the accumulation of algae and detritus in the pipeline. This accumulated debris and sediment was then mobilized when pumping rates were increased to a modest 30 mgd to support the concurrent impingement monitoring studies. While the net was designed, and has previously been used, to sample the flow entering the VSWTP when pumping rates are much higher than 30 mgd, the amount of debris accumulation in the pipeline and its eventual mobilization when the pumps at the Freeport Water Intake Facility were diverting 30 mgd from the Sacramento River unexpectedly overwhelmed the net, causing it to tear open.

WY 2014

The slide gate to which the hoop net is attached became disabled during the May 21–22, monitoring event, 11 hours after monitoring commenced (Table 9). Upon further inspection, it was determined that the thrust nut that guides the stem broke, rendering the slide gate inoperable. The nut was replaced and the slide gate was returned to service in time before the June monitoring event.

Reverse flows in the Sacramento River during the May 14–15 monitoring event required that the Freeport water intake facility stop diverting from the river from 06:10 to 11:35 hours, approximately 18 hours after monitoring commenced (Table 9). Monitoring was extended an additional 3 hours during this monitoring event to compensate for the 5.5 hour interruption in sampling. In addition, the results for this monitoring event were not used to correlate results with environmental variables because of the interruption in sampling during the monitoring event and because of a similar interruption in pumping immediately prior to the start of the monitoring event.

Unlike that which occurred in WY 2012 and WY 2013, no problems with the net tearing occurred during the WY 2014 monitoring period. Close monitoring of turbidity levels, limiting the flow through the net (i.e., splitting the flow between the two weir boxes, when necessary), and retrieving and cleaning the net more frequently during periods when heavy debris loads were present prevented the net from becoming overloaded with debris.

3.3 Impingement and Predator Monitoring

3.3.1 Environmental Conditions during Impingement and Predator Monitoring

To provide context for the impingement and predator monitoring results, this section describes the hourly environmental conditions for the Sacramento River and the hourly facility operations on the days when impingement and predator monitoring with the DIDSON/ARIS sonar camera were conducted. It should be noted that hourly environmental conditions are more relevant to impingement and predator monitoring results than daily environmental conditions, which are discussed in section 3.1.1 “Environmental Conditions,” for the WY 2012–2014 entrainment monitoring periods.

Sacramento River Flow, Stage, and Velocity

Figure 29 shows the hourly flow values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Hourly Sacramento River flow levels were highest during WY 2012 and lowest during WY 2014 impingement and predator monitoring. Hourly fluctuations in flows were in response to the twice-daily tidal cycles. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of river flows.

Figure 30 shows the hourly stage values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Like flow, hourly Sacramento River stage levels were highest during WY 2012 and lowest during WY 2014 impingement and predator monitoring. Hourly fluctuations in stage were in response to the twice-daily tidal cycle, as discussed above for flow. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of river stages.

Figure 31 shows the hourly mean water velocity values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Like flow and stage, hourly Sacramento River mean water velocities were highest during WY 2012 and lowest during WY 2014 impingement and predator monitoring. As mentioned earlier, river velocity can have important implications for entrainment with respect to sweeping velocities (i.e., velocities parallel to the screen face); higher river velocity results in higher sweeping velocity, which reduces the time fish are exposed to the fish screen as they are transported across the face of the fish screen. Hourly fluctuations in river velocity were in response to rising and falling stage associated with the twice-daily tidal cycles. Figure 31 also shows the measured water velocities taken every half hour in front of the water intake facility during each 4-hour impingement monitoring period. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of river velocities (and, therefore, sweeping velocities).

Sacramento River Turbidity, Water Temperature, and Electrical Conductivity

Figure 32 shows the 15-minute turbidity values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Generally, Sacramento River turbidity levels were lower but more variable during WY 2013 and WY 2014 impingement and predator monitoring than they were during WY 2012 impingement and predator monitoring. Overall, turbidity levels were lowest during WY 2014 and highest during WY 2012 impingement and predator monitoring, although peak turbidities were highest during WY 2013 impingement monitoring. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of turbidity levels.

Figure 33 shows the 15-minute water temperature values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Sacramento River water temperatures generally were between 59 and slightly above 68°F during impingement and predator monitoring over the course of the three water years. Generally, Sacramento River water temperatures were warmest during WY 2014 and coolest during WY 2013 impingement and predator monitoring. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of Sacramento River temperature conditions.

Figure 34 shows the 15-minute EC values for the Sacramento River at Freeport on the days when impingement and predator monitoring were conducted during WYs 2012–2014. Sacramento River EC values were highest during WY 2014 and lowest during WY 2012 impingement and predator monitoring between 135 and 140 µS/cm during the impingement and predator monitoring periods. The data show that impingement and predator monitoring over the three water years were conducted under a wide range of EC conditions.

3.3.2 Impingement Monitoring

Overview of Monitoring Activities and Facility Operations during Impingement Monitoring

A combined total of 48.75 hours of impingement monitoring with the DIDSON/ARIS sonar camera and 9 hours of diver observations were conducted over the course of the WY 2012–2014 monitoring periods. Monitoring activities and facility operations for each of the three impingement and predator monitoring periods are summarized below.

WY 2012

Table 22 summarizes the timing and duration of impingement monitoring, pumps that were operating, and total pumping rate that occurred while impingement monitoring was being conducted on April 25–27, 2012. A total of 16.75 hours of monitoring for impingement of fish on 31.5 sf of the upper portion of fish screen panel 1 using the DIDSON sonar camera was conducted over 2 days. Impingement monitoring with the DIDSON sonar camera was conducted during daylight and nighttime on both days. In addition, divers spent 4.72 hours inspecting the fish screen panels for impinged fish over the 2 days. Divers inspected the fish screen panels three times each day, once during daylight, once during twilight, and once during nighttime.

Most of the time, only one pump (pump 1) was operating when impingement was being monitored with the DIDSON sonar camera and the fish screen panels were being inspected by the divers. During the time when only pump 1 was operating, the Freeport water intake facility was diverting 23 cfs (15 mgd) of water from the Sacramento River, or slightly less than 0.10% of the total flow of the river. When a second pump (pump 2) was brought into service at 23:00 hours on the second day of impingement monitoring (April 26, 2012) and the diversion rate was increased to flush sediment from the pipeline, pumping increased to 90 cfs (58 mgd), or about 0.38% of the total flow of the river.

Table 22. Summary of Impingement Monitoring Activities, WY 2012 (April 25–27, 2012)

Monitoring Activity (Location)	Monitoring Interval (Elapsed Time [Hours:Minutes])	Operating Pump Number[1]	Total Pumping Rate (**cubic feet per second** [million gallons per day])
April 25–26, 2012[2]			
Dive Inspection 1 (Fish Screen Panels 1–16)	15:30–16:30 (1:00)	1	**23** [15]
Daylight DIDSON Monitoring (Fish Screen Panel 1)	16:37–20:52 (4:15)	1	**23** [15]
Dive Inspection 2 (Fish Screen Panels 1–8)	20:52–21:30 (0:38)	1	**23** [15]
Nighttime DIDSON Monitoring (Fish Screen Panel 1)	21:30–01:30 (4:00)	1	**23** [15]
Dive Inspection 3 (Fish Screen Panels 1–8)	01:30–02:15 (0:45)	1	**23** [15]
April 26–27, 2012[3]			
Dive Inspection 1 (Fish Screen Panels 1–8)	14:30–15:20 (0:50)	1	**23** [15]
Daylight DIDSON Monitoring (Fish Screen Panel 1)	15:20–19:45 (4:25)	1	**23** [15]
Dive Inspection 2 (Fish Screen Panels 1–8)	19:45–20:30 (0:45)	1	**23** [15]
Nighttime DIDSON Monitoring (Fish Screen Panel 1)	20:30–23:00 (2:30) 23:00–00:30 (1:30)	1 1 and 2	**23** [15] **90** [58]
Dive Inspection 3 (Fish Screen Panels 1–8)	00:30–1:15 (0:45)	1 and 2	**90** [58]

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2).

[2] Sunset occurred at 19:53 hours and moonset occurred at 22:41 hours on April 25.

[3] Sunset occurred at 19:54 hours and moonset occurred at 23:36 hours on April 26.

WY 2013

Table 23 summarizes the timing and duration of impingement monitoring, pumps that were operating and total pumping rate that occurred while impingement monitoring was being conducted on April 10–11, 2013. A total of 16 hours of monitoring for impingement of fish on 26 sf of the upper portion of fish screen panel 11 using the ARIS sonar camera was conducted over 2 days. Impingement monitoring with the ARIS sonar camera was conducted during daylight and nighttime on both days. In addition, divers spent a total of 2.12 hours inspecting the fish screen panels for impinged fish over the 2 days. Divers inspected the fish screen panels three times each day, once before the start of the daylight impingement monitoring period, once between the daylight and nighttime impingement monitoring periods, and once after the nighttime impingement monitoring period. Divers also inspected all 16 fish screen panels on April 9, 2013, to determine the general condition of the fish screens and the fish screen cleaner system; the inspection occurred during mid-day.

Pumps 5 and 6 were operating when impingement was being monitored with the ARIS sonar camera and the fish screen panels were being inspected by the divers. On the days impingement monitoring was conducted, the Freeport water intake facility was diverting 46 cfs (30 mgd) of water from the Sacramento River, or from 0.24% to 0.36% of the total flow of the river depending on the tides.

Table 23. Summary of Impingement Monitoring Activities, WY 2013 (April 10–11, 2013)

Monitoring Activity (Location)	Monitoring Interval (Elapsed Time [Hours:Minutes])	Operating Pump Number[1]	Total Pumping Rate (**cubic feet per second** [million gallons per day])
April 10, 2013[2]			
Dive Inspection 1 (Fish Screen Panels 9–16)	14:00–14:40 (0:30)	5 and 6	**46** [30]
Daylight ARIS Monitoring (Fish Screen Panel 11)	15:00–19:00 (4:00)	5 and 6	**46** [30]
Dive Inspection 2 (Fish Screen Panels 9–16)	19:04–19:21 (0:17)	5 and 6	**46** [30]
Nighttime ARIS Monitoring (Fish Screen Panel 11)	20:00–00:00 (4:00)	5 and 6	**46** [30]
Dive Inspection 3 (Fish Screen Panels 9–16)	00:10–00:30 (0:20)	5 and 6	**46** [30]
April 11, 2013[3]			
Dive Inspection 1 (Fish Screen Panels 9–16)	14:05–14:25 (0:20)	5 and 6	**46** [30]
Daylight ARIS Monitoring (Fish Screen Panel 11)	15:00–19:00 (4:00)	5 and 6	**46** [30]
Dive Inspection 2 (Fish Screen Panels 9–16)	19:04–19:23 (0:19)	5 and 6	**46** [30]
Nighttime ARIS Monitoring (Fish Screen Panel 11)	20:00–00:00 (4:00)	5 and 6	**46** [30]
Dive Inspection 3 (Fish Screen Panels 9–16)	00:10–00:31 (0:21)	5 and 6	**46** [30]

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2).

[2] Sunset occurred at 19:38 hours and moonset occurred at 20:19 hours on April 10.

[3] Sunset occurred at 19:39 hours and moonset occurred at 21:17 hours on April 11.

WY 2014

Table 24 summarizes the timing and duration of impingement monitoring, pumps that were operating and total pumping rate that occurred while impingement monitoring was being conducted on April 9–10, 2014. A total of 16 hours of monitoring for impingement of fish on 24 sf of the upper portion of fish screen panel 14 using the ARIS sonar camera was conducted over 2 days. Impingement monitoring with the ARIS sonar camera was conducted during daylight and nighttime on both days. In addition, divers spent a total of 2.2 hours inspecting the fish screen panels for impinged fish over the 2 days. Divers inspected the fish screen panels three times each day, once before the start of the daylight impingement monitoring period, once between the daylight and nighttime impingement monitoring periods, and once after the nighttime impingement monitoring period. Divers also inspected all 16 fish screen panels on April 8, 2014, to determine the general condition of the fish screens and the fish screen cleaner system; the inspection occurred during mid-day.

Pumps 6, 7, and 8 in the downstream forebay chamber were operating when impingement was being monitored with the ARIS sonar camera and the fish screen panels were being inspected by the divers. On the days impingement monitoring was conducted, the Freeport water intake facility was diverting 139 cfs (90 mgd) of water from the Sacramento River, or from 0.98% to 6.12% of the total flow of the river depending on the tides.

Table 24. Summary of Impingement Monitoring Activities, WY 2014 (April 9–10, 2014)

Monitoring Activity (Location)	Monitoring Interval (Elapsed Time [Hours:Minutes])	Operating Pump Number1	Total Pumping Rate (cubic feet per second [million gallons per day])
April 9, 2014[2]			
Dive Inspection 1 (Fish Screen Panels 9–16)	14:50–15:20 (0:30)	6, 7, and 8	**139** [90]
Daylight ARIS Monitoring (Fish Screen Panel 14)	15:30–19:30 (4:00)	6, 7, and 8	**139** [90]
Dive Inspection 2 (Fish Screen Panels 9–16)	19:43–20:05 (0:22)	6, 7, and 8	**139** [90]
Nighttime ARIS Monitoring (Fish Screen Panel 14)	20:30–00:30 (4:00)	6, 7, and 8	**139** [90]
Dive Inspection 3 (Fish Screen Panels 9–16)	00:35–01:05 (0:20)	6, 7, and 8	**139** [90]
April 10, 2014[3]			
Dive Inspection 1 (Fish Screen Panels 9–16)	14:54–15:30 (0:20)	6, 7, and 8	**139** [90]
Daylight ARIS Monitoring (Fish Screen Panel 14)	15:30–19:30 (4:00)	6, 7, and 8	**139** [90]
Dive Inspection 2 (Fish Screen Panels 9–16)	19:51–20:18 (0:19)	6, 7, and 8	**139** [90]
Nighttime ARIS Monitoring (Fish Screen Panel 14)	20:30–00:30 (4:00)	6, 7, and 8	**139** [90]
Dive Inspection 3 (Fish Screen Panels 9–16)	00:10–00:31 (0:21)	6, 7, and 8	**139** [90]

[1] The eight water intake facility pumps are numbered sequentially from upstream to downstream (Figure 2).

[2] Sunset occurred at 19:37 hours and moonrise occurred at 14:34 hours on April 9.

[3] Sunset occurred at 19:38 hours and moonrise occurred at 15:30 hours on April 10.

General Fish Observations during Impingement Monitoring

WY 2012

A total of 1,613 fish were observed passing between the DIDSON sonar camera and fish screen panel 1 during the 2 days impingement was monitored with the DIDSON sonar camera (Table 25). Fish that were observed during the daylight and moving in the upstream direction accounted for 82% of the total observations; however, the substantial number of fish (1,169) observed moving upstream during the daylight on Day 2 accounted for the majority of these observations. Even in the absence of these large numbers of fish on Day 2, more fish were observed during daylight than during nighttime.

The average size of fish observed with the DIDSON sonar camera was 186 mm (range 30–800 mm) (Table 25). It should be noted that targets smaller than 30 mm could not be reliably identified as fish; therefore, these results do not include fish smaller than 30 mm that may have been passing in front of the DIDSON sonar camera. On average, fish observed during the nighttime and on Day 1 were larger than those observed at other times. In addition, fish moving upstream were slightly larger on average than fish moving downstream.

Other than fish size and direction of travel, no other information (e.g., species identification) could be determined about individual fish that were observed with the DIDSON sonar camera.

Table 25. Number and Length of Fish Observed Passing Fish Screen Panel 1 during Impingement Monitoring Using Fixed DIDSON, WY 2012 (April 25–27, 2012)

Period	Direction of Travel	Number Observed	Average Size (millimeters)	Size Range (millimeters)
Day 1				
Daylight	Upstream	155	298	50–800
Daylight	Downstream	62	167	40–520
Nighttime	Upstream	21	363	50–620
Nighttime	Downstream	50	108	30–410
Day 1 Totals		**288**	**242**	**30–800**
Day 2				
Daylight	Upstream	1,169	163	40–800
Daylight	Downstream	102	211	30–630
Nighttime	Upstream	34	384	40–650
Nighttime	Downstream	20	220	30–570
Day 2 Totals		**1,325**	**173**	**30–800**
Day 1 and 2 Totals		**1,613**	**186**	**30–800**
Daylight versus Nighttime				
Daylight		1,488	181	30–800
Nighttime		125	244	30–650
Upstream versus Downstream				
	Upstream	1,379	187	40–800
	Downstream	234	178	30–630

WY 2013

A total of 942 fish were observed passing between the ARIS sonar camera and fish screen panel 11 during the 2 days impingement was monitored (Table 26). Similar numbers of fish were observed passing fish screen panel 11 on each day. More fish were observed during daylight than at nighttime and more fish were observed traveling in an upstream direction than in a downstream direction; this pattern held across both days (Table 26). Fish observed traveling upstream during daylight accounted for 84% (789 fish out of a total of 942 fish) of all fish observed swimming past fish screen panel 11. The direction of travel for 54 fish could not be determined because they did not cross any sonar beams during the period when they were visible.

The average size of all fish observed with the ARIS sonar camera was 115 mm (range 23–583 mm) (Table 26). The average size of fish observed was similar on both days, although the range of sizes observed on Day 1 was smaller than the range of sizes observed on Day 2. On average, fish observed during the nighttime were 94 mm larger than those observed during the day. In addition, fish moving downstream were about 25 mm (1 inch) larger on average than fish moving upstream (Table 26).

Other than fish size and direction of travel, no other information (e.g., species identification) could be determined about individual fish that were observed with the ARIS sonar camera.

Table 26. Number and Length of Fish Observed Passing Fish Screen Panel 11 during Impingement Monitoring Using Fixed ARIS, WY 2013 (April 10–11, 2013)

Period	Direction of Travel	Number Observed	Average Size (millimeters)	Size Range (millimeters)
Day 1 (April 10)				
Daylight	Upstream	409	110	52–415
Daylight	Downstream	33	100	68–246
Daylight	Undetermined	11	94	66–141
Nighttime	Upstream	17	190	72–449
Nighttime	Downstream	7	223	96–367
Nighttime	Undetermined	1	382	382
Day 1 Totals		**478**	**114**	**52–449**
Day 2 (April 11)				
Daylight	Upstream	380	110	54–421
Daylight	Downstream	30	136	75–432
Daylight	Undetermined	37	121	51–418
Nighttime	Upstream	8	212	126–424
Nighttime	Downstream	4	286	25–583
Nighttime	Undetermined	5	113	23–345
Day 2 Totals		**464**	**116**	**23–583**
Day 1 and 2 Totals		**942**	**115**	**23–583**
Daylight versus Nighttime				
Daylight		900	110	51–432
Nighttime		42	204	23–583
Upstream versus Downstream				
	Upstream	814	112	52–449
	Downstream	74	136	25–583
	Undetermined	54	119	23–418

Note: The moon was New on April 10 and a waxing crescent (2% of visible surface illuminated) on April 11. Moonset on April 11 occurred at 21:17.

WY 2014

A total of 719 fish were observed passing between the ARIS sonar camera and fish screen panel 14 during the 2 days impingement was monitored (Table 27). Similar numbers of fish were observed passing fish screen panel 14 on each day. More fish were observed during daylight than at nighttime and more fish were observed traveling in an upstream direction than in a downstream direction; this pattern held across both days with the exception of nighttime on Day 2 (Table 27). Fish observed traveling upstream during daylight accounted for 65% (465 fish out of a total of 719 fish) of all fish observed swimming past fish screen panel 14.

The average size of all fish observed with the ARIS sonar camera was 117 mm (range 34–492 mm) (Table 27). The average size of fish observed was similar on both days, although the range of sizes observed on Day 2 was smaller than the range of sizes observed on Day 1. On average, fish observed during the nighttime were 35 mm larger than those observed during the day; however, the presence of several large fish and fewer total fish at night likely was responsible for increasing the average size. In addition, fish moving downstream were similar in size to fish moving upstream (Table 27).

Other than fish size and direction of travel, no other information (e.g., species identification) could be determined about individual fish that were observed with the ARIS sonar camera.

Table 27. Number and Length of Fish Observed Passing Fish Screen Panel 14 during Impingement Monitoring Using Fixed ARIS, WY 2014 (April 9–10, 2014)

Period	Direction of Travel	Number Observed	Average Size (millimeters)	Size Range (millimeters)
Day 1 (April 9)				
Daylight	Upstream	242	107	34–294
Daylight	Downstream	92	126	44–492
Nighttime	Upstream	11	137	53–272
Nighttime	Downstream	2	63	52–73
Day 1 Totals		**347**	**113**	**34–492**
Day 2 (April 10)				
Daylight	Upstream	223	116	39–351
Daylight	Downstream	129	120	37–377
Nighttime	Upstream	9	249	57–418
Nighttime	Downstream	11	99	79–120
Day 2 Totals		**372**	**120**	**37–418**
Day 1 and 2 Totals		**719**	**117**	**34–492**
Daylight versus Nighttime				
Daylight		686	115	34–492
Nighttime		33	150	52–418
Upstream versus Downstream				
	Upstream	485	121	34–418
	Downstream	234	115	37–492

Note: The moon was a waxing gibbous (72% of visible surface illuminated) on April 9 and a waxing gibbous (80% of visible surface illuminated) on April 10. Moonrise occurred at 14:34 hours on April 9 and at 15:30 hours on April 10.

Observations of Fish Impingement

WY 2012

No incidences of fish impingement on fish screen panel 1 were observed during monitoring with the DIDSON sonar camera, although some fish were observed to change trajectory toward the fish screen, indicating that they were potentially influenced by the diversion. Additional information on these fish is provided below.

No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–8 during any of the dive inspections. In addition, there was no significant debris accumulation on any of the screen panels, other than the growth of fine algae on the upper 25–35% of the screens where the fish screen cleaner brushes were not making sufficient contact with the fish screen. When only pump 1 was operating and 23 cfs (15 mgd) were being diverted by the water intake facility, divers were unable to detect any current passing through the fish screen (i.e., approach velocities appeared negligible). When pumps 1 and 2 were operating and 90 cfs (58 mgd) were being diverted by the water intake facility, divers were able to detect a slight current passing through the fish screen, based on the movement of fine suspended particles being drawn through the fish screen panels and the occurrence of small leaves being held against the fish screen.

A total of seven fish appeared to change trajectory toward the fish screen and possibly be influenced by the diversion; however, none of them was smaller than 50 mm. These seven fish ranged in size from 70 to 130 mm (average 89 mm) and all but one were observed during daylight. The changes in trajectory occurred when the water intake facility was diverting 23 cfs (15 mgd). No fish were observed to change their trajectory toward the fish screen when the water intake facility was diverting a total of 90 cfs (58 mgd) when pumps 1 and 2 were operating on Day 2, although a target that appeared to be debris (possibly a leaf) was observed to have a trajectory toward the fish screen, presumably in response to the flow of diverted water. There was no difference in the number of fish changing trajectory based on their direction of travel (up or downstream); one fish was observed holding in front of the fish screen.

Of the seven fish observed to change trajectory toward the fish screen, only one (a 90-mm fish) appeared to come in contact with the fish screen; however, this behavior was in response to a pursuit by a larger fish (i.e., a possible failed predation event). One other fish appeared to change its trajectory toward the fish screen in response to a passing school of larger fish.

WY 2013

No incidences of fish impingement on fish screen panel 11 were observed during monitoring with the ARIS sonar camera, although one fish was observed to change trajectory toward the fish screen, indicating that it was potentially influenced by the diversion. This fish was 52 mm long and was traveling in the upstream direction on Day 1.

No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–16 during the initial dive inspection on April 9 or during any of the repeated dive inspections of fish screen panels 9–16 on Day 1 or 2 of impingement monitoring. In addition, there was no significant debris accumulation on any of the screen panels, other than occasional streaks of fine algae growth where the fish screen cleaner brushes were not making sufficient contact with the fish screen. When pumps 5 and 6 were operating and 46 cfs (30 mgd) was being diverted by the water intake facility, divers were unable to detect any current passing through the fish screen (i.e., approach velocities appeared negligible).

WY 2014

No incidences of fish impingement on fish screen panel 14 were observed during the 16 hours of impingement monitoring with the ARIS sonar camera.

No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–16 during the initial dive inspection on April 8 or during any of the repeated dive inspections of fish screen panels

9–16 on Day 1 or 2 of impingement monitoring. In addition, there was no significant debris accumulation on any of the screen panels, other than slight coating of fine algae growth on the upper 2–3 feet of the screen panels where the fish screen cleaner brushes were not making sufficient contact with the fish screen. When pumps 6, 7, and 8 were operating and 139 cfs (90 mgd) was being diverted by the water intake facility, divers were able to detect current passing through the fish screen (i.e., approach velocities were present but not strong).

Other Information on Fish Observed with the ARIS Sonar Camera

WY 2012

Figure 35 shows the length-frequency distribution of all fish observed during impingement monitoring with the DIDSON sonar camera during WY 2012. Three relatively distinct modes of fish size classes were observed, depending on the time of day and direction fish were swimming: 30–120 mm, 70–210 mm, and 220–590 mm. Fish in the 30–120 mm size range were observed primarily moving downstream during the daylight and nighttime monitoring periods, while fish in the 70–210 mm and 220–590 mm size ranges were observed primarily moving upstream in the daylight monitoring periods. The fish size class modes appeared to overlap with one another at times.

Numerous (up to 114) schools of fish, ranging in size from 3 to 45 fish, were observed during impingement monitoring with the DIDSON sonar camera. All of the schools of fish were observed during the daylight monitoring periods and most (108 out of 114) were observed on Day 2. Fish in the schools ranged in size from 73 to 570 mm.

WY 2013

Figure 36 shows the length-frequency distribution of all upstream and downstream moving fish observed during impingement monitoring with the ARIS sonar camera during WY 2013. Most fish observed with the ARIS sonar camera were in the 65–175 mm range. Two distinct modes of fish size classes were observed in this size range: one mode was centered on 90–95 mm and the other mode was centered on 140–150 mm. These modes were most evident in the data for fish traveling upstream during the daytime. Abundance at other times generally was too low to observe any patterns, although fish traveling downstream during the daytime had a similar size range as the fish moving upstream during the daytime (Figure 36).

Numerous (up to 53) distinct schools of fish, ranging in number from 4 to 19 fish, were observed moving upstream during impingement monitoring with the ARIS sonar camera. A total of 345 fish were observed in these schools. All of the schools of fish were observed traveling upstream during the daylight monitoring periods. Thirty schools of fish were observed on Day 1, while 23 schools were observed on Day 2. Fish in the schools averaged 113 mm long and ranged in size from 64 to 416 mm.

WY 2014

Figure 37 shows the length-frequency distribution of all upstream and downstream moving fish observed during impingement monitoring with the ARIS sonar camera during WY 2014. Most fish observed with the ARIS sonar camera were in the 65–175 mm range with a mode centered on 95–100 mm.

Numerous (up to 49) distinct schools of fish, ranging in number from 3 to 21 fish, were observed moving upstream during impingement monitoring with the ARIS sonar camera. A total of 288 fish were observed in these schools. The majority (37 of 49) of the schools of fish were observed traveling upstream during the daylight monitoring periods. Only one school of fish was observed at night. Twenty-six schools of fish were observed on Day 1, while 23 schools were observed on Day 2. Fish in the schools averaged 117 mm long and ranged in size from 34 to 492 mm.

3.3.3 Predator Monitoring

Description of Predator Monitoring Reaches

Figure 38 shows the measured water depths in each of the three predator monitoring reaches (Downstream Control, Facility, Upstream Control). Water depths were measured along the river margin from shallow, nearshore areas out to deep water and included the areas surveyed for predator-size and prey-size fish with the mobile ARIS sonar camera.

Although average measured water depths were similar across all reaches (Table 28), there are some notable differences between reaches. Several deep holes occur in the Downstream Control and Facility Reaches, and some of these holes exceeded 30 feet in the Downstream Control Reach (Figure 38). A larger, shallow shelf up to several feet deep extends from shore out 20–30 feet in the Downstream Control Reach and the lower end of the Facility Reach. By contrast, near shore water depths in the Upstream Control Reach tend to be 5–10 feet deep.

These were the most notable differences in habitat conditions among the three predator monitoring reaches. None of the reaches contains overhanging riparian vegetation and, based on sonar imaging during water depth measurements, underwater hardcover features (e.g., woody material and rock) are limited, except in the Facility Reach where the water intake facility's log boom and associated pilings create underwater structure. Sand is the dominated substrate in all reaches, except in localized areas where riprap extends into the water. Water velocities were not measured but based on visual observations appear to be lower in the Downstream Control Reach on average compared with the other two reaches.

Table 28. Summary of Measured Water Depths by Predator Monitoring Reaches April 5–6, 2013

Monitoring Reach	Measured Water Depth (Feet)[1]		
	Average	Minimum	Maximum
Downstream Control	14.2	2.4	32.8
Facility	15.3	1.3	29.7
Upstream Control	14.4	4.1	22.9

[1] Measured from a boat on April 5–6, 2013.

Overview of Monitoring Activities and Facility Operations during Predator Monitoring

Table 29 summarizes the timing and duration of predator monitoring by reach, for each of the three predator monitoring periods. Monitoring activities and facility operations during each of the three predator monitoring periods are further discussed below.

WY 2012

A total of 3.27 hours of monitoring for predator-size fish in the Upstream Control, Facility, and Downstream Control Reaches was conducted in WY 2012. A total of four surveys were conducted: two surveys (surveys 1 and 2) were conducted during daylight and two surveys (surveys 3 and 4) were conducted at night. During predator monitoring, pump 1 was operating and was diverting 23 cfs (15 mgd) of water from the Sacramento River.

WY 2013

A total of 3.28 hours of monitoring for predator-size and prey-size fish in the Upstream Control, Facility, and Downstream Control Reaches was conducted in WY 2013. A total of four surveys were conducted: two surveys (surveys 1 and 2) were conducted during daylight, one survey was conducted during twilight (survey 3), and one survey (survey 4) was conducted at night. In addition, one drifting survey was conducted in the backwater eddy downstream of the water intake facility. This survey was conducted to observe juvenile Chinook salmon which were observed to be foraging in the backwater eddy during late afternoon and evening. The drifting survey was conducted from 21:34 to 21:46 hours. During predator monitoring and the drifting survey, pumps 5 and 6 were operating and the water intake facility was diverting 46 cfs (30 mgd) of water from the Sacramento River.

WY 2014

A total of 4.35 hours of monitoring for predator-size and prey-size fish in the Upstream Control, Facility, and Downstream Control Reaches was conducted in WY 2014. A total of four surveys were conducted: two surveys (surveys 1 and 2) were conducted during daylight, one survey (survey 3) was conducted during twilight, and one survey (survey 4) was conducted at night. During predator monitoring, pumps 6, 7, and 8 were operating and the water intake facility was diverting 139 cfs (90 mgd) of water from the Sacramento River.

Table 29. Summary of Predator Monitoring Activities, WYs 2012–2014

Survey Number	Monitoring Period	Monitoring Reach/Monitoring Interval (Elapsed Time [Hrs:Min])		
		Downstream Control	Facility	Downstream Control
WY 2012	(April 27, 2012)[1]			
1	Daylight	18:15–18:29 (0:14)	17:53–18:14 (0:21)	18:49–19:07 (0:18)
2	Daylight	19:24–19:39 (0:15)	19:10–19:23 (0:13)	19:49–20:02 (0:13)
3	Nighttime	21:45–21:56 (0:11)	21:34–21:44 (0:10)	21:17–21:32 (0:15)
4	Nighttime	22:39–22:50 (0:11)	22:27–22:37 (0:10)	22:10–22:25 (0:15)
WY 2013	(April 12, 2013)[2]			
1	Daylight	16:43–17:03 (0:20)	17:03–17:15 (0:12)	17:15–17:31 (0:16)
2	Daylight	17:47–18:07 (0:20)	18:07–18:21 (0:14)	18:21–18:38 (0:17)
3	Twilight	19:16–19:34 (0:17)	19:34–19:47 (0:13)	19:47–20:03 (0:16)
4	Nighttime	20:30–20:50 (0:20)	20:50–21:03 (0:13)	21:03–21:21 (0:18)
WY 2014	(April 11, 2014)[3]			
1	Daylight	16:50–17:19 (0:29)	17:19–17:37 (0:18)	17:37–17:55 (0:18)
2	Daylight	18:13–18:39 (0:26)	18:39–18:54 (0:15)	18:54–19:16 (0:22)
3	Twilight	19:31–19:56 (0:25)	19:56–20:13 (0:17)	20:13–20:34 (0:21)
4	Nighttime	21:44–22:16 (0:32)	22:16–22:32 (0:16)	22:32–22:54 (0:22)

[1] Sunset occurred at 19:55 hours on April 27, and moonset occurred at 00:29 hours on April 28, 2012. The moon was a waxing crescent (44% of the moon's visible surface was illuminated).

[2] Sunset occurred at 19:40 hours and moonset occurred at 22:14 hours on April 12, 2013. The moon was a waxing crescent (6% of the moon's visible surface was illuminated).

[3] Sunset occurred at 19:39 hours and moonrise occurred at 16:27 hours on April 11, 2014. The moon was a waxing gibbous (88% of the moon's visible surface was illuminated).

Observations of Predator-Size Fish

WY 2012

A total of 48 predator-size fish were observed during predator monitoring with the DIDSON sonar camera (Table 30; Figures 39a–d). More fish (32) were observed during daylight than were observed at night (16), and the total number of fish observed during each survey declined with each successive survey. The greater number of observations of fish during the daylight portion of predator monitoring was consistent with the trends observed during impingement monitoring with the fixed DIDSON.

The average size of all predator-size fish observed during predator monitoring was 480 mm (range 310–780 mm), and there was no trend in average size of fish across reaches. The average size of all fish observed was 454 mm in the Downstream Control Reach, 454 mm in the Facility Reach, and 503 mm in the Upstream Control Reach.

Densities of predator-size fish across surveys and reaches ranged from 0.5 fish (Downstream Control Reach, surveys 1, 3, and 4) to 9.7 fish (Upstream Control Reach, survey 1) per 1,000 feet of shoreline (Table 30). Overall, the average density of predator-size fish observed was 0.6 in the

Downstream Control Reach, 3.3 in the Facility reach, and 3.9 in the Upstream Control reach (Table 31). Density of predator-size fish in the Facility Reach remained relatively high at night, compared with the other reaches (Table 30).

Table 30. Number, Density, and Length of Predator-Size Fish Observed in the Sacramento River during Predator Monitoring Using Mobile DIDSON, WY 2012 (April 27, 2012)

Survey Number	Monitoring Period/Times[1]	Monitoring Reach	Number Observed	Number Observed per 1,000 Feet[2]	Average Size (millimeters)	Size Range (millimeters)
1	Daylight (18:15–18:29)	Downstream Control	1	0.5	430	430
		Facility	5	3.9	446	350–550
		Upstream Control	16	9.7	499	310–780
2	Daylight (19:24–20:02)	Downstream Control	2	1.0	510	470-550
		Facility	5	3.9	438	350–550
		Upstream Control	3	1.8	523	430–630
3	Nighttime (21:45–21:32)	Downstream Control	1	0.5	470	470
		Facility	3	3.1	430	390–470
		Upstream Control	5	2.4	494	430–550
4	Nighttime (22:39–22:25)	Downstream Control	1	0.5	350	350
		Facility	4	3.1	490	430–590
		Upstream Control	2	1.2	530	470–590

[1] See Table 29 for starting and ending times and elapsed time for each monitoring interval.

[2] Downstream Control Reach = 2,065 feet long; Facility Reach = 1,295 feet long; and Upstream Control Reach = 1,647 feet long.

Table 31. Total Number and Average Density of Predator-Size Fish Observed by Survey Reach (All Surveys Combined) during Predator Monitoring Activities Using a Mobile DIDSON/ARIS Sonar Camera, WYs 2012–2014

Survey Reach	Reach Length (Feet)	Total Number of Fish Observed	Average Density (Number Observed per 1,000 Feet per survey)[1]
WY 2012[2]			
Downstream Control	2,065	5	0.61
Facility	1,295	17	3.3
Upstream Control	1,647	26	3.9
WY 2013[3]			
Downstream Control	2,281	92	10.1
Facility	1,295	49	9.5
Upstream Control	1,744	73	10.5
WY 2014[3]			
Downstream Control	2,281	171	18.7
Facility	1,295	74	14.3
Upstream Control	1,744	205	29.4

[1] Average density is calculated as: (total number of fish observed/reach length/4 surveys x 1,000 feet)

[2] Predator monitoring was conducted with a DIDSON sonar camera.

[3] Predator monitoring was conducted with an ARIS sonar camera.

WY 2013

A total of 214 predator-size fish (i.e., fish 12 inches long [305 mm long] and larger) were observed during predator monitoring with the ARIS sonar camera (Table 32; Figures 40a–d). There was no consistent trend in the number of fish observed across surveys, although more fish (73) were observed at night (survey 4) than were observed at any other time. The greater number of observations of fish during the nighttime portion of predator monitoring was in contrast to the decreasing trend in fish abundance at night that was observed during impingement monitoring with the fixed ARIS the previous two days during impingement monitoring.

The average size of all predator-size fish observed during predator monitoring was 410 mm (range: 305–1,033 mm), and the average size of all predator-size fish observed in each reach was similar across all reaches.

Densities of predator-size fish across surveys and reaches ranged from 3.9 fish (Facility Reach, survey 1) to 18.4 fish (Upstream Control Reach, survey 4) per 1,000 feet of shoreline (Table 32). Overall, the average density of predator-size fish observed was similar across reaches for all surveys combined (Table 31). Density of predator-size fish in the Facility Reach showed an increasing trend across surveys, with four times as many predator-size fish observed during survey 4 (nighttime) as was observed during survey 1 (daylight) (Table 32). No other trends in predator density were observed across reaches or surveys.

Table 32. Number, Density, and Length of Predator-Size Fish Observed in the Sacramento River during Predator Monitoring Activities Using a Mobile ARIS Sonar Camera, WY 2013 (April 12, 2013)

Survey Number	Monitoring Period/Times[1]	Monitoring Reach	Number Observed	Number Observed per 1,000 Feet[2]	Average Size (millimeters)	Size Range (millimeters)
1	Daylight (16:43–17:31)	Downstream Control	20	8.8	368	316–506
		Facility	5	3.9	368	321–413
		Upstream Control	18	10.3	399	324–476
		Total	**43**			
2	Daylight (17:47–18:38)	Downstream Control	29	12.7	398	305–491
		Facility	10	7.7	396	342–445
		Upstream Control	13	7.5	398	312–493
		Total	**52**			
3	Twilight (19:16–20:03)	Downstream Control	24	10.5	473	305–1,033
		Facility	12	9.3	449	305–615
		Upstream Control	10	5.7	382	323–472
		Total	**46**			
4	Nighttime (20:30–21:21)	Downstream Control	19	8.3	416	307–523
		Facility	22	17	405	324–510
		Upstream Control	32	18.4	418	314–640
		Total	**73**			

[1] See Table 29 for starting and ending times and elapsed time for each monitoring interval.

[2] Downstream Control Reach = 2,281 feet long; Facility Reach = 1,295 feet long; and Upstream Control Reach = 1,744 feet long.

WY 2014

A total of 450 predator-size fish (i.e., fish 12 inches long [305 mm long] and larger) were observed during predator monitoring with the ARIS sonar camera (Table 33; Figures 41a–d). There was no consistent trend in the number of fish observed across surveys, although more fish (179) were observed during survey 1 than were observed at any other time.

The average size of all predator-size fish observed during predator monitoring was 456 mm (range: 305–1,289 mm), and there was a decreasing trend in average size of all predator-size from downstream to upstream. The average size of all fish observed was 507 mm in the Downstream Control Reach, 462 mm in the Facility Reach, and 411 mm in the Upstream Control Reach.

Densities of predator-size fish across surveys and reaches ranged from 7.7 fish (Facility Reach, survey 2) to 66.5 fish (Upstream Control Reach, survey1) per 1,000 feet of shoreline (Table 33). Overall, the average density of predator-size fish observed was less in the Facility Reach for all surveys combined (Table 31). Density of predator-size fish in all reaches showed a decreasing trend between daylight surveys and an increasing trend between nighttime surveys (Table 33). No other trends in predator density were observed across reaches or surveys.

Table 33. Number, Density, and Length of Predator-Size Fish Observed in the Sacramento River during Predator Monitoring Activities Using a Mobile ARIS Sonar Camera, WY 2014 (April 11, 2014)

Survey Number	Monitoring Period/Times[1]	Monitoring Reach	Number Observed	Number Observed per 1,000 Feet[2]	Average Size (millimeters)	Size Range (millimeters)
1	Daylight (16:50–17:55)	Downstream Control	43	18.9	564	318–1,128
		Facility	20	15.4	475	310–937
		Upstream Control	116	66.5	365	308–552
		Total	**179**			
2	Daylight (18:13–19:16)	Downstream Control	32	14.0	491	308–1,255
		Facility	10	7.7	470	305–633
		Upstream Control	25	14.3	492	310–856
		Total	**67**			
3	Twilight (19:31–20:34)	Downstream Control	38	16.7	549	310–1,289
		Facility	14	10.8	443	306–756
		Upstream Control	30	17.2	460	316–611
		Total	**82**			
4	Nighttime (21:44–22:54)	Downstream Control	58	25.4	447	316–1,042
		Facility	30	23.2	460	316–960
		Upstream Control	34	19.5	466	318–630
		Total	**122**			
		Overall Total	**450**			

[1] See Table 29 for starting and ending times and elapsed time for each monitoring interval.

[2] Downstream Control Reach = 2,281 feet long; Facility Reach = 1,295 feet long; and Upstream Control Reach = 1,744 feet long.

Observations of Prey-Size Fish

Because the DIDSON sonar camera settings were chosen to maximize observing predator-size fish in WY 2012, the resulting resolution of the sonar images was not sufficient to simultaneously observe, enumerate, and measure prey-size fish. Therefore, predator monitoring in WY 2012 focused solely on quantifying the presence of predator-size fish. Results of monitoring for prey-size fish in WY 2013 and WY 2014 are discussed below.

WY 2013

A total of 277 prey-size fish (i.e., fish less than 12 inches long [305 mm long]) were observed during predator monitoring with the ARIS sonar camera (Table 34; Figures 42a–d). More fish (77) were observed during the first pass than were observed at any other time, and there was a decreasing trend in the total number of fish observed during subsequent surveys. The greater number of observations of fish during the daytime portion of predator monitoring was consistent with the trends of fish abundance observed during impingement monitoring with the fixed ARIS during the previous two days.

The average size of all prey-size fish observed during predator monitoring was 152 mm (range 39–301 mm), and the average size of all prey-size fish observed was smallest in the Facility Reach.

Densities of prey-size fish across surveys and reaches ranged from 5.2 fish (Upstream Control Reach, survey 1) to 26.3 fish (Downstream Control Reach, survey 1) per 1,000 feet of shoreline (Table 34). Generally, the densities of prey-size fish were highly variable across reaches and surveys, although density was the least variable in the Upstream Control Reach (range: 5.2–13.2 fish per 1,000 feet of shoreline) (Table 34). Average density of prey-size fish showed a decreasing trend across reaches (from downstream to upstream) for all surveys combined (Table 35). No other trends in prey-size density were observed across reaches or surveys.

Table 34. Number, Density, and Length of Prey-Size Fish Observed in the Sacramento River during Predator Monitoring Using a Mobile ARIS Sonar Camera, WY 2013 (April 12, 2013)

Survey Number	Monitoring Period/Times[1]	Monitoring Reach	Number Observed	Number Observed per 1,000 Feet[2]	Average Size (millimeters)	Size Range (millimeters)
1	Daylight (16:43–17:31)	Downstream Control	60	26.3	141	54–298
		Facility	8	6.2	136	75–268
		Upstream Control	9	5.2	211	93–295
		Total	**77**			
2	Daylight (17:47–18:38)	Downstream Control	21	9.2	184	78–301
		Facility	31	23.9	98	39–295
		Upstream Control	20	11.5	142	57–293
		Total	**72**			
3	Twilight (19:16–20:03)	Downstream Control	38	16.7	169	59–301
		Facility	10	7.7	166	81–294
		Upstream Control	20	11.5	135	85–204
		Total	**68**			
4	Nighttime (20:30–21:21)	Downstream Control	18	7.9	173	73–300
		Facility	19	14.7	145	60–236
		Upstream Control	23	13.2	186	89–297
		Total	**60**			

[1] See Table 29 for starting and ending times and elapsed time for each monitoring interval.

[2] Downstream Control Reach = 2,281 feet long; Facility Reach = 1,295 feet long; and Upstream Control Reach = 1,744 feet long.

Table 35. Total Number and Average Density of Prey-Size Fish Observed by Survey Reach during Predator Monitoring Using a Mobile ARIS Sonar Camera, WYs 2013–2014

Survey Reach	Reach Length Feet)	Total Number of Fish Observed	Average Density (Number Observed per 1,000 Feet per survey)
WY 2013			
Downstream Control	2,281	137	15.0
Facility	1,295	68	13.1
Upstream Control	1,744	72	10.3
WY 2014			
Downstream Control	2,281	119	13.0
Facility	1,295	118	22.8
Upstream Control	1,744	279	40.0

Notes:

Prey-size fish were not detectable with the DIDSON sonar camera in WY 2012.

Average density is calculated as (total number of fish observed/reach length/4 surveys x 1,000 feet)

WY 2014

A total of 516 prey-size fish (i.e., fish less than 12 inches long [305 mm long]) were observed during predator monitoring with the ARIS sonar camera (Table 36; Figures 43a–d). More fish (268) were observed during the first pass than were observed at any other time, and there was a decreasing trend in the total number of fish observed during subsequent surveys. The greater number of observations of fish during the daytime portion of predator monitoring was consistent with the trends of general fish abundance observed during impingement monitoring with the fixed ARIS during the previous two days.

The average size of all prey-size fish observed during predator monitoring was 180 mm (range 50–304 mm), and the average size of prey-size fish observed was smallest in the facility reach.

Densities of prey-size fish across surveys and reaches ranged from 4.0 fish (Upstream Control Reach, survey 4) to 107.8 fish (Upstream Control Reach, survey 1) per 1,000 feet of shoreline (Table 36). Generally, the densities of prey-size fish were highly variable across reaches and surveys, although density was the least variable in the Downstream Control Reach (range: 6.1–19.7 fish per 1,000 feet of shoreline) (Table 36). Average density of prey-size fish showed an increasing trend across reaches (from downstream to upstream) for all surveys combined (Table 35). No other trends in prey-size fish density were observed across reaches or surveys.

Table 36. Number, Density, and Length of Prey-Size Fish Observed in the Sacramento River during Predator Monitoring Using a Mobile ARIS Sonar Camera, WY 2014 (April 11, 2014)

Survey Number	Monitoring Period/Times[1]	Monitoring Reach	Number Observed	Number Observed per 1,000 Feet[2]	Average Size (millimeters)	Size Range (millimeters)
1	Daylight (16:50–17:55)	Downstream Control	18	7.9	182	93–283
		Facility	62	47.9	141	50–300
		Upstream Control	188	107.8	199	73–304
		Total	**268**			
2	Daylight (18:13–19:16)	Downstream Control	42	18.4	177	80–301
		Facility	40	30.9	160	107–283
		Upstream Control	76	43.6	136	63–303
		Total	**158**			
3	Twilight (19:31–20:34)	Downstream Control	45	19.7	198	112–303
		Facility	9	6.9	223	170–277
		Upstream Control	8	4.6	203	130–289
		Total	**62**			
4	Nighttime (21:44–22:54)	Downstream Control	14	6.1	237	155–301
		Facility	7	5.4	251	214–304
		Upstream Control	7	4.0	248	130–300
		Total	**28**			
		Overall Total	**516**			

[1] See Table 29 for starting and ending times and elapsed time for each monitoring interval.

[2] Downstream Control Reach = 2,281 feet long; Facility Reach = 1,295 feet long; and Upstream Control Reach = 1,744 feet long.

Observations of Fish during Drifting Survey of Backwater Eddy

In WY 2013, a drifting survey of the backwater eddy was conducted with the ARIS sonar camera to observe juvenile Chinook salmon that had been observed earlier from shore and the boat feeding in the backwater eddy. A total of 82 fish were observed while drifting for 12 minutes in the backwater eddy with the boat-mounted ARIS sonar camera. Fifty-nine of the fish ranged in size from 16 to 80 mm, 19 fish ranged in size from 102 to 157 mm, 2 fish ranged in size from 258 to 268 mm, and 2 fish ranged in size from 310 to 379 mm.

3.4 Summary

3.4.1 Monitoring Locations and Schedule

Entrainment Monitoring

Entrainment monitoring behind the fish screens of the Freeport water intake facility was conducted in WYs 2012–2014 using a 505-micron mesh hoop net attached to the discharge end of the inlet pipe at the VSWTP, which is about 17 miles from the Freeport water intake facility on the Sacramento River, near the town of Freeport, California (Figure 1). In addition, entrainment monitoring was conducted in WY 2013 and WY 2014 using floating larval light traps that were placed in the forebay chambers of the water intake facility (Figure 2).

Entrainment monitoring was conducted over 12 monitoring events from December through July in WY 2012, from January through June in WY 2013, and from December through June (with the exception of January and February) in WY 2014, and followed closely the methods described in the adopted biological monitoring plan (Appendix A). Each entrainment monitoring event consisted of sampling for 24 hours with the hoop net and from 4 to 12 hours with 2–4 larval light traps. In WY 2012, entrainment monitoring using the hoop net at the VSWTP was conducted from December through July (Tables 1 and 6). In WY 2013 and WY 2014, entrainment monitoring using the hoop net at the VSWTP and the floating larval light traps in the forebay chambers was conducted from January through June in WY 2013, and from December through June (with the exception of January and February) in WY 2014 (Tables 1, 2, and 7–10).

Impingement Monitoring

Impingement monitoring was conducted over 2 consecutive days each in WYs 2012–2014 using a combination of DIDSON/ARIS sonar camera and diver observations. Monitoring for impinged fish with the sonar cameras and by the divers spanned daylight, twilight, and nighttime conditions. In WY 2012, monitoring for impinged fish at screen panel 1 (upstream forebay; Figure 2) was conducted on April 25–26, 2012, using a DIDSON sonar camera (Table 22). In addition, divers using scuba inspected fish screen panels 1–8 for impinged fish during three separate dives on each day impingement monitoring was conducted. The same methods used in WY 2012 to monitor for impinged fish were also used in WY 2013 and WY 2014, except that an ARIS sonar camera was used rather than a DIDSON sonar camera and the location of monitoring changed. In WY 2013, monitoring for impinged fish at screen panel 11 (downstream forebay; Figure 2) was conducted on April 10–11, 2013, using an ARIS sonar camera and divers using scuba inspected fish screen panels

9–16. In WY 2014, monitoring for impinged fish at screen panel 14 (downstream forebay; Figure 2) was conducted on April 9–10, 2014, using an ARIS sonar camera and divers using scuba inspected fish screen panels 9–16.

Predator Monitoring

Predator monitoring was conducted on 1 day immediately following each 2-day impingement monitoring event in WYs 2012–2014. Monitoring for predator-size (12 inches long and larger) and prey-size fish (smaller than 12 inches long) was conducted with the DIDSON/ARIS sonar cameras and spanned daylight, twilight, and nighttime conditions. Monitoring for predator- and prey-size fish was conducted in three reaches of the Sacramento River (Figure 7): a downstream control reach unaffected by the water intake facility; a facility reach centered on the water intake facility; and an upstream control reach also unaffected by the water intake facility. In WY 2012, predator monitoring for predator-size fish only was conducted using a DIDSON sonar camera. In WY 2013 and WY 2014, predator monitoring was conducted using an ARIS sonar camera and focused on prey-size fish in addition to predator-size fish. Also in WY 2013, a drifting survey of the backwater eddy located downstream of the water intake facility (Figure 7) was conducted with the ARIS sonar camera to observe juvenile Chinook salmon that were visually observed from shore and boat feeding, especially during twilight and at nighttime.

3.4.2 Environmental Conditions

Entrainment, impingement, and predator monitoring were conducted under a wide range of environmental conditions and facility operations in WYs 2012–2014. These environmental conditions and facility operations are summarized below.

River flows generally were between 5,000 and 20,000 cfs, although flows of 20,000 to 40,000 cfs coincided with several monitoring events in WY 2012 (Figure 8). Because of the continuing drought conditions, river flows in WY 2013 and WY 2014 generally were lower than in WY 2012, and reverse flows were relatively common in WY 2014 during high tides. Daily fluctuations in flow occurred in response to the twice-daily tidal cycles.

River stage and velocity generally tracked river flow because of the positive relationship between each of these parameters (i.e., as flows increase, stage and velocity also increase). River stage generally was between 2 and 4 feet, but ranged from about 1 foot at low tide when river flow was low to 10 feet when flows were high in response to storm events (Figure 9). Stage fluctuated daily for the same reasons discussed above for flow. River stage is hypothesized to have important implications for entrainment with respect to the depth at which the water intake facility’s fish screens are submerged. Higher river stage results in the fish screens being submerged at greater depths, potentially reducing the risk of entrainment for surface dwelling fish, and vice-versa (the top of the fish screen panels are at an elevation of -1.0 foot).

Mean daily river velocity generally was 1–2 fps in WY 2012 and WY 2013 (Figure 11; top and middle graph) and 1 fps or less in WY 2014 (Figure 11; bottom graph), except during periods when flows were elevated in response to storm events. Velocities fluctuated daily for the same reasons discussed above for flow and stage. Negative velocities (up to about -0.5 fps) occurred during reverse flows and were a frequent occurrence in WY 2014. River velocity can have important implications for entrainment with respect to sweeping velocities (i.e., velocities parallel to the screen face); higher river velocity results in higher sweeping velocity, which reduces the time fish are exposed to the fish screen as they are transported across the face of the fish screen.

Turbidity levels in the Sacramento River generally followed flow trends and occasionally exceeded 50 NTUs during periods of elevated flows (Figure 12). At relatively low flows, turbidity levels typically were below 15 NTU. Turbidity can have implications for entrainment; higher turbidities may increase entrainment risk by making the fish screen less visible to fish.

Across seasons and water years, minimum average water temperatures ranged from about 43°F in winter (December–January) to as much as 75–80°F by late May to mid-June (Figure 13). Daily fluctuations were minimal (about 1–2°F) and occurred primarily after late April. Water temperature influences the timing of migration and spawning and the suitability of habitats for fish in the Sacramento River.

Electrical conductivity is the amount of dissolved material in an aqueous solution. Low EC levels are indicative of freshwater. EC ranged from approximately 100–300 (μS/cm), and generally were higher and more variable in WY 2014 (Figure 14). EC levels generally followed the reverse of flow trends (i.e., as river flow increased, EC decreased). EC levels can have implications on delta and longfin smelt spawning, and, therefore, the occurrence of eggs and larvae in the river. Delta smelt are considered a semi-anadromous species and longfin smelt are considered an anadromous species, spawning in the freshwater reaches of the San Francisco Estuary and primarily in the Delta. Some spawning occurs in the Sacramento River each year by both species and the EC levels (fresh water) found during this study would support spawning by each species.

3.4.3 Freeport Water Intake Facility Operations

In WY 2012, the Freeport water intake facility typically operated intermittently on weekdays and ceased operations for the weekend from December through May. Instantaneous diversion were about 23 cfs (15 mgd) when the water intake facility was operating; however, pumping rates were often increased to as much as 93 cfs (60 mgd) for a few hours overnight to flush the pipeline of accumulated sediment (Figure 15; top graph). By early May, instantaneous diversion rates of about 35 cfs (23 mgd) occurred more frequently to meet increased water demand. By early June, demand for water required continuous pumping over the weekends, although pumping was intermittent during the weekdays (i.e., only at night). Instantaneous diversion rates were at 23 cfs (15 mgd) during impingement and predator monitoring, although the diversion rate was increased to 90 cfs (58 mgd) for the final 1.5 hours of impingement monitoring.

In WY 2013, the Freeport water intake facility began operating on January 8th; no pumping occurred in December or the first week of January. From early January through early April, the Freeport water intake facility typically operated continuously on weekdays and ceased operations for the weekend. By mid-April, demand for water required continuous pumping, including during the weekends. Typically, instantaneous diversion rates were about 20–25 cfs (13–16 mgd) when the water intake facility was operating (Figure 15; middle graph). Instantaneous diversion rates were at 46 cfs (30 mgd) during impingement and predator monitoring.

In WY 2014, pumping occurred in early December and then operations ceased on December 12th; operations resumed on March 11th and continued throughout the remainder of the entrainment monitoring period. The Freeport water intake facility typically operated continuously, except for intermittent operations in March, April, and May when reverse flows required that the water intake facility cease pumping temporarily (i.e., for several hours each of the days during reverse flows). From December through March, instantaneous diversion rates were about 17–23 cfs (11–15 mgd) when the water intake facility was operating (Figure 15; bottom graph). Beginning in early April, instantaneous diversion rates increased incrementally to 163 cfs (90 mgd) as EBMUD prepared to take its dry-year deliveries, which commenced on April 7. Instantaneous diversion rates peaked at 163 cfs (105 mgd) through mid-May and then were 120–132 cfs (78–85 mgd) throughout the remainder of the entrainment monitoring period. Instantaneous diversions rates were at 139 cfs (90 mgd) during impingement and predator monitoring, which is also when the hydraulic evaluation was conducted (ICF International 2015).

In WY 2012 and WY 2013, the proportion of Sacramento River flow diverted by the Freeport water intake facility typically was less than 0.5% (Figure 18; top and middle graphs). In WY 2014, the proportion of Sacramento River flow diverted by the Freeport water intake facility was higher and more variable than in WY 2012 and WY 2013 (Figure 18; bottom graph). The much larger percent diversions observed in WY 2014 were caused by the intermittent very low or negative hourly river flows (Figure 8; bottom graph) resulting from the combination of unseasonable low river levels caused by the drought and seasonable high tides, as well as the higher pumping rates.

3.4.4 Entrainment Monitoring

A combined total of 759 hours of sampling with the hoop net at the VSWTP and a combined total of 676 trap-hours of sampling with the floating larval light traps behind the fish screens at the Freeport water intake facility were conducted over the course of the WY 2012–2014 entrainment monitoring periods, resulting in the detection of a total of 15 species of fish (Table 37). Six of the fish species detected were native and nine were non-native. In addition to fish, numerous fish eggs were detected in the net. These eggs belonged to prickly sculpin, Sacramento sucker, and one or more unidentified Cyprinids.

The number of fish and species detected in the net was greater than the number detected in the larval light traps. Out of the 15 species of fish detected in the net, 8 of these species also were detected in the larval light traps (Table 37). However, at least three of the fish species detected in the net—lamprey ammocoete, white catfish, and Chinook salmon—were not likely to have entered the larval light traps at the time they were detected in the net because either they were too large to pass through the slot openings of the larval light traps at the time of their detection in the net or the species typically do not enter larval light traps. Therefore, it is estimated that the light traps were able to detect 8 of the 12 (67%) fish species in the net that were likely to be detected by both sampling methods.

The total number of fish that were detected in WY 2014 greatly exceeded the detection of fish in WY 2012 or WY 2013, even though less total volume of water was sampled by the net in WY 2014 (Table 37). The higher catch rate of fish in WY 2014 may be attributed to the higher pumping rates, lower river flows, higher percent of discharge diverted, higher rate of entrainment (e.g., lower sweeping velocities), and possibly other factors (e.g., higher fish abundance).

No delta smelt or longfin smelt were detected in the net or in the larval light traps during entrainment monitoring. The only species of management concern detected during entrainment monitoring were Sacramento splittail and a single pre-juvenile fall-run Chinook salmon. Across all monitoring years, prickly sculpin were the most abundant species detected in the net, followed by Sacramento splittail and bigscale logperch (Tables 11, 12, and 14). Prickly sculpin were also the most abundant species detected in the larval light traps, followed by Sacramento splittail, Sacramento sucker, and inland silverside (Tables 13 and 15).

In WY 2013 and WY 2014, an investigation was conducted to determine whether entrainment rates were correlated with any of the environmental variables. In WY 2013, there was limited support for any of the environmental variables (day/night, river velocity (feet per second), and proportion of discharge diverted) being appreciable predictors of entrainment rate for all fishes (Table 16), prickly sculpin (Table 17), or Sacramento splittail (Table 18). In WY 2014, there was limited support for the environmental variables (day/night, river velocity (feet per second), proportion of discharge diverted, and water temperature) being appreciable predictors of entrainment rate for prickly sculpin (Table 19), bigscale logperch (Table 20), or Sacramento splittail (Table 21).

Table 37. Summary of Fish Species Detected in the Hoop Net and Floating Larval Light Traps, WYs 2012–2014

	Hoop Net			Larval Light Traps[1]	
Species	WY 2012	WY 2013	WY 2014	WY 2013	WY 2014
Prickly sculpin* *Cottus asper*	x	x	x	x	x
Lamprey ammocoete* *Entosphenus/Lampetra* spp.	x	x	x		
Striped bass *Marone saxatilis*	x	x	x		
Sacramento splittail* *Pogonichthys macrolepidotus*	x	x	x	x	x
Sacramento sucker* *Catostomus occidentalis*	x	x	x	x	x
White catfish *Ameiurus catus*	x				
Common carp *Cyprinus carpio*	x	x	x		x
Threadfin shad *Dorosoma petenense*	x	x			
Chinook salmon* *Oncorhynchus tshawytscha*	x				
Bigscale logperch *Percina macrolepida*		x	x		x
Sacramento blackfish* *Orthodon microlepidotus*		x			
Wakasagi *Hypomesus nipponensis*		x			x
Largemouth bass *Micropterus salmoides*		x	x		x
Western mosquitofish *Gambusia affinis*		x			

	Hoop Net			Larval Light Traps[1]	
Species	WY 2012	WY 2013	WY 2014	WY 2013	WY 2014
Inland silverside *Menidia beryllina*			x		x
Unidentified smelt spp.			x		
Unknown spp.		x	x		x
Total Identified Species	9	12	9	3	8
Total Number of Fish Detected	113	435	58,716	41	652
Total Volume of Diverted Water Sampled by the Net (Mgal)	212.2	150	121		
Average Catch Rate of Larval Fish (number per 1 Mgal)	0.46	2.9	485	NA	NA

*= Native Species

NA = Not Applicable

[1] Larval light traps first used in WY 2013

3.4.5 Impingement Monitoring

A combined total of 48.75 hours of impingement monitoring with the DIDSON/ARIS sonar camera and 9 hours of diver observations were conducted over the course of the WY 2012–2014 impingement and predator monitoring periods (Tables 22–24).

In WY 2012, a total of 1,613 fish were observed passing between the DIDSON sonar camera and fish screen panel 1 during the 2 days impingement was monitored with the DIDSON sonar camera (Table 25). The average size of fish observed with the DIDSON sonar camera was 186 mm (range 30–800 mm) (Table 25). No incidences of fish impingement on fish screen panel 1 were observed during monitoring with the DIDSON sonar camera, although some fish were observed to change trajectory toward the fish screen, indicating that they were potentially influenced by the diversion. A total of seven fish appeared to change trajectory toward the fish screen and possibly be influenced by the diversion; however, none of them was smaller than 50 mm. No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–8 during any of the dive inspections. Of the seven fish observed to change trajectory toward the fish screen, only one (a 90-mm fish) appeared to come in contact with the fish screen; however, this behavior was in response to a pursuit by a larger fish (i.e., a possible failed predation event). One other fish appeared to change its trajectory toward the fish screen in response to a passing school of larger fish.

In WY 2013, a total of 942 fish were observed passing between the ARIS sonar camera and fish screen panel 11 during the 2 days impingement was monitored (Table 26). The average size of all fish observed with the ARIS sonar camera was 115 mm (range 23–583 mm) (Table 26). No incidences of fish impingement on fish screen panel 11 were observed during monitoring with the ARIS sonar camera, although one fish was observed to change trajectory toward the fish screen, indicating that it was potentially influenced by the diversion. This fish was 52 mm long and was traveling in the upstream direction on Day 1. No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–16 during the initial dive inspection on April 9 or during any of the repeated dive inspections of fish screen panels 9–16 on Day 1 or 2 of impingement monitoring.

In WY 2014, a total of 719 fish were observed passing between the ARIS sonar camera and fish screen panel 14 during the 2 days impingement was monitored (Table 27). The average size of all fish observed with the ARIS sonar camera was 117 mm (range 34–492 mm) (Table 27). No incidences of fish impingement on fish screen panel 14 were observed during the 16 hours of impingement monitoring with the ARIS sonar camera. No fish, fish larvae, or fish eggs were observed to be impinged on fish screen panels 1–16 during the initial dive inspection on April 8 or during any of the repeated dive inspections of fish screen panels 9–16 on Day 1 or 2 of impingement monitoring.

There was no significant debris accumulation on any of the screen panels, other than slight coating of fine algae growth on the upper 2–3 feet of the screen panels where the fish screen cleaner brushes were not making sufficient contact with the fish screen.

3.4.6 Predator Monitoring

A combined total of 10.9 hours of predator monitoring with the DIDSON/ARIS sonar camera was conducted over the course of the WY 2012–2014 monitoring periods (Table 29).

Predator-Size Fish

In WY 2012, a total of 48 predator-size fish (i.e., fish 12 inches long [305 mm long] and larger) were observed during predator monitoring with the DIDSON sonar camera (Table 30; Figures 39a–d). Overall, the average density (number per 1,000 feet of shoreline) of predator-size fish observed in the Facility Reach was intermediate to the Upstream and Downstream Control reaches (Table 31). Density of predator-size fish in the Facility Reach remained relatively high at night, compared with the other reaches (Table 30).

In WY 2013, a total of 214 predator-size fish were observed during predator monitoring with the ARIS sonar camera (Table 32; Figures 40a–d). Overall, the average density of predator-size fish observed was similar across reaches for all surveys combined (Table 31).

In WY 2014, a total of 450 predator-size fish were observed during predator monitoring with the ARIS sonar camera (Table 33; Figures 41a–d). Overall, the average density of predator-size fish observed was less in the Facility Reach than in the Upstream and Downstream Control reaches for all surveys combined (Table 31).

Prey-Size Fish

In WY 2013, a total of 277 prey-size fish (i.e., fish less than 12 inches long [305 mm long]) were observed during predator monitoring with the ARIS sonar camera (Table 34; Figures 42a–d). Overall, the average density of prey-size fish showed a decreasing trend across reaches (from downstream to upstream) for all surveys combined (Table 35).

In WY 2014, a total of 516 prey-size fish were observed during predator monitoring with the ARIS sonar camera (Table 36; Figures 43a–d). Overall, the average density of prey-size fish showed an increasing trend across reaches (from downstream to upstream) for all surveys combined (Table 35).

Observations of Fish during Drifting Survey of Backwater Eddy

In WY 2013, a total of 82 fish were observed while conducting the drifting survey for 12 minutes in the backwater eddy with the boat-mounted ARIS sonar camera. Fifty-nine of the fish ranged in size from 16 to 80 mm, 19 fish ranged in size from 102 to 157 mm, 2 fish ranged in size from 258 to 268 mm, and 2 fish ranged in size from 310 to 379 mm.

4.0 Discussion

WY 2014 monitoring represented the third time that entrainment, impingement, and predator monitoring were conducted for the Freeport water intake facility. Because WY 2014 monitoring concludes three years of monitoring, this section provides a comprehensive discussion of the monitoring results for all three monitoring years (WYs 2012–2014) so that the monitoring program can be assessed to determine whether monitoring requirements have been satisfied.

Unlike during previous monitoring years when the Freeport water intake facility was operated at less than 10% of total capacity, in WY 2014 the facility was operated at up to 163 cfs (105 mgd), or 57% of total capacity. However, for about 2 weeks in April when the facility was operated at 139 cfs (90 mgd), or about 49% total capacity, all three pumps were operated side-by-side in one forebay chamber to support the impingement monitoring and hydraulic evaluation studies being undertaken. Because the two forebay chambers were hydraulically isolated[13] from one another at this time, the facility was effectively operating at 85% of total capacity for the operating forebay chamber. The WY 2014 impingement and predator monitoring and two of the 12 entrainment monitoring events were conducted while the facility was effectively operating at 85% of total capacity for the operating forebay chamber.

The following sections provide more detailed interpretation of the entrainment, impingement, and predator monitoring results for WYs 2012–2014.

4.1 Entrainment Monitoring

The primary purposes of entrainment monitoring were to demonstrate the fish screen's effectiveness for minimizing entrainment of delta and longfin smelt and other listed species and to evaluate take of delta and longfin smelt. A secondary purpose of the monitoring was to provide data on life stages of other fish species passing through the fish screen.

The monitoring conducted in WYs 2012–2014 documented the entrainment of 113 young fish in the net at the VSWTP in WY 2012, 476 young fish (435 in the net at the VSWTP and 41 in the light traps in the forebay chambers) in WY 2013, and 59,368 young fish (58,716 in the net at the VSWTP and 652 in the larval light traps in the forebay chambers) in WY 2014 with Sacramento River flow diverted by the Freeport water intake facility. However, none of the fish detected in the net or in the light traps over the WY 2012–2014 entrainment monitoring periods was a federally listed or state listed species, including delta smelt, longfin smelt, winter- and spring-run Chinook salmon, and green sturgeon.

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[13] At river elevations of less than 10 feet, the two forebay chambers are not hydraulically connected, and act as separate forebay chambers to their respective pumps, effectively reducing the total capacity of the forebay chamber to 143.5 cfs (92.5 mgd). Therefore, water is drawn through only the 8 fish screen panels that are located directly in front of the operating forebay chamber when the two forebay chambers are hydraulically isolated from one another.

4.1.1 Delta and Longfin Smelt

Delta and longfin smelt are assumed to be vulnerable to entrainment by the Freeport water intake facility based on the following observations:

- Entrainment at other diversion facilities, ranging from large diversions (e.g., the state and federal water pumping facilities in the south Delta) to small agricultural irrigation diversions (e.g., Horseshoe Bend diversion facility on the lower Sacramento River; Nobriga et al. 2004).
- Entrainment of larvae of other fish species, including Wakasagi (Japanese pond smelt), by the water intake facility as documented by this monitoring.

The fact that no delta or longfin smelt were detected in the net at the VSWTP does not mean that they were not entrained by the water intake facility at other times. The lack of detection of delta and longfin smelt in the net at the VSWTP and in the floating larval light traps in the forebay chambers during entrainment monitoring may be explained by one or more factors.

One factor may have been a low abundance of larval smelt in the vicinity of the Freeport water intake facility during the entrainment monitoring periods. This is suggested by the relatively low abundance of adult delta smelt and longfin smelt in the catch by the USFWS trawl and beach seine surveys: a total of 90 adult delta smelt and one adult longfin smelt were detected by the USFWS trawl and beach seine surveys of the Sacramento River at Sherwood Harbor and Garcia Bend, respectively, during the WY 2012–2014 entrainment monitoring periods (Speegle pers. comm.).

Another factor may have been an absence of spawning. Although adult delta smelt and longfin smelt, many of which were in spawning condition, were detected by the USFWS trawls and beach seine surveys at that time that entrainment monitoring was being conducted, it is unknown whether delta smelt and longfin smelt spawned in the vicinity of the water intake facility and produced offspring during either of the three entrainment monitoring periods. Obviously, the absence of spawning would explain the lack of detecting smelt larvae in the net and the light traps. Although no juvenile delta smelt or longfin smelt were detected by the USFWS trawls or beach seine surveys over the course of the three entrainment monitoring periods, suggesting that spawning did not occur or juvenile abundance was very low, it is possible that young smelt may not be vulnerable to capture by the USFWS trawls and beach seines. In addition, because the USFWS does not identify and count fish smaller than 20 mm in length, any delta smelt or longfin smelt smaller than 20 mm that were captured by the USFWS trawl and beach seine surveys would not have been included in the catch count.

The large percentage of damaged and unidentifiable larvae in the WY 2014 samples also may have contributed to the lack of detecting larval delta smelt and longfin smelt in WY 2014, especially if the numbers of smelt in the samples were low. However, numerous larvae in the WY 2014 samples were intact and identifiable—6,305 individual larvae out of a total of 18,447 total larvae were sorted from the samples and identified to species—and if a significant number of smelt larvae were entrained it would stand to reason that a few larvae would have remained intact and identifiable, provided that smelt larvae are no more fragile than similarly sized larvae of other species that were intact and identifiable. In addition, it is likely that the species composition of the unknown larvae in the WY 2014 samples was similar to the species composition of the intact and identified larvae that were detected at the same time as the unknown larvae, although given the large number of larvae that were unknown it is possible that some of these could have been delta smelt and/or longfin smelt. The three smelt larvae detected in the April 9–10, 2014, net samples (Table 9) that could not be identified to species represent the only larvae detected in the net that were identified as smelt in WY 2014; two Wakasagi were detected one month later in the May 7–8, 2014, larval light samples (Table 10).

The detection of Wakasagi in the larval light traps in WY 2014 when no smelt larvae in the net were sufficiently intact to be able to be identified to species raises an important point about the use of the larval light traps in tandem with the net at the VSWTP. Because the larval light traps are a passive sampling technique and were placed in the forebay chambers in front of the pumps, larvae entering the light traps typically were undamaged or sufficiently intact that species identification was possible (although some larvae appeared to have been partially consumed or damaged by macroinvertebrates which also were drawn into the traps). In addition, the larval light traps appeared to detect at least 67% of the species that also were detected in the net at the VSWTP (after removing from consideration those species detected in the net that would not be expected to enter, or are excluded by, the light traps). It, therefore, stands to reason that had delta smelt or longfin smelt constituted a significant percentage of the unknown larvae detected in the WY 2014 net samples, the chances were good that their presence in the forebay chambers would have been detected by the larval light traps.

The final factor contributing to the absence of smelt detections during monitoring may have been insufficient sampling. The frequency, duration, or timing of monitoring may not have been sufficient to detect delta smelt or longfin smelt, particularly if abundance was low or their presence in the river or risk to entrainment was short-lived. However, either of these conditions would lead to a low smelt entrainment rate. It is also possible that smelt were missed as a result of the subsampling approach used to sort the WY 2014 net samples, particularly if smelt were rare. However, the methods used to subsample the WY 2014 net samples were developed to reduce bias associated with subsampling and should have been sufficient to detect smelt, particularly if they were not rare. If sampling were insufficient for any of the reasons mentioned above, entrained smelt may have gone undetected.

One factor that likely did not contribute to the absence of smelt detections during monitoring is sample processing. It is improbable that smelt larvae were missed during sorting of samples and subsamples because entrained delta and longfin smelt larvae would have been of a similar size and as readily observable in the samples as the other fish larvae that were detected during sample sorting. The use of Rose Bengal stain further ensured that any delta smelt or longfin smelt larvae that were present in the sample debris were visible to sorters. The detection of eggs and larvae as small as 1.1 and 2.5 mm, respectively, and Wakasagi larvae, a species related to delta smelt, provides further evidence that sorting methods were adequate to detect smelt eggs (about 1 mm in size) and larvae (minimum size approximately 5 mm) that may have been present in the samples.

Regardless of the reason for the absence of detections of delta smelt and longfin smelt in the net at the VSWTP and in the larval light traps in the forebay chambers, the entrainment monitoring results and the ancillary data suggest that the rate of entrainment of delta smelt and longfin smelt by the Freeport water intake facility is probably low.

4.1.2 Comparison of Entrainment Results across Monitoring Periods

The most notable difference in entrainment results between WY 2014 and the two previous monitoring periods is the large numbers of larvae that were detected in the net and in the light traps in WY 2014 despite less volume of water being sampled in WY 2014. When standardized for differences in the volume of water sampled across monitoring years, the average catch rate of larval fish per Mgal was 0.46 in WY 2012, 2.9 in WY 2013, and 485 in WY 2014.

The increase in the number of larval fish detected in WY 2014 is likely explained by the differences in facility operations between the monitoring years. In WY 2012 and WY 2013, the Freeport water intake facility typically was pumping 18–23 cfs (12–15 mgd) during the entrainment monitoring period. By comparison, in WY 2014 the Freeport water intake facility was pumping as much as 163 cfs (105 mgd). The higher diversion rate likely caused a higher proportion of larvae in the Sacramento River to be entrained. This is evident by the dramatic increase in the number of larvae estimated to be detected in the net starting with the April 9–10, 2014, monitoring event, the first monitoring event following the increase in pumping to 139 cfs (90 mgd) (Table 9). However, the observed increase in fish larvae is not likely to be entirely the result of increased pumping. For example, independent of facility operations, the daily entrainment of larvae by the water intake facility is also influenced by differences in the abundance of larvae in the river, environmental conditions (e.g., flow, turbidity, river velocity), and possibly other unknown factors. These differences may be responsible for the more moderate fluctuations in entrainment of larvae observed between the March 20–21 and March 26–27, 2014, monitoring events when pumping was relatively constant at around 18 cfs (11 mgd) and the total number of larvae detected in the net varied between 993 and 258, respectively (Table 9). Although other factors may explain an increase (or decrease) in entrainment of larvae, increased pumping is likely to be largely responsible for the increases observed in WY 2014.

Across all three entrainment monitoring periods, numbers of larvae detected in the net generally were low from December through mid-March, increasing or high beginning in late March and continuing through mid-May, and then decreasing or low from mid-May and into June and July (Tables 6, 7, and 9). This pattern is fairly consistent across monitoring years and, because the pattern was observed in monitoring periods when pumping rate throughout the monitoring period was relatively constant (e.g., WY 2012 and WY 2013), reflects the seasonal timing of larvae occurrence in the Sacramento River.

4.1.3 Correlation of Entrainment to Environmental Variables

Continuous water intake facility operations and the detection of substantial numbers of larval fish in WY 2013 and WY 2014 permitted investigation of a correlation between entrainment and environmental conditions. The limited support for any of the environmental variables tested (day/night, river velocity, proportion river discharge diverted, and water temperature) being appreciable predictors of entrainment rate for all fishes may be explained by the variability in the temporal occurrence of larvae in the river relative to the timing of sampling, incorrect estimates for the travel time of fish from the Sacramento River to the net at the VSWTP, insufficient numbers of entrained fish, a combination of these factors, or other factors. The anticipated faster travel times of fish from the Sacramento River to the net at the VSWTP during periods of high pumping rates (e.g., 90 mgd and higher) in WY 2014 were expected to increase the accuracy of determining the travel time between when fish pass through the slot openings in the fish screen and when fish enter the net at the VSWTP and strengthen any correlations between entrainment and environmental conditions. While it is expected that travel times in the pipeline at these higher pumping rates are likely to be accurate, it is also likely that the substantial forebay area between the fish screens and the pumps may delay the travel of fish across the forebay and to the pumps by an unknown and variable amount, thereby resulting in incorrect estimates of travel time for fish from the Sacramento River to the net at the VSWTP. Correlating entrainment to environmental variables is probably more suited for situations where sampling is conducted immediately behind the fish screens.

4.1.4 Effectiveness of Fish Screens

Susceptibility of fish to entrainment with water diverted by the Freeport water intake facility, and the eventual detection of fish in the net at VSWTP and in the larval light traps in the forebay chambers, is a function of a number of interrelated factors, including:

- Occurrence of individuals in the Sacramento River.
- Proximity of individuals to the water intake facility (e.g., nearshore versus offshore).
- Size of the hydraulic zone of influence of the diversion, which is a function of PDD (as PDD increases, the size of the hydraulic zone of influence increases).
- Approach and sweeping velocities.
- Size and configuration of the fish screen openings.
- Fish body dimensions.
- Fish swimming ability and behavior.
- Environmental conditions (e.g., turbidity).

While each one of these factors is an important determinant of entrainment, an in-depth discussion of all factors is beyond the scope of this report. However, because fish body dimension and the size and configuration of the fish screen openings play a clear role in entrainment; these two factors are discussed further here.

The size at which a larval or juvenile fish is entrained (passes through the screen) is a function of the size (length, body depth, or head width) of the fish and the size of the screen slot opening (Turnpenny 1981; Margraf et al. 1985; Young et al. 1997). The analysis of the effectiveness of the Freeport water intake facility's fish screens to exclude fish from entrainment is based on the 1.75-mm smooth vertical profile bar screen used at the intake facility. The minimum size (standard length) of each fish species that would be excluded can be estimated based on the equation originally formulated by Turnpenny (1981), as rearranged by Margraf et al. (1985) and presented by Young et al. (1997) (Figure 44):

Eq. 1 $SL = (0.06564 \times M + 1.199 \times M \times F)/(1 - 0.0209 \times M)$

Where SL = standard length (mm), M = screen mesh size, F = fineness ratio (i.e., standard length/head width [HW] or body depth [BD]).

Calculation of Fineness Ratios

Fineness ratios were calculated for larvae of six fish species that have potential to be entrained by the water intake facility. Although body depth is generally larger than head width in most fishes, head width was assumed to be more appropriate than body depth for calculating the fineness ratio (SL/HW) for Chinook salmon, delta smelt, and prickly sculpin because of the vertical orientation of the fish screen openings at the Freeport water intake facility. However, it was decided that body depth was more appropriate to develop fineness ratios for Sacramento splittail, striped bass, and

Sacramento sucker because of the lack of published head widths for these species and their generally smaller head width relative to body depth.

In the absence of published head widths for larval and juvenile Sacramento splittail and specimens with a broad size range from which to take measurements, fineness ratios were developed by taking body depth and length measurements from high-resolution color photographs from Wang and Reyes (2007). Similarly, to develop fineness ratios for larval and juvenile striped bass and Sacramento sucker, measurements of body depth and length were made from high-resolution color photographs from Wang (2010). The fineness ratio for Chinook salmon was based on standard lengths and head widths provided by Mueller et al. (1995). The fineness ratio for prickly sculpin was developed based on measurements from 12 preserved specimens collected during entrainment monitoring.

For Delta smelt, fineness ratios were calculated from Young et al. (1997), using the following formula relating head width to standard length:

Eq. 2 $$\textit{Head width}\ (\text{mm}) = -3.724 + (0.392 \times SL) - (0.006 \times SL^2) + (0.00004 \times SL^3),$$

where SL = standard length (mm).

The developed fineness ratios for a 20 mm-size fish for each species are presented in Table 38.

Table 38. Calculated Fineness Ratios for Select Larval Fish Species (20 mm) at Risk of Entrainment by the Freeport Water Intake Facility Compared with the Size Ranges of Larvae Detected in the Net and Light Traps during WY 2012–2014 Entrainment Monitoring

Species	Fineness Ratio (Standard Length/Body Depth or Head Width)	Body Metric Used for Fineness Ratio	Minimum Size Excluded (mm, SL)[1]	Size Range (mm, Total Length) Detected in the Net and Light Traps in WY 2013
Chinook salmon	8.7	Head width	19.3	32
Delta smelt	10.0	Head width	21.9	NA
Sacramento splittail	9.1	Body width	19.9	5.0–22.6[2]
Striped bass	5.3	Body width	11.7	2.5–5.6
Prickly sculpin	5.0	Head width	11.0	3.3–21.0[3]
Sacramento sucker	6.4	Body width	14.1	9.3–19.0

NA = Not applicable (i.e., species not detected in net at the VSWTP or in larval light traps in forebay chambers).

[1] From Equation 1 (Figure 44).

[2] Second largest was 16.5 mm (Figure 20).

[3] All but 5 were less than 10 mm (Figure 24).

Based on the calculated fineness ratios, delta smelt are at a higher risk of entrainment (with the largest minimum size excluded [21.9 mm]) than the other five species evaluated (Table 38). By contrast, prickly sculpin are the least at risk of entrainment (smallest minimize size excluded at 11.0 mm).

The 32-mm-long (fork length) juvenile Chinook salmon that was detected in the net should, theoretically, have been excluded by the fish screen because of its standard length of 27.5 mm, head width of 3.6 mm, and body width of 3.8 mm. However, individuals larger than the size of the fish screen openings may pass through the fish screen if they become impinged on the fish screen and, during the process of trying to free themselves, change their orientation and are pulled through the fish screen openings by the current passing through the slot openings of the fish screen. Alternatively, fish that exceed the minimize size criteria for exclusion and that are impinged on the fish screen may pass through the fish screen if they are pushed through by the screen cleaner brushes.

All but one of the Sacramento splittail detected by the entrainment monitoring were smaller than the calculated minimum size that should be excluded by the 1.75mm openings of the fish screen (Table 38, Figure 20). The 22.6 mm splittail detected in the larval light trap in WY 2014 was much larger than the next largest (16.5 mm) splittail detected, and may have reared (and grew) for an indeterminate time in the forebay chamber before being detected in the larval light trap. The 16.5 mm splittail, together with the detection of 11 other splittail in the 12 to 16 mm size range over the course of the 3 years of entrainment monitoring (Figure 20), may indicate that the true minimum exclusion size is actually closer to 16 mm, rather than the calculated minimum exclusion size of 19.9 mm (Table 38). However, it is also unclear whether these splittail in the 12 to 16 mm size range passed through the fish screen at the size they were when they were detected in the net and in the light traps, or whether they had passed through the fish screen at a smaller size a few weeks prior and fed and grew prior to being detected. In the case of the latter, their size at the time of their detection in the net and in the light traps would not represent the maximum size that is vulnerable to entrainment.

All striped bass detected during the WY 2012–2014 entrainment monitoring periods were smaller than the calculated minimum size that should be excluded by the 1.75mm openings of the fish screen (Table 38). However, larval striped bass were not very abundant in the catch and those detected in the net and measured may not reflect the true size range of striped bass larvae vulnerable to entrainment.

Some prickly sculpin and Sacramento sucker detected during the WY 2012–2014 entrainment monitoring were larger than the calculated minimum size that should be excluded by the 1.75 mm openings of the fish screen based on the developed fineness ratios (Table 38). The detection of these larger individuals in the net and in the larval light traps may indicate that the calculated fineness ratios and/or minimum exclusion sizes are incorrect for these species or that these individuals spent a period of time in the forebay chambers feeding and growing prior to being detected in the net and in the larval light traps, as discussed earlier for Sacramento splittail.

The detection of prickly sculpin, Sacramento sucker eggs, and Cyprinid eggs in the net at VSWTP suggests that fish eggs are entrained with water diverted by the Freeport water intake facility. However, some of the prickly sculpin eggs detected in the net may have originated from within the forebay chambers. Adult prickly sculpin were detected in the net during the WY 2012 and 2014 entrainment monitoring periods and, given their ability to lay eggs on the undersides of submerged objects in the forebay chambers, may have spawned within the forebay chambers and been the source of the prickly sculpin eggs detected in the net. The detection of prickly sculpin eggs in the net during WY 2013, however, supports the conclusion that some prickly sculpin eggs may pass through the slot openings in the fish screen (i.e., they originated from the Sacramento River). In WY 2013, no adult prickly sculpin were detected in the net at the VSWTP and their absence was likely the result of the forebay chambers having been dewatered in late 2012 for maintenance purposes, which presumably removed all fish in the forebay chambers (including adult prickly sculpin). It is also likely that the Sacramento sucker eggs detected in the net during WY 2013 and WY 2014 originated in the Sacramento River because of the lack of spawning habitat in the forebay chambers and the presumed absence of adult suckers in the forebay chambers, based on their absence in the entrainment samples.

4.1.5 Effectiveness of Floating Larval Light Traps to Detect Entrained Fish

The primary purpose of using floating larval light traps was to determine whether the species being detected in the net at the VSWTP are representative of the species being entrained. Advantages of using the larval light traps included having a secondary means for detecting entrained species and, because the light traps were located ahead of the pumps and pipeline, having a higher rate of intact individuals in the catch that could be identified (some larvae were found partially consumed or damaged, presumably by captured macro-invertebrates, and not identifiable).

The results presented here demonstrate that the floating larval light traps were effective at capturing fish larvae in the forebay chambers, although not all species detected in the net at the VSWTP were detected by the light traps over the three entrainment monitoring periods. When considering that not all fish species and sizes enter light traps (e.g., white catfish, Chinook salmon, and lamprey), it is estimated that the light traps were able to detect eight of the 12 (67%) fish species that were likely to be detected by both sampling methods (Table 37). In addition, if the two species that were detected in the net only once (i.e., Sacramento blackfish and Western mosquitofish) (Table 37) are ignored, the effectiveness of the larval light traps increases to 80% (i.e., eight of the 10 fish with multiple detections in the net were detected by the light traps). However, the ability of the net to detect species with presumably low abundance (e.g., Sacramento blackfish and Western mosquitofish) is also one of the advantages of using the net. It is interesting to note that, in WY 2014, lamprey and striped bass were the only species detected in the net that were not also detected in the light traps, while Wakasagi were the only species detected in the light trap samples that were not also detected in the net (perhaps a result of smelt being more fragile and, therefore, more likely to be damaged by the sleeve valve , as discussed above for delta smelt and longfin smelt) (Table 37). If the lamprey that were detected in the net and the Wakasagi that were detected in the light traps are removed from consideration, light trap detections relative to detections in the net in WY 2014 improve to seven of the eight (88%) species detected in the net.

The higher species detection rate for the light traps in WY 2014 than in WY 2013 is likely a result of the increased effort in WY 2014 and the use of an improved light source. As recommended in the WY 2013 final annual report (ICF International 2013), the number of light traps was increased to four, the duration was increased to up to 12 hours, and a new light source that better illuminated the traps and for longer duration without diminishment was used.

The generally lower species detection rate for the light traps compared with the net could be a reflection of some of the observed biases of light traps, including being selective toward a particular taxonomic group (Marchetti and Moyle 2000). Lower species detection by the light traps could also have been caused by placement of the light traps in areas of the forebay chambers where species densities favored one species over another as a result of differences in velocity in the forebay chamber or the proximity of the light traps to underwater structure or equipment (e.g., the sediment removal system) that differentially repelled or attracted species.

Overall, the relative abundance of species detected in the light traps was similar to the net. Prickly sculpin was the most numerous species detected in both the net and in the traps, while bigscale logperch, Sacramento splittail, and inland silverside were among the top six most abundant species for both methods.

4.1.6 Problems Encountered

Frequent communication between VSWTP operators and the lead fish biologist in WY 2014 prevented incidences of the net tearing as it had in WY 2012 and WY 2013. One unexpected, but avoidable, problem in WY 2014 was the broken slide gate on the second to last monitoring event. The lesson learned was that routine inspections of not only the net but also the equipment used to raise and lower the net are needed to ensure trouble-free operation. Overall, these equipment breakdowns had minimal effect on entrainment monitoring results because equipment was fixed before the next scheduled monitoring event. In addition, FRWA conducted 12 monitoring events each year despite the water intake facility being idle on two occasions in WY 2013 (in December 2012) and WY 2014 (in January and February 2014), thereby offsetting, in part, these temporary equipment breakdowns.

4.2 Impingement and Predator Monitoring

WY 2014 monitoring represented the third time that monitoring of impingement and predator abundance were conducted for the Freeport water intake facility. It also represented the second time that monitoring with an ARIS sonar camera and monitoring of prey abundance in the vicinity of the water intake facility were conducted.

In contrast to WY 2012 and WY 2013 impingement and predator monitoring when the Freeport water intake facility was operated at 15 mgd and 30 mgd, respectively, WY 2014 impingement and predator monitoring were conducted with the water intake facility diverting 90 mgd through a single forebay chamber. This diversion rate was effectively 85% of design capacity for the forebay chamber.

The following sections provide more detailed interpretation of the impingement and predator monitoring results for WYs 2012–2014.

4.2.1 Impingement Monitoring

The primary purpose of impingement monitoring was to determine whether fish are being impinged on the face of the fish screen. Secondary purposes of impingement monitoring were to provide general information on fish occurrence, size, and behavior in the vicinity of the fish screen.

Fish may take several possible pathways when encountering a screened water diversion like the Freeport water intake facility. Fish that are physically small enough to fit through the 1.75-mm openings of the fish screen may pass directly through the fish screen without making contact with the screen, while fish that are about the same size or slightly larger than the openings may temporarily become impinged on the fish screen until they are pulled through by the current of the diverted flow. Fish that are too large to pass or be pulled through the fish screen openings may become impinged on the fish screen temporarily (if they can eventually escape the pull of water) or permanently (where they die if they cannot free themselves from the fish screen). Finally, some fish may have incidental contact with the fish screen as they swim upstream or downstream past the facility. While the fate of fish that pass through the fish screen or become permanently impinged on the fish screen and die is known, the fate of those fish that are only temporarily impinged or that make incidental contact with the fish screen as they pass the facility is unknown. All of the impingement events described above were the focus of monitoring with the DIDSON/ARIS sonar camera and diver observations.

No fish were observed by the divers or with the DIDSON/ARIS sonar camera to be impinged on the fish screen during WYs 2012–2014. Although impinged fish were not observed, it is assumed that some fish are impinged when the water intake facility is diverting water. This assumption is based on the fact that entrainment monitoring has confirmed that the larvae of many fish species pass through the fish screen when water is being diverted by the water intake facility. Consequently, some of these fish, such as the 32-mm-long juvenile Chinook salmon detected in the net at the VSWTP on January 30, 2012, or the 41-mm lamprey ammocoete that was detected in the net at the VSWTP on April 11, 2013, may become temporarily impinged on the fish screen or make incidental contact with the fish screen before they pass or are pulled through the fish screen openings.

Approach velocities too low to impinge fish, limited field of view with the DIDSON/ARIS sonar camera, limitations associated with the sonar camera, and poor underwater visibility during the dive surveys may explain why no fish were observed to be impinged on the fish screens. Even though the Freeport water intake facility was diverting three and six times the flow in WY 2014 that was monitored during WY 2013 and WY 2012, respectively, the average approach velocity in front of the fish screens would have been 0.16 fps[14], which is below the water intake facility's maximum design approach velocity of 0.2 fps. The hydraulic evaluation conducted just days after the impingement monitoring in WY 2014 confirmed that approach velocities matched the design approach velocities for the flow that was being diverted (ICF International 2015). Low approach velocities, in combination with the occurrence of measured positive sweeping velocities (Figure 31) may have contributed to the apparent lack of impinged fish.

Limited field of view of the fish screen panel being monitored likely reduced the chances of observing an impingement event. The estimated area of the fish screen panel viewable with the DIDSON/ARIS sonar camera was 31.5 sf in WY 2012, 26 sf in WY 2013, and 24 sf in WY 2014, and represented 29%, 24%, and 22%, respectively, of the entire area of the fish screen panel being monitored. The slightly less area of the fish screen that was viewable with the ARIS sonar camera during WY 2013 and WY 2014 monitoring was the result of placing the higher resolution ARIS sonar camera closer to the fish screen panel in an attempt to observe the behavior of fish smaller than 30 mm (30 mm was the smallest fish that could be confidently identified with the DIDSON sonar camera during WY 2012 monitoring). Although the ARIS sonar camera offered improved resolution compared with the DIDSON sonar camera, its effectiveness may have been offset, at least partially, by the reduced viewing area associated with moving the ARIS sonar camera closer to the fish screen.

Despite the improved resolution of the ARIS sonar camera, targets smaller than 23 mm (the smallest target observed with the ARIS sonar camera and confirmed as a fish during impingement

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[14] Based on the calculation: 139 cfs (90 mgd)/850 sf (diversion rate in cfs divided by total screen area for the forebay).

monitoring) were not reliably identified as fish using the ARIS sonar camera. These small fish are the fish most vulnerable to impingement because of their weaker swimming ability. Therefore, the absence of observed fish impingement may have been the result of DIDSON and ARIS sonar camera capability rather than absence of fish impingement. For example, fish smaller than the minimum size observed with the sonar cameras (i.e., 30 mm for DIDSON and 23 mm for ARIS) simply may not have exhibited behaviors (e.g., tail movement, swimming motion) that permitted the observers who processed the DIDSON/ARIS results to identify targets as a fish as the targets passed through the beams of the DIDSON and ARIS sonar cameras. As discussed below, the minimum fish size observed during a drifting survey of the backwater eddy was 16 mm; therefore, it is assumed that the ARIS sonar camera was capable of observing fish as small as 16 mm passing between the ARIS sonar camera and the fish screen during impingement monitoring (provided that the fish exhibited behavior that distinguished it from debris).

Out of all the fish observed passing the respective fish screen panels during WY 2012–2014 impingement monitoring, only eight fish appeared to change trajectory toward the fish screen. While the change in trajectory by these fish appeared to suggest that they were influenced by the diversion, none of these fish became impinged on the fish screen and none of them was smaller than 50 mm. The low approach velocities and the swimming capability of fish that are larger than 50 mm (some were swimming upstream against the current) suggest that fish behavior, rather than the effects of the diversion, may have been responsible for the observed change in trajectory toward the fish screen undertaken by these fish.

4.2.2 Predator Monitoring

The primary purpose of predator monitoring was to evaluate whether the water intake facility and fish screen may be concentrating predators, increasing predator activity, concentrating prey, or causing prey species to become disoriented. Unlike for the DIDSON sonar camera, the improved video resolution of the ARIS sonar camera permitted the simultaneous observations of predator-size and prey-size fish during each predator monitoring survey. The following sections provide an interpretation of the WY 2012–2014 predator monitoring results.

Predator-Size Fish

The results of WY 2012–2014 predator monitoring are difficult to interpret and no clear trend emerged over the 3 years of monitoring. In WY 2012, comparatively high densities of predator-size fish were observed in the Facility Reach during the night surveys, suggesting that the water intake facility may be creating habitat for predators at night. In WY 2013, the increasing trend in density of predator-size fish across surveys that was observed in the Facility Reach suggested a potential preference by predators for the Facility Reach as the day progressed, In WY 2014, the average density of predator-size fish observed was less in the Facility Reach for all surveys combined. With respect to the WY 2012 observations, nighttime lighting does not appear to be a factor in the occurrence of predator-size fish in the Facility Reach because the structure has minimal lighting at night. While it appears that these fish may be attracted to the cover provided by the physical structure of the facility (e.g., the log boom and log boom piles), there doesn't appear to be a consistent trend, day or night, in predator abundance associated with the water intake facility or its operation. In addition, the distribution and density trends of predator-size fish did not appear to follow any obvious distribution or density patterns of prey-size species (Table 39).

Table 39. Average Density of Predator-Size and Prey-Size Fish Observed by Survey Reach during Predator Monitoring Using a Mobile ARIS Sonar Camera, WYs 2013–2014

Survey Reach	Reach Length (Feet)	Average Density of Predator-Size Fish (Number Observed per 1,000 Feet per survey)	Average Density of Prey-Sized Fish (Number Observed per 1,000 Feet per survey)
WY 2013			
Downstream Control	2,281	10.1	15.0
Facility	1,295	9.5	13.1
Upstream Control	1,744	10.5	10.3
WY 2014			
Downstream Control	2,281	18.7	13.0
Facility	1,295	14.3	22.8
Upstream Control	1,744	29.4	40.0

Notes:
Prey-size fish were not detectable with the DIDSON sonar camera in WY 2012.
Average density is calculated as (total number of fish observed/reach length/4 surveys x 1,000 feet)

The increasing trend in total number of predator-size fish observed during predator monitoring during WYs 2012–2014 may reflect the annual variability in the abundance of predator-size fish in the Sacramento River, the concentration of fish as a result of declining river volumes in response to the ongoing drought conditions, a combination of factors, or other unknown factors. The higher numbers of predator-size fish observed in WY 2013 and WY 2014 than in WYU 2012 during predator monitoring is likely attributable to the superior quality of the sonar images with the ARIS sonar camera. In WY 2012, more fish were observed passing between the DIDSON sonar camera and the fish screen during impingement monitoring than were observed in either WY 2013 or WY 2014, yet more predator-size fish were observed from the boat with the ARIS sonar camera during WY 2013 and WY 2014 predator monitoring than were observed from the boat with the DIDSON sonar camera during WY 2012 impingement monitoring, when fish abundance was presumably greater.

Prey-Size Fish

The only obvious trend in prey-size fish that is evident from the WY 2013 and WY 2014 predator monitoring is that the average density of prey-size fish increased across survey reaches from downstream to upstream in WY 2013 and from upstream to downstream in WY 2014 (Table 39). The intermediate average densities of prey-size fish in the Facility Reach observed during the predator surveys supports the conclusion that the water intake facility and its operation are not concentrating prey-size fish. However, the results of the WY 2013 drifting survey in the low velocity area coupled with the visual observations of numerous juvenile Chinook salmon feeding in this low velocity area indicates that this localized area appears to be concentrating prey-size fish. The low velocity area is a large backwater eddy that occurs immediately downstream of the water intake facility as a result of the structure's encroachment into the river (Figure 7). Based on the drifting survey conducted with the ARIS sonar camera, most fish observed in the low velocity area were less than 80 mm long, which is consistent with the size of the juvenile Chinook salmon that were observed feeding in this area. Interestingly, only two of the 82 fish that were observed in this low velocity area with the ARIS sonar camera were predator-size (i.e., greater than 305 mm). As discussed above for predator-size fish, there appeared to be no obvious relationship between the density patterns of predator-size fish and the density patterns of prey-size species (Table 39).

4.2.3 General Fish Observations

Two general observations can be made about the fish observed with the DIDSON and ARIS sonar cameras during the WY 2012–2014 impingement monitoring: in all years, most fish were observed moving upstream past the fish screen during daylight, and many of these fish did so while in schools consisting of several to 45 individuals.

Unlike those observed with the DIDSON sonar camera in WY 2012, few fish larger than 200 mm were observed with the ARIS sonar camera during WY 2013 and WY 2014 monitoring. In WY 2012, many of the larger fish in the 220–590 mm size range were presumed to be striped bass, Sacramento pikeminnow, and American shad making their way upstream to spawn. The general absence of these larger individuals in the WY 2013 and WY 2014 observations likely reflects the earlier timing of the impingement monitoring in WY 2013 and WY 2014 (early April in WY 2013 and WY 2014, and late April in WY 2012) relative to the general migration timing of these species.

4.2.4 Suitability of Using the ARIS Sonar Camera for Impingement and Predator Monitoring

The ARIS sonar camera was an effective tool for observing and counting fish that were in proximity to the fish screen. It also appeared to be an effective tool for observing and counting predator-size and prey-size fish during mobile surveys of the river. The ARIS sonar camera imaging was superior to the DIDSON sonar camera imaging. The image qualities of the ARIS sonar camera permitted observing smaller fish and likely more fish during impingement and predator monitoring than was possible with the DIDSON sonar camera. During impingement and predator monitoring, fish smaller than 30 mm were observed with the ARIS sonar camera; the minimum size observed with the ARIS sonar camera during the drifting survey was 16 mm. This was an improvement over the DIDSON sonar camera, which could only be used to identify targets larger than 30 mm. The ARIS sonar camera also permitted simultaneous observation of predator-size and prey-size fish during the mobile surveys (the DIDSON sonar camera required that the settings be chosen to maximize observing either predatory-size or prey-size species, but not both).

5.0 Conclusions

The biological monitoring program successfully monitored the Freeport water intake facility over a 3-year period (WYs 2012–2014). In addition to assessing fish entrainment and impingement, the program monitored predator and prey abundance in the vicinity of the water intake facility. The monitoring was conducted under a wide range of environmental conditions, including low river flow conditions, and under a range of facility operations.

The monitoring demonstrated that the fish screens have performed as designed to minimize fish entrainment losses for listed species—specifically, delta smelt, longfin smelt, winter- and spring-run Chinook salmon, steelhead, and green sturgeon—as well as other native and introduced species. The monitoring also has demonstrated that impingement of fish is probably a rare event, and the results are consistent with what is to be expected given the facility's low design approach velocities, which were designed specifically to protect delta smelt and other listed species. The hydraulic evaluation conducted concurrently with this monitoring program during April 2014, under the same environmental conditions and facility operations, confirmed that approach velocities in front of the facility's fish screens were consistent with the facility's design approach velocities. Lastly, the monitoring demonstrated that the water intake structure and facility operations do not appear to concentrate predator-size or prey-size fish in the vicinity of the Freeport water intake facility.

It is with these results in mind that FRWA believes that the intent of the biological opinion's requirement for the monitoring program has been met, and recommends that the monitoring program be discontinued.

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6.2 Personal Communications

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Meier, Dan. Program manager. U.S. Fish and Wildlife Service, Anadromous Fish Screen Program, Sacramento, CA. October 21, 2008—telephone conversation. June 8, 2009—meeting and site tour at Freeport water intake. July 2, 2009—email to Jeff Kozlowski, ICF Jones & Stokes. July 10, 2009—meeting at ICF Jones & Stokes with Jeff Kozlowski and Bill Mitchell.

Pasterski, Tom. Water Treatment Plant Manager 1. Sacramento County Water Agency. July 28, 2014—email and attached Excel file to Jeff Kozlowski, ICF International, regarding flow readings entering the Vineyard Surface Water Treatment Plant.

Speegle, Jonathan. Data Manager. U. S. Fish and Wildlife Service, Lodi Field Office. December 4, 2012–June 30, 2014—emails containing weekly reports to Jeff Kozlowski, ICF International, regarding USFWS trawl and beach seine survey results. Data on file.

Wang, Johnson C. S. Fish Taxonomist. Private Consultant. September 16, 2013—data sheets to Jeff Kozlowski, ICF International, regarding identification of fish larvae and eggs in entrainment samples. January 14, 2015—fish egg identification results for WY 2014 entrainment samples. Data on File.

Figures

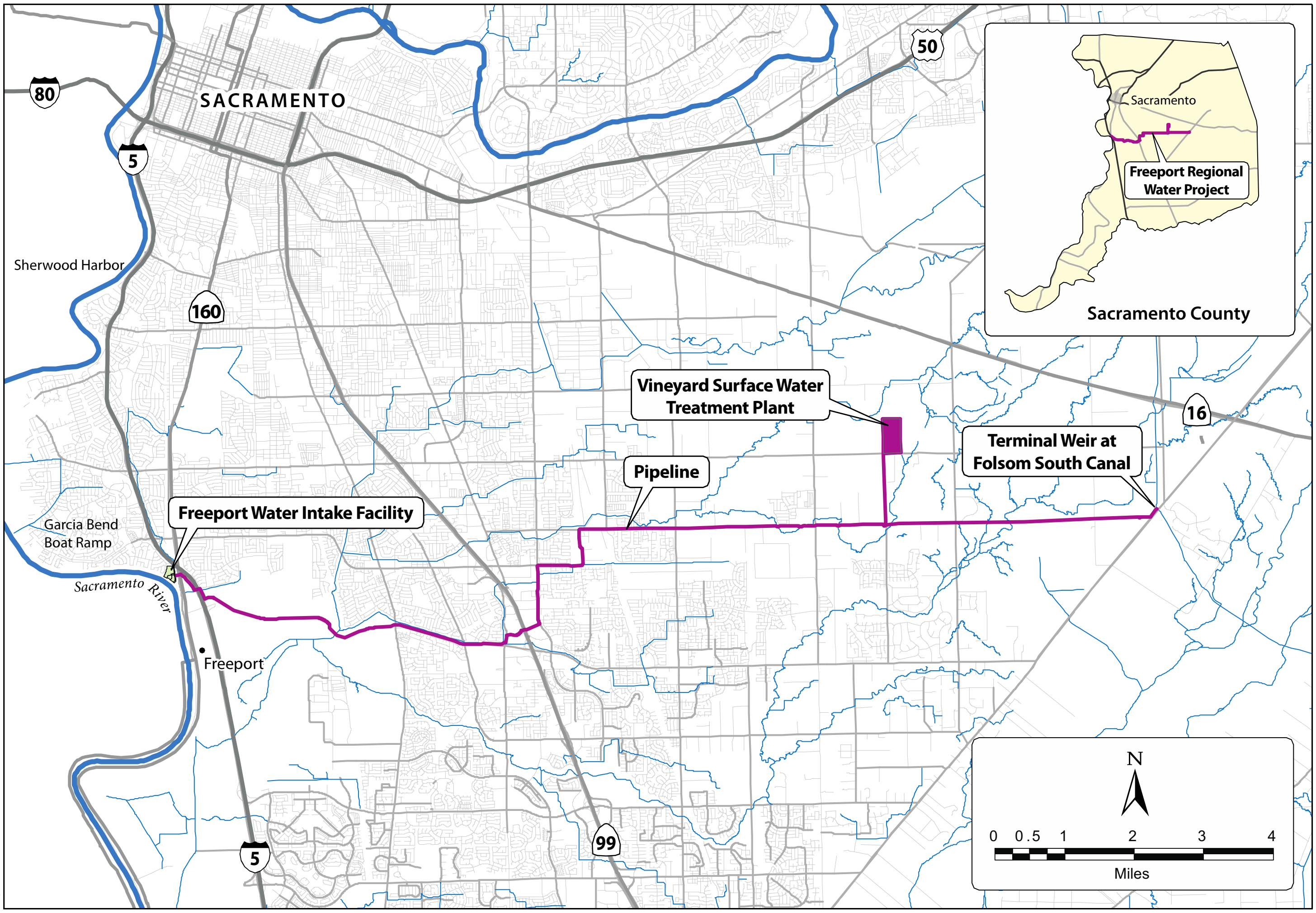

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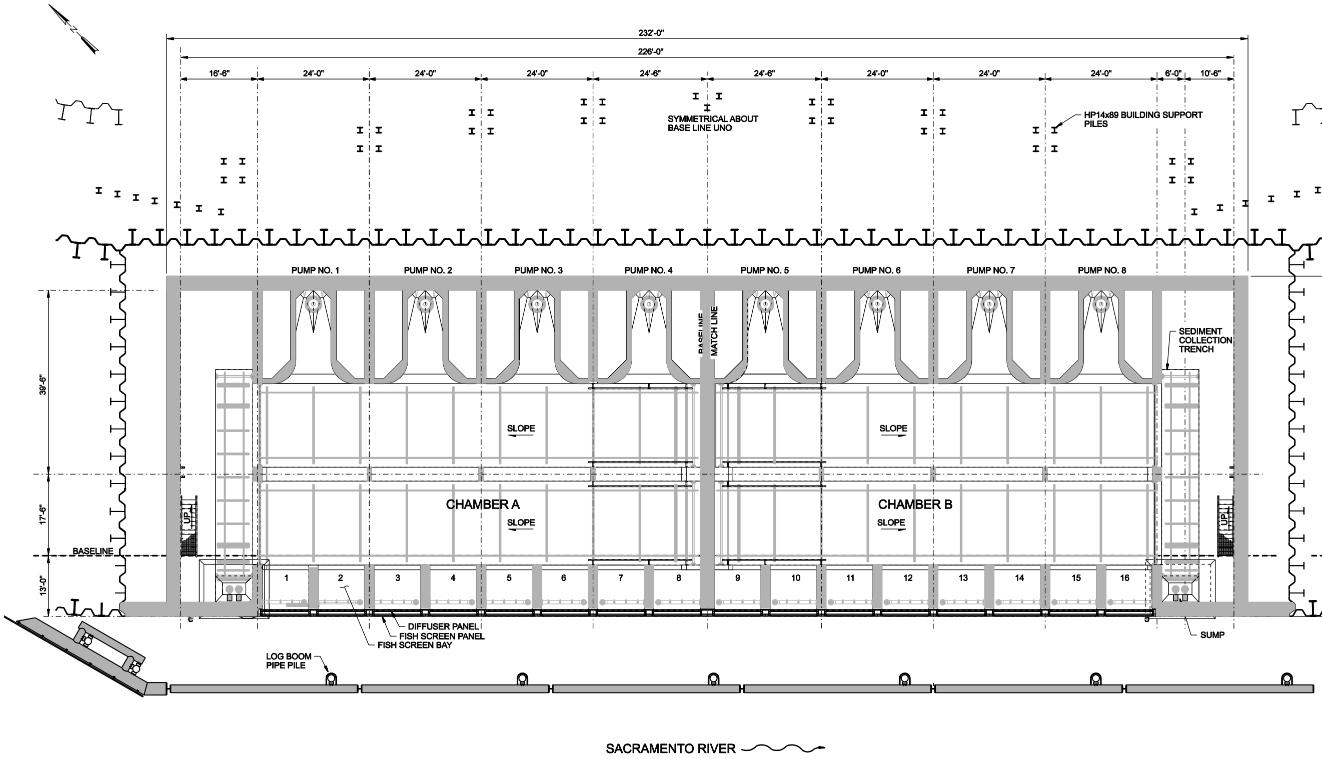
Figure 1
Freeport Water Intake Facility and
Vineyard Surface Water Treatment Plant Location



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Source: CH2MHill, 6-29-06.

Figure 2
Plan View of Freeport Water Intake Facility

Figure 3. Two Types of Floating Larval Light Traps Used at the Freeport Water Intake Facility

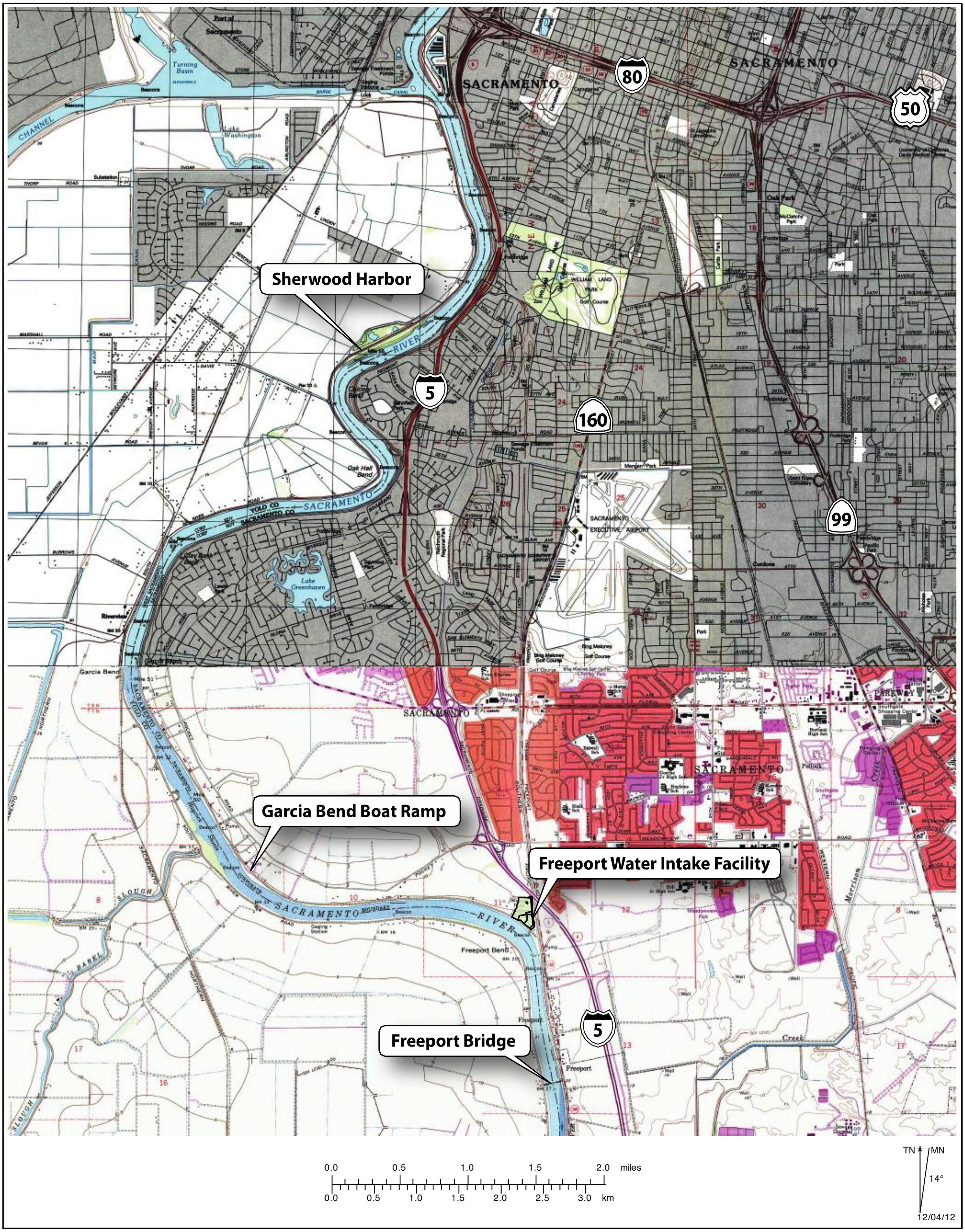

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Figure 4
Location of Garcia Bend Boat Ramp, Sherwood Harbor, and the Freeport Water Intake Facility on the Sacramento River

Figure 5. DIDSON/ARIS Pole Mount Attached to Fish Screen Cleaner Assembly

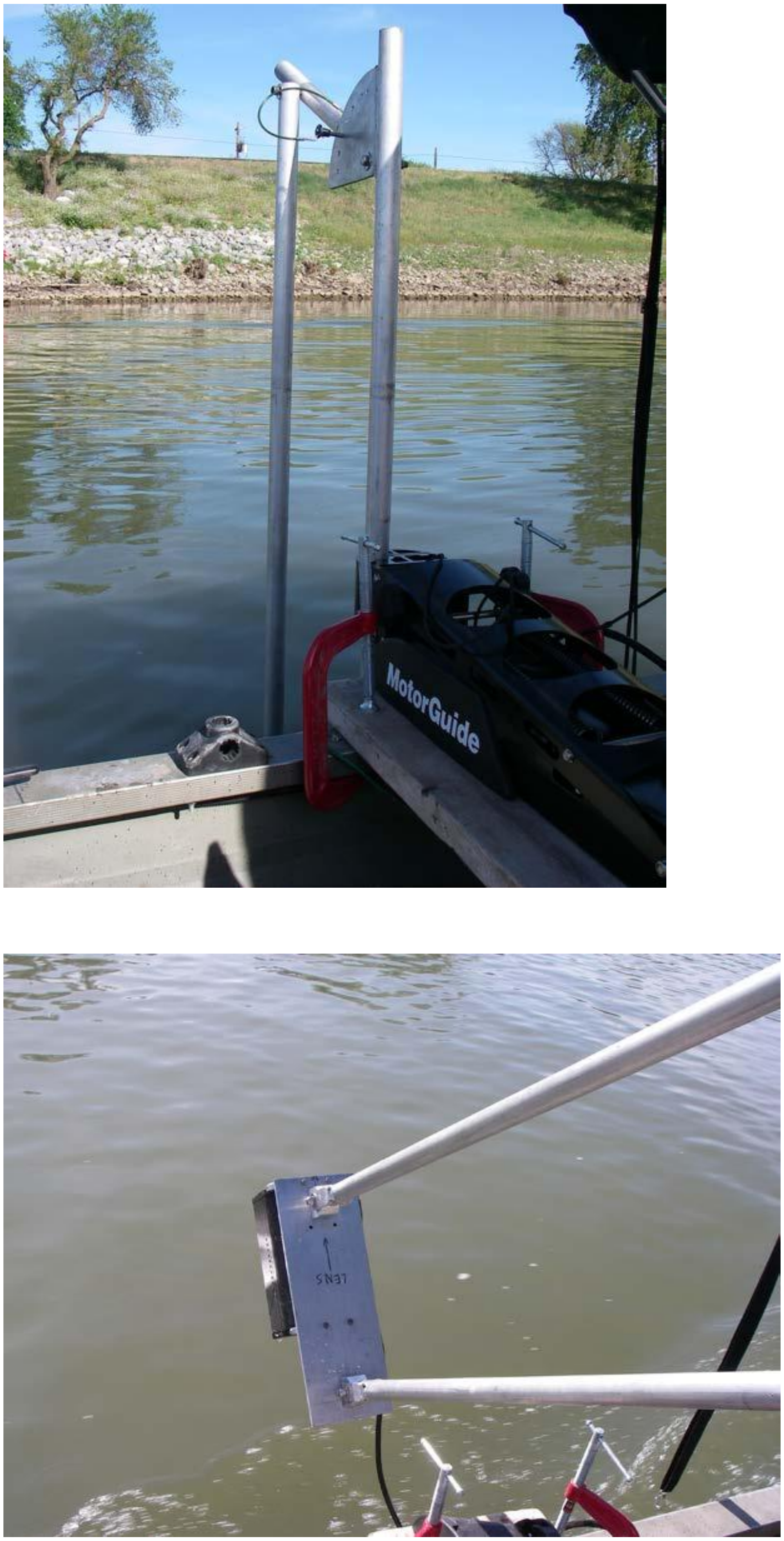
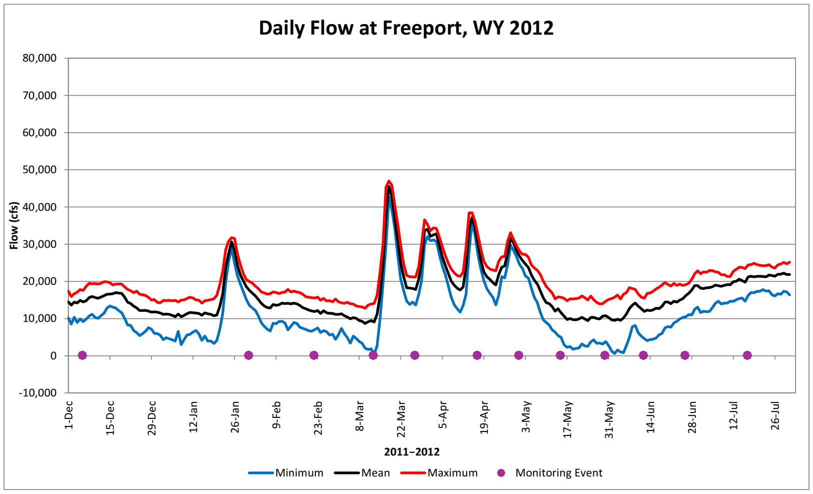


Figure 6. Pole Mount for Mobile Surveys using DIDSON/ARIS Sonar Camera

Figure 7

Figure 7. Location of Reaches Surveyed during Predator Monitoring Using a Mobile DIDSON/ARIS Sonar Camera



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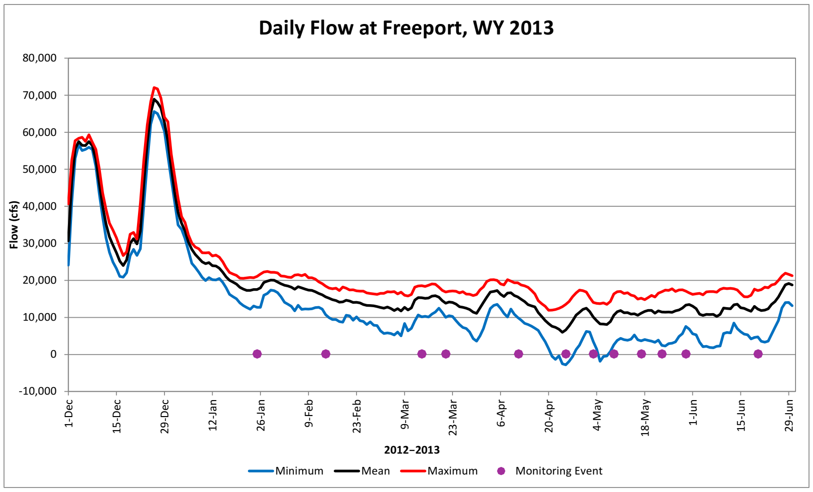

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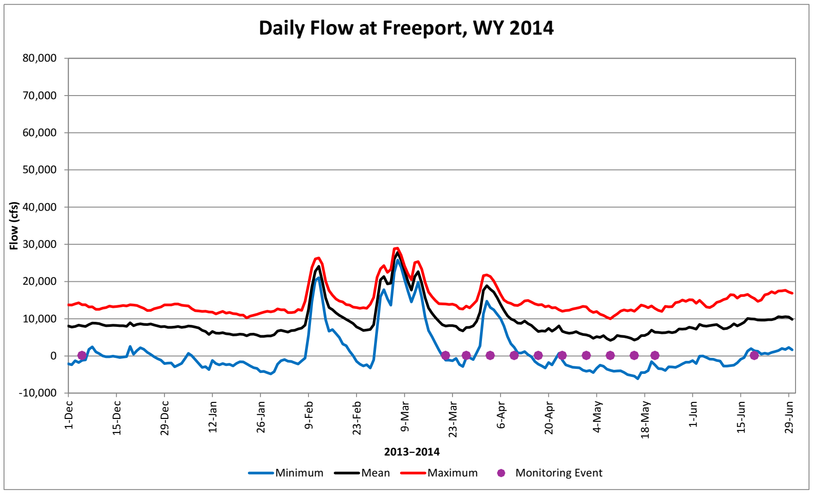
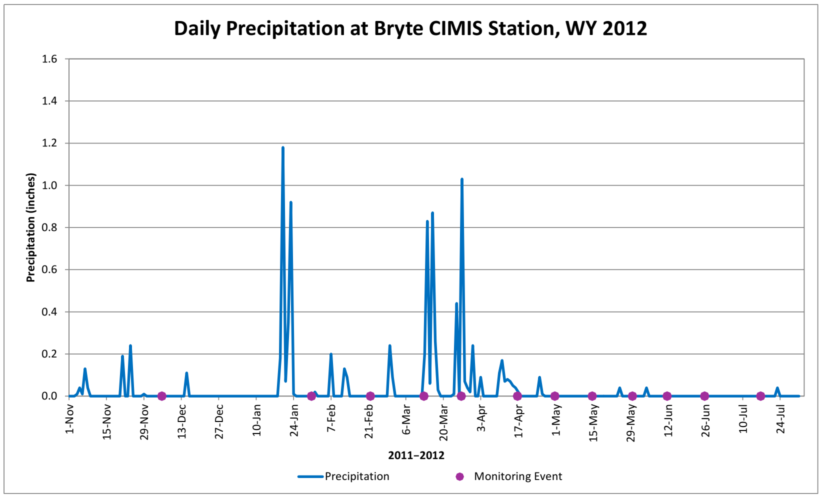
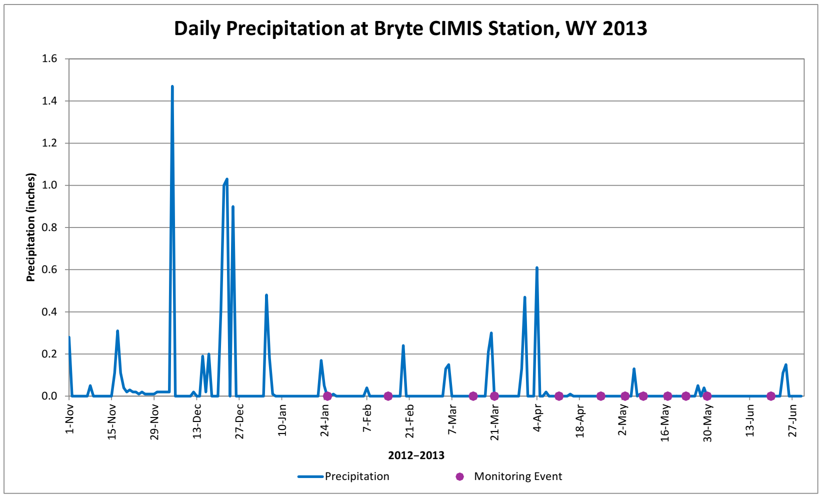


Source: California Data Exchange Center 2014.

Figure 8. Maximum, Minimum, and Mean Daily Sacramento River Flows at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



Source: California Irrigation Management Information System 2012.



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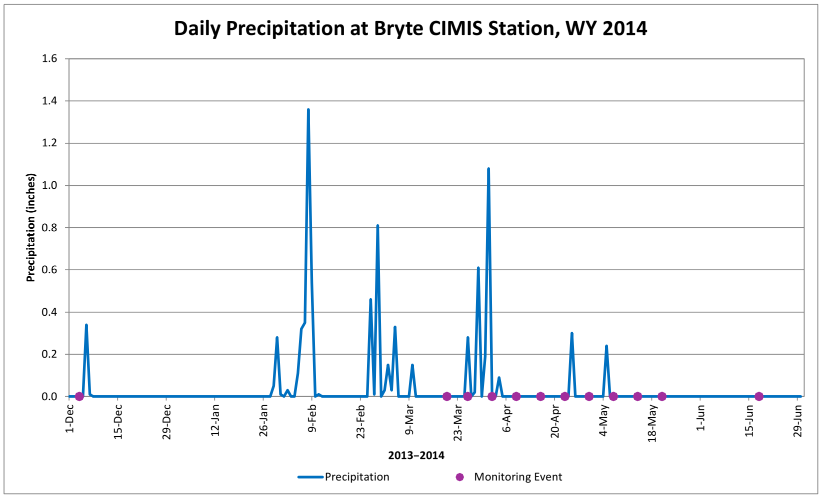
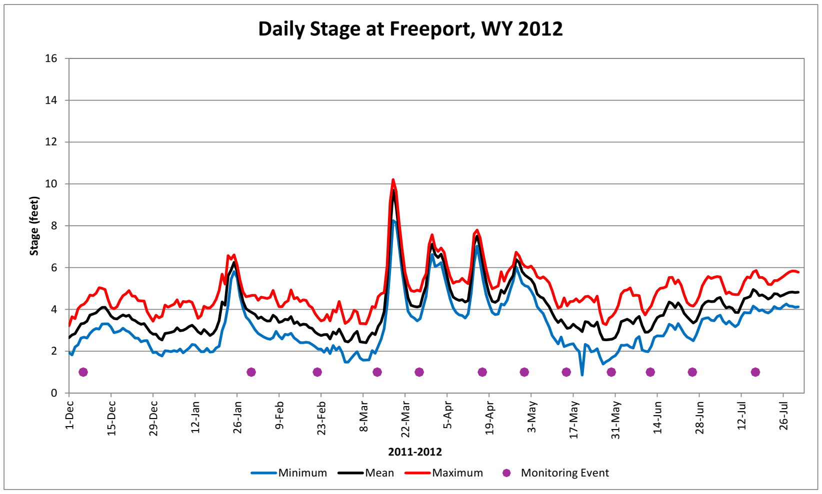


Source: California Irrigation Management Information System 2014.

Figure 9. Daily Precipitation for the Sacramento Region as Measured at the Bryte CIMIS Station, near West Sacramento, California, during the Entrainment Monitoring Period, WYs 2012–2014



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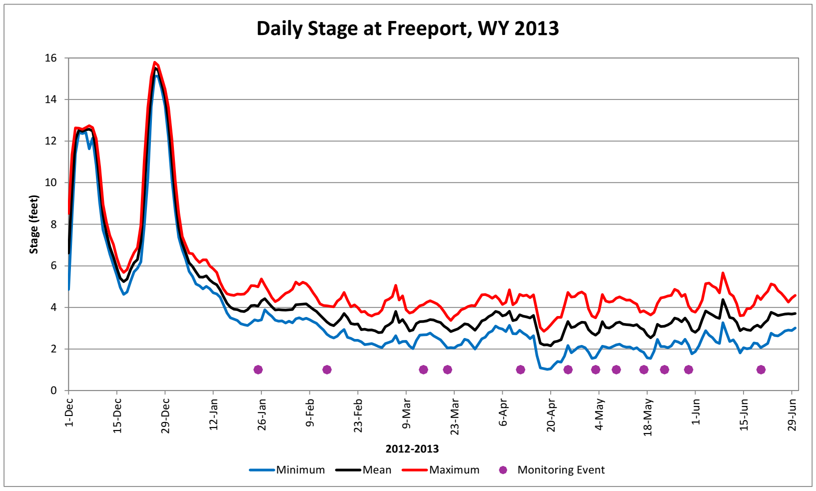

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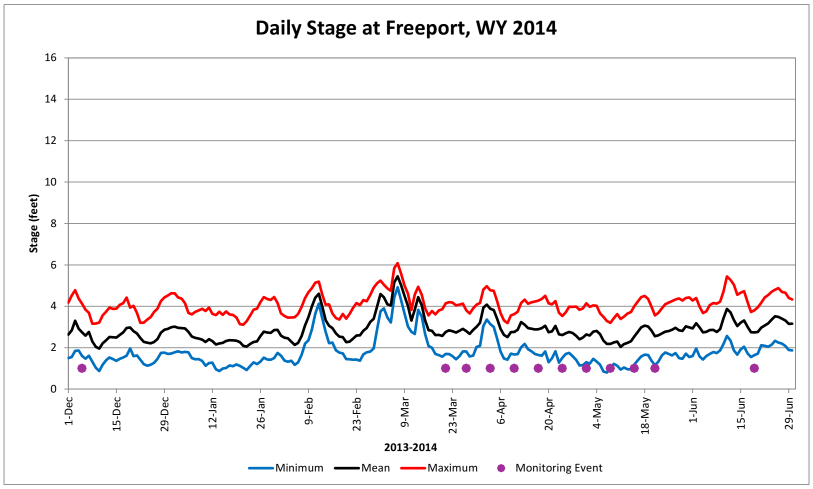
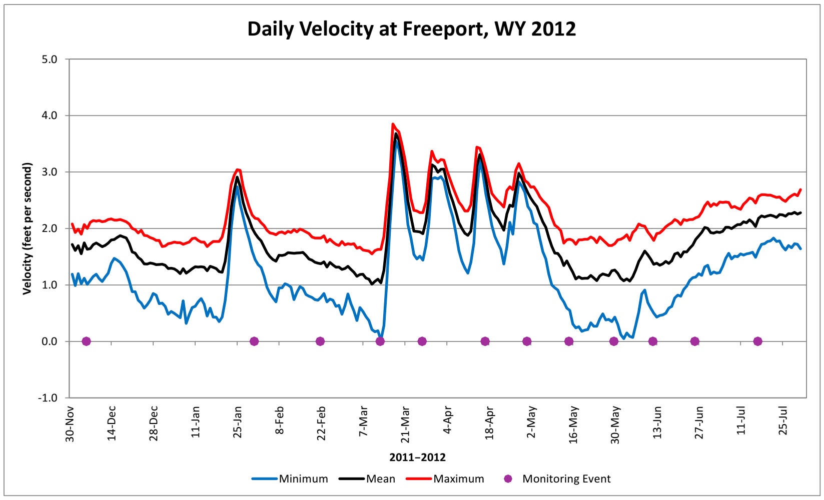


Source: California Data Exchange Center 2014.

Figure 10. Maximum, Minimum, and Mean Daily Sacramento River Stage at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



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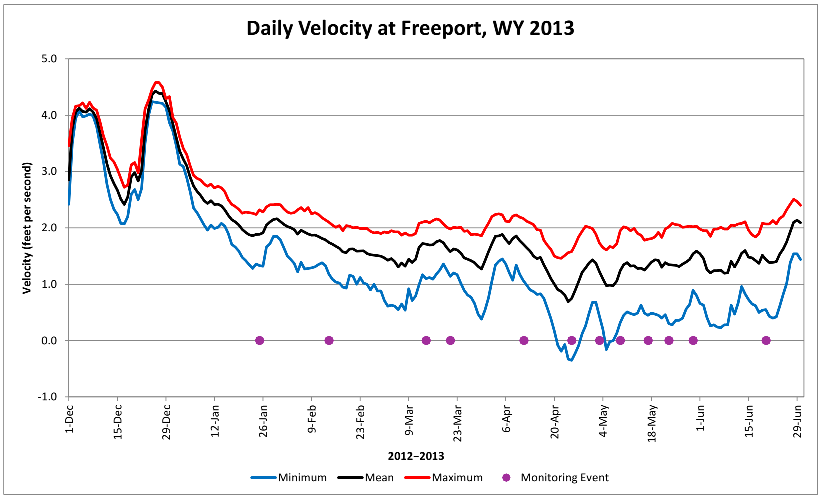

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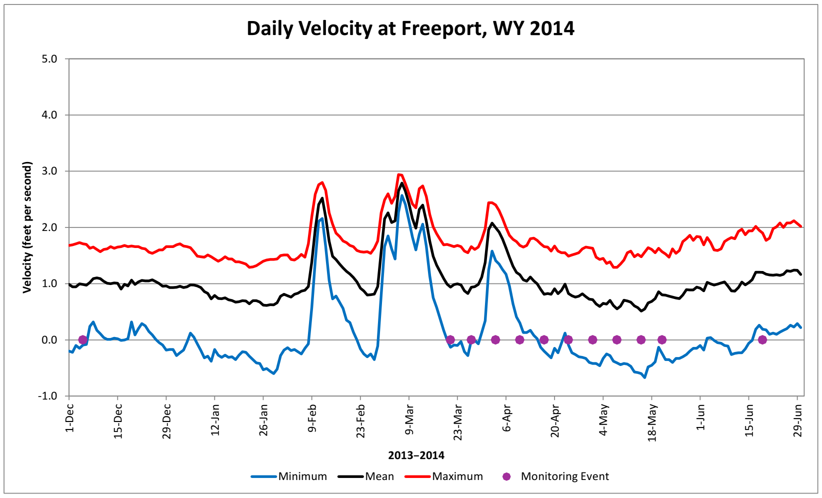
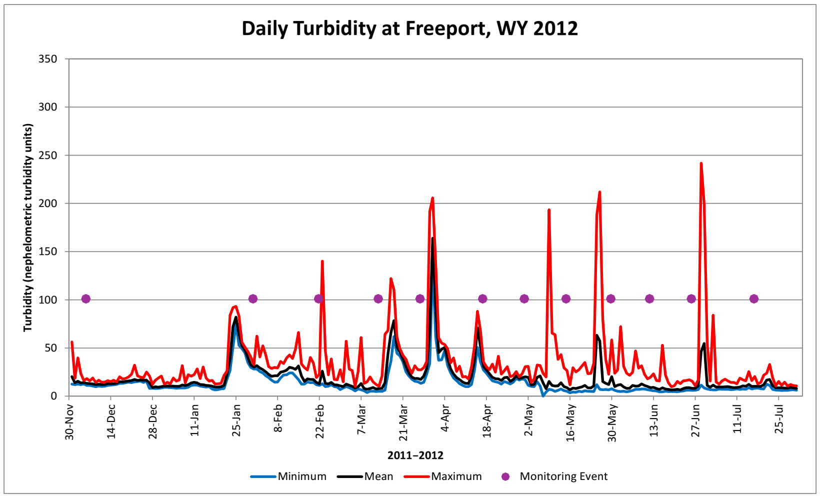


Source: California Data Exchange Center 2014.

Figure 11. Maximum, Minimum, and Mean Daily Sacramento River Velocity at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



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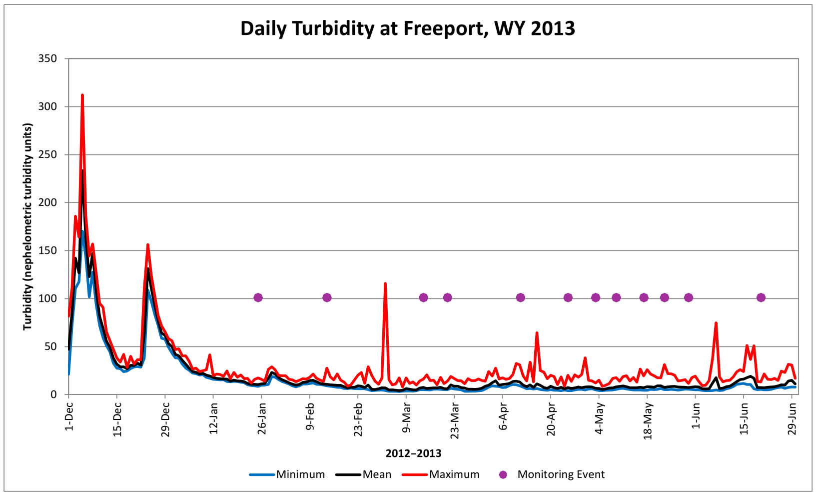

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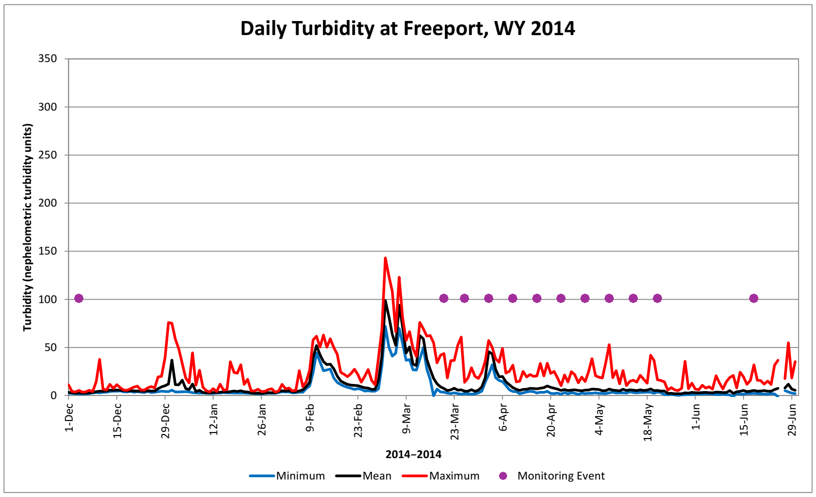
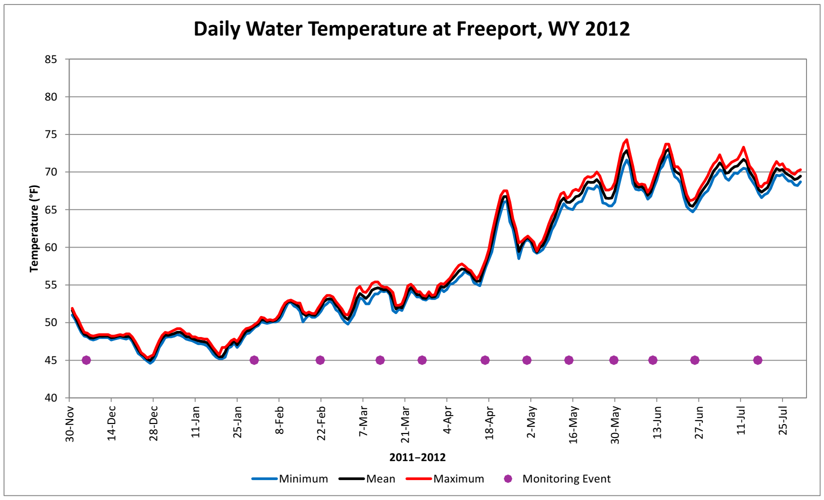


Source: California Data Exchange Center 2014.

Figure 12. Maximum, Minimum, and Mean Daily Sacramento River Turbidity at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



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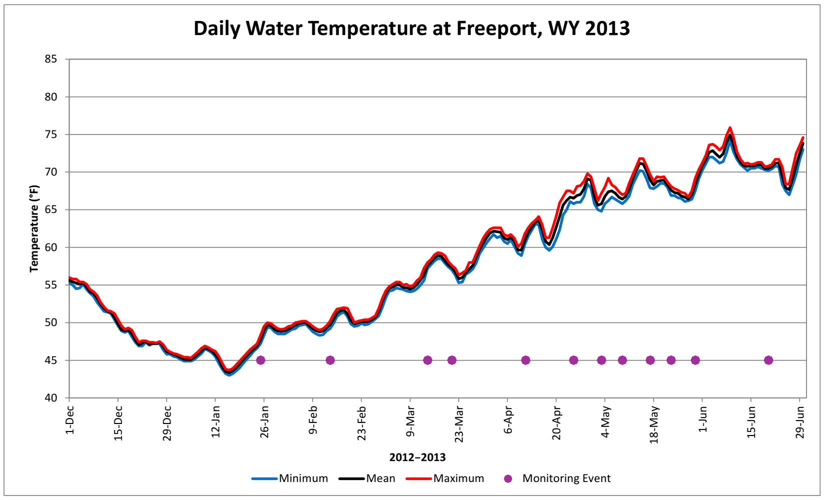

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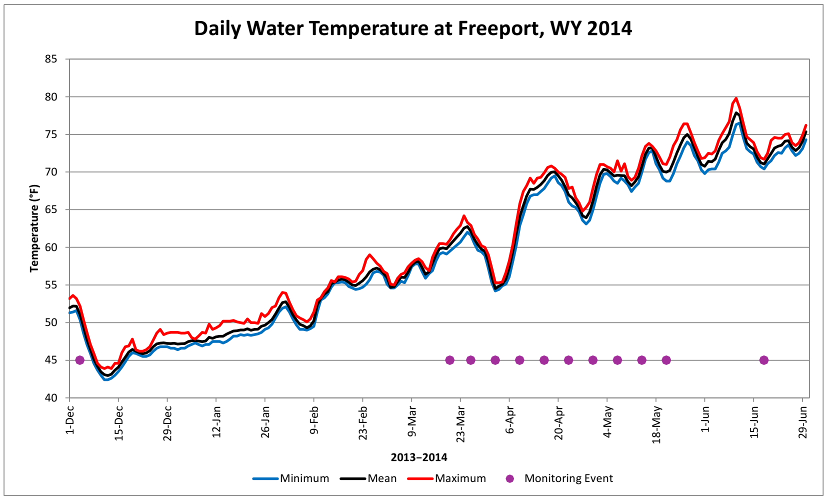
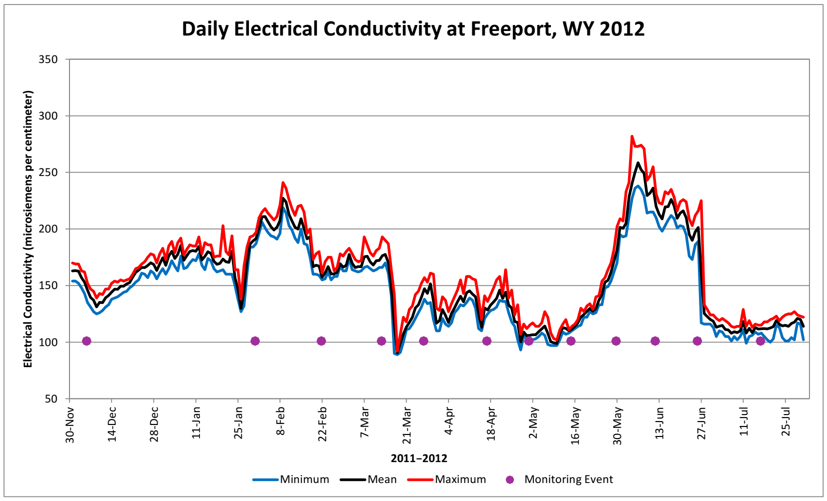


Source: California Data Exchange Center 2014.

Figure 13. Maximum, Minimum, and Mean Daily Sacramento River Water Temperature at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



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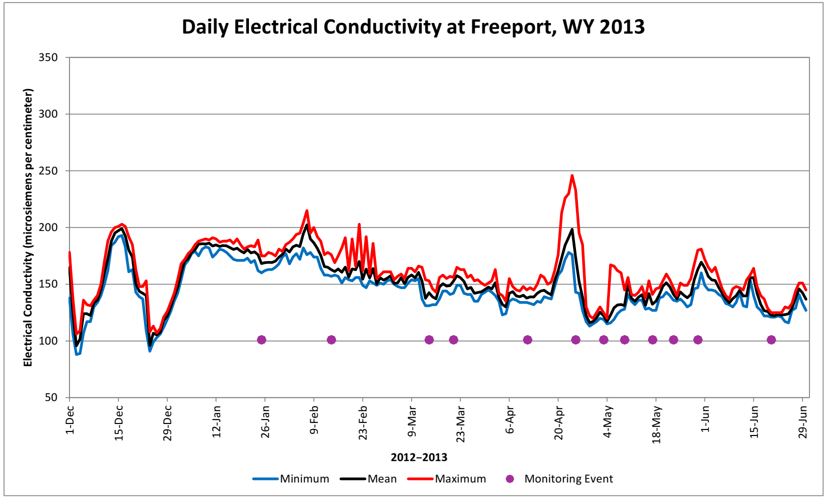

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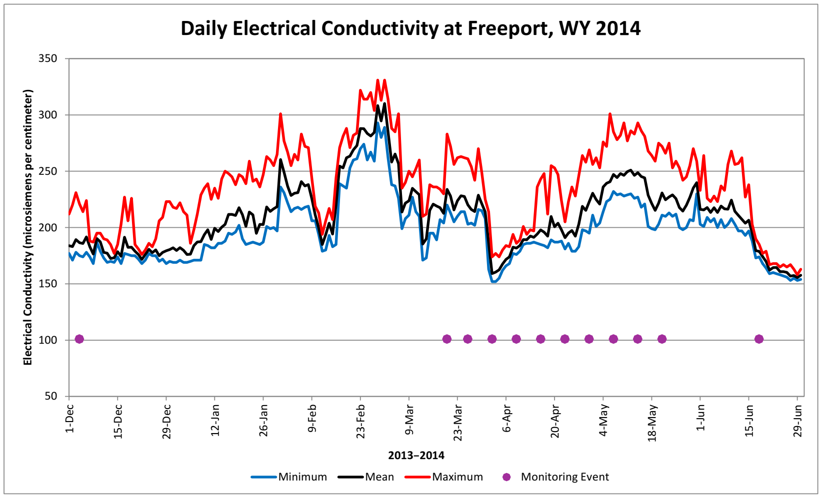
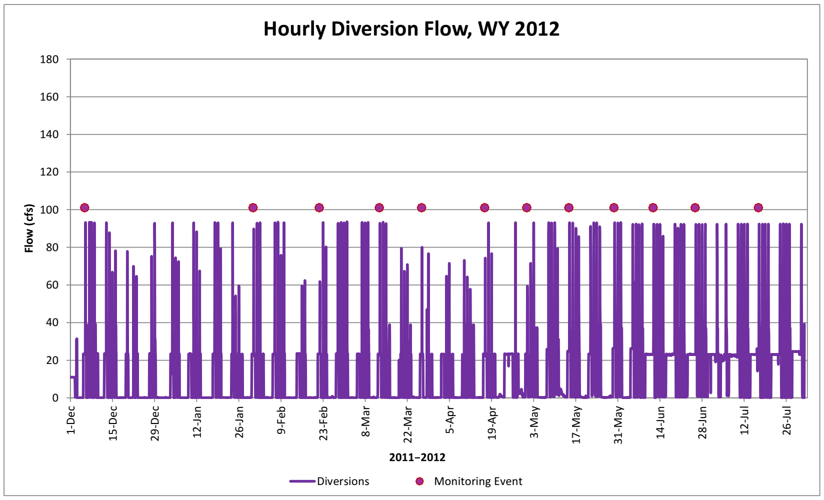
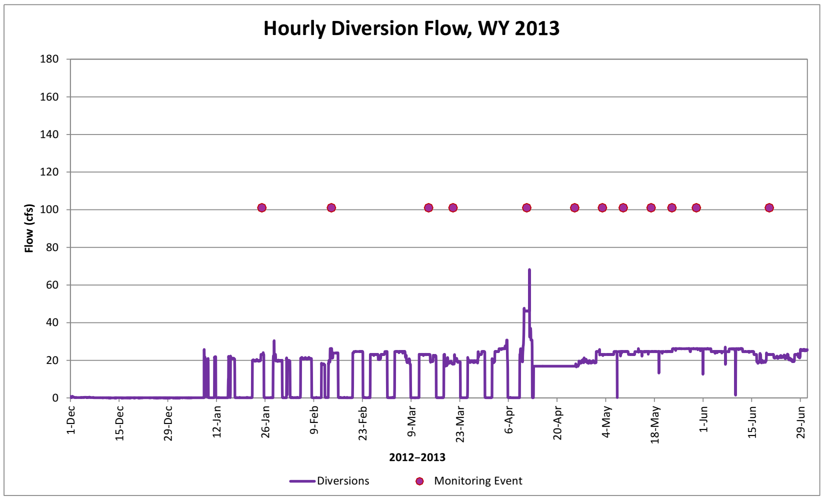


Source: California Data Exchange Center 2014.

Figure 14. Maximum, Minimum, and Mean Daily Sacramento River Electrical Conductivity at Freeport during the Entrainment Monitoring Period, WYs 2012–2014



Source: Houston pers. comm.



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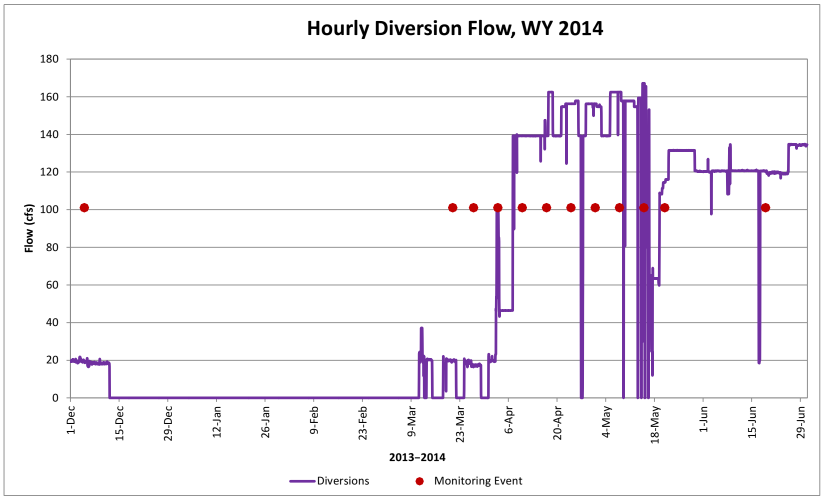
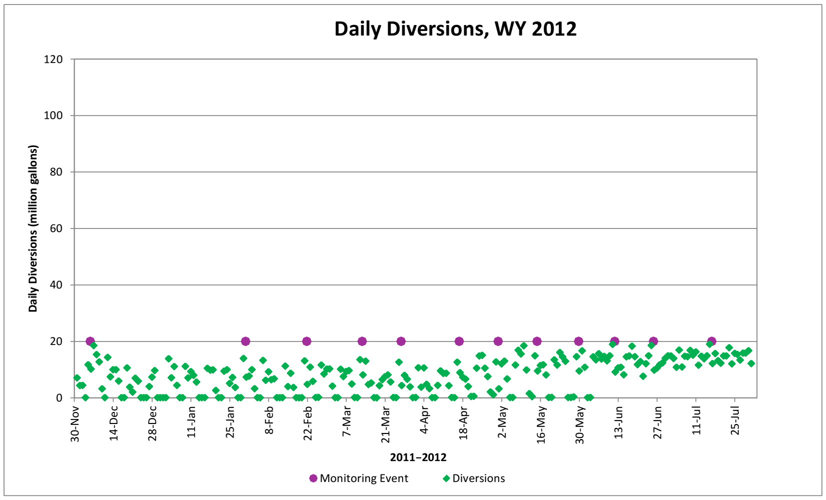
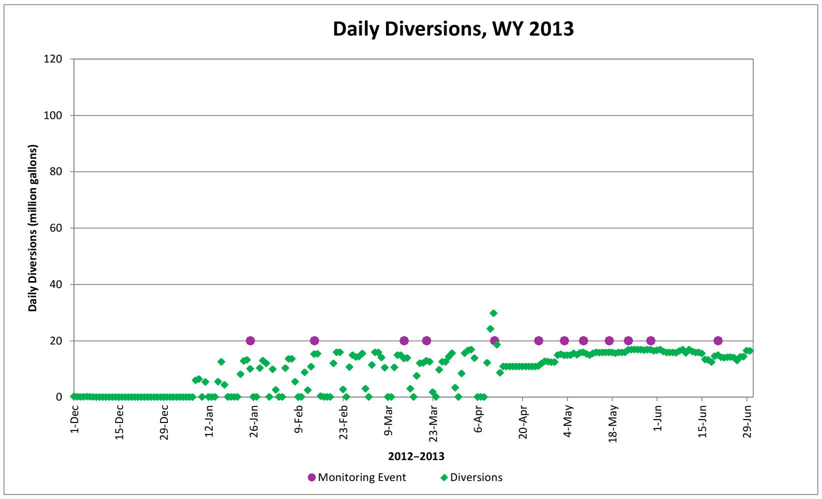


Source: Pasterski pers. comm.

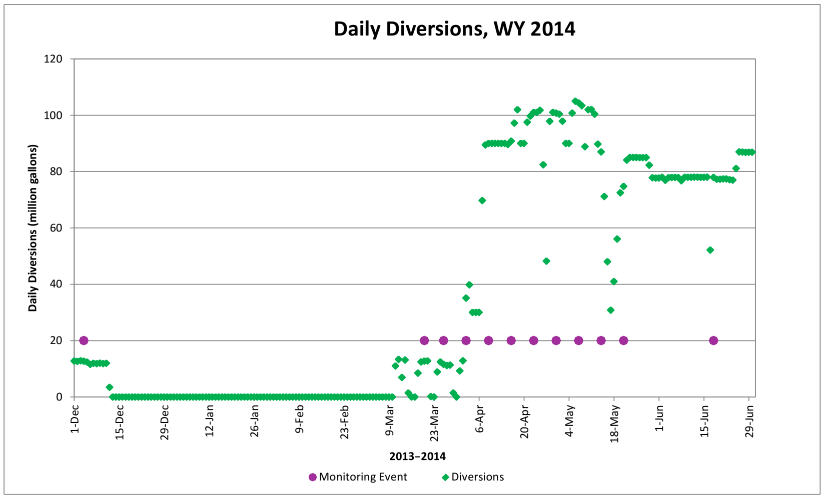
Figure 15. Hourly Flow Diverted from the Sacramento River by the Freeport Water Intake Facility during the Entrainment Monitoring Period, WYs 2012–2014



Source: Houston pers. comm.

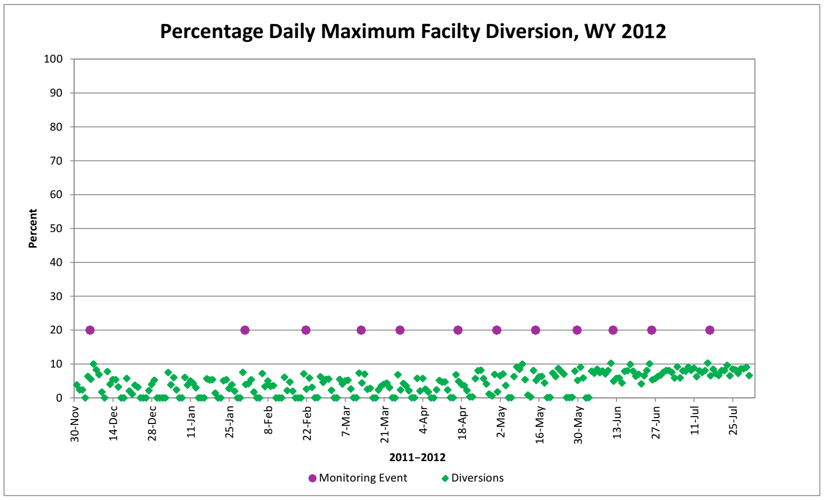


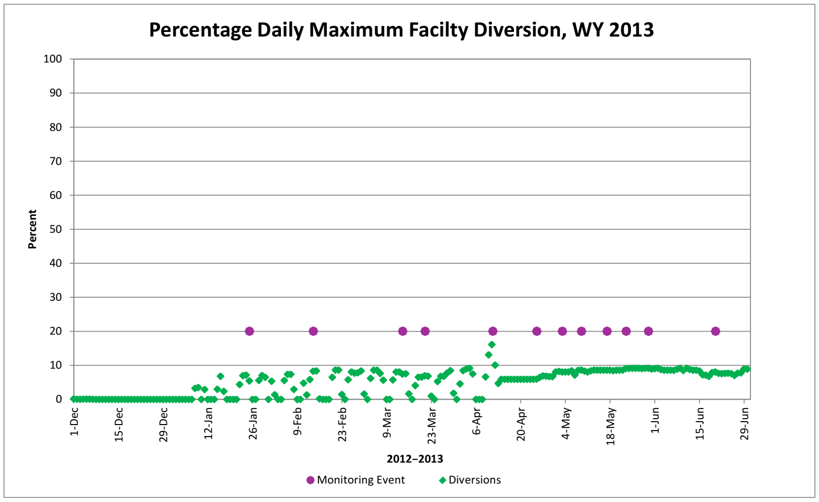
Source: Houston pers. comm.



Source: Pasterski pers. comm.

Figure 16. Daily Volumes of Water Diverted from the Sacramento River by the Freeport Water Intake Facility during the Entrainment Monitoring Period, WYs 2012–2014





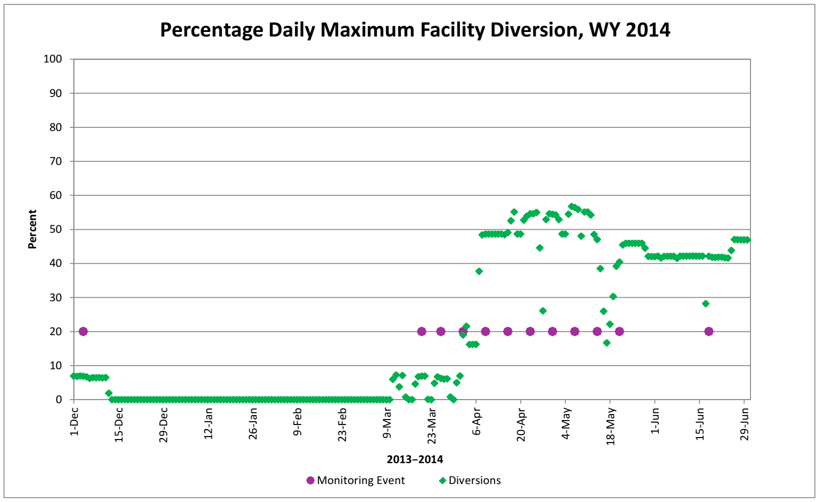
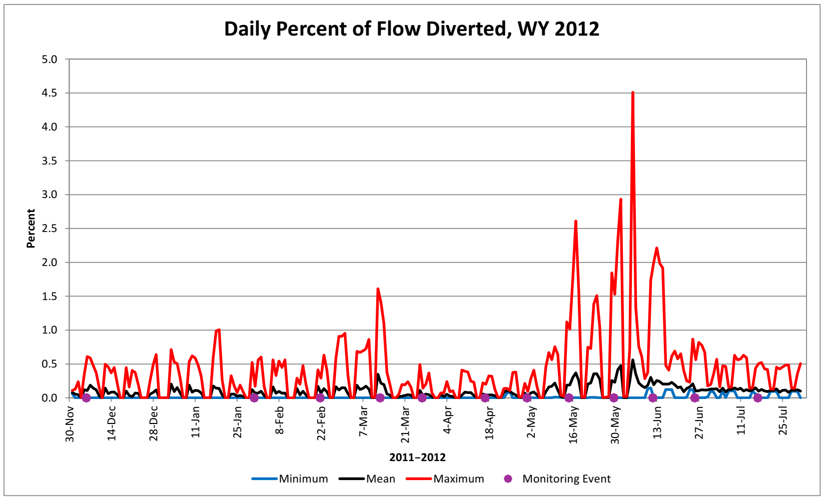
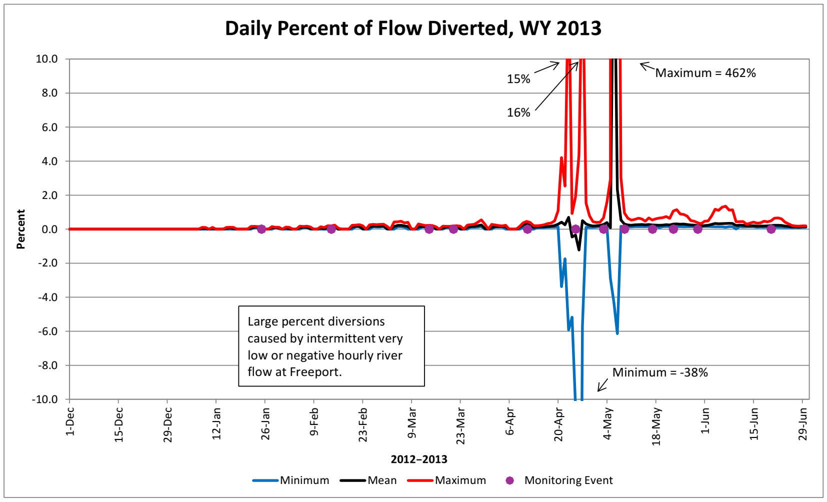
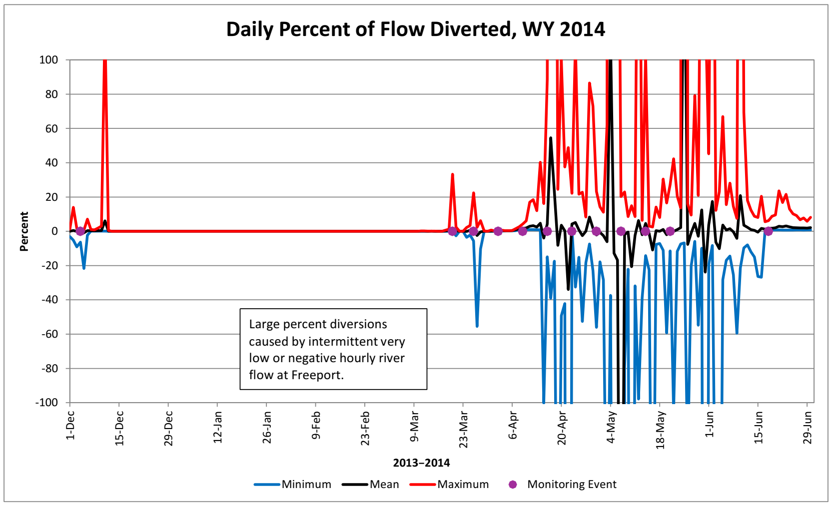


Figure 17. Daily Diversions as a Percentage of Maximum Design Capacity (185 MGD) for the Freeport Water Intake Facility during the Entrainment Monitoring Period, WYs 2012–2014



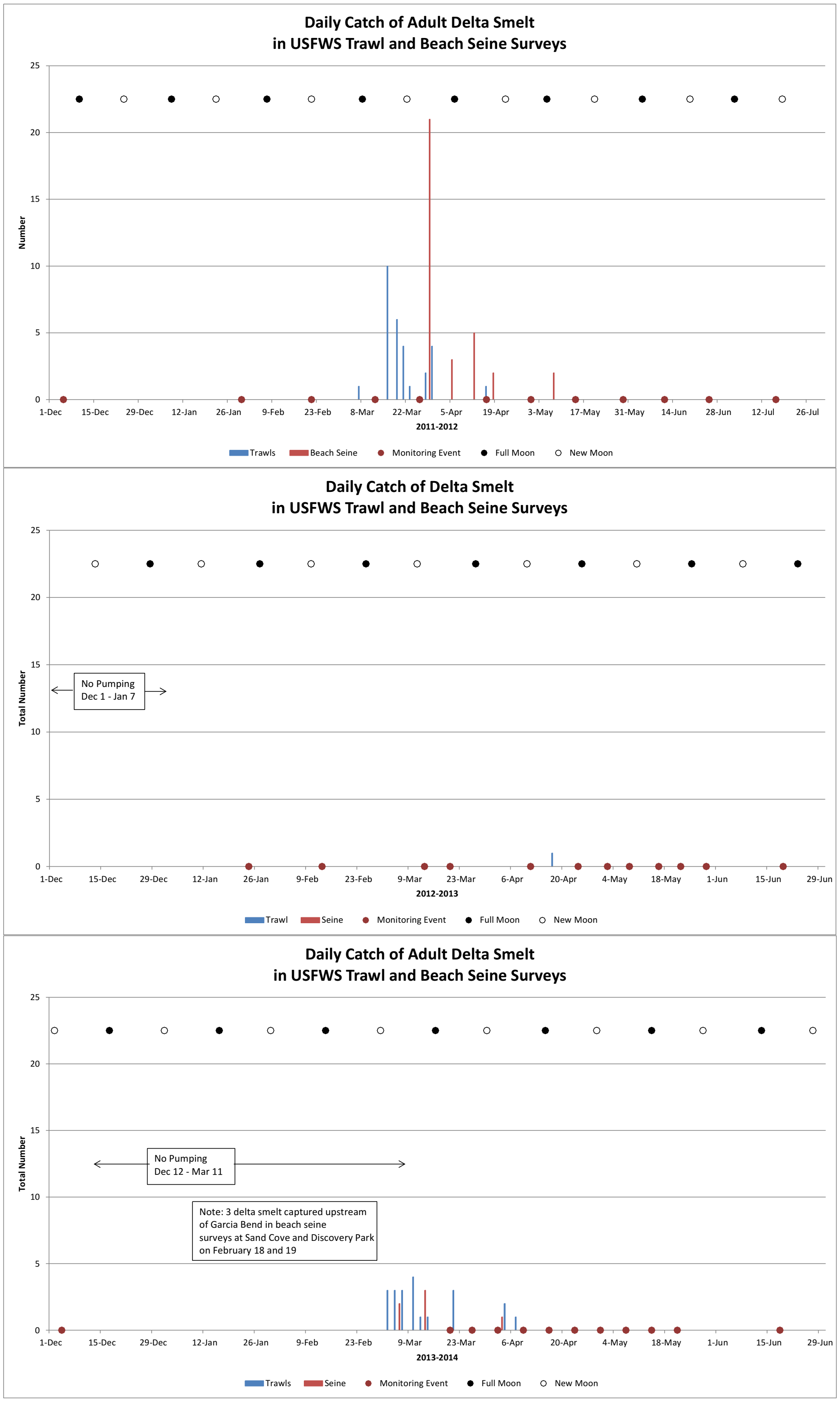


Large percent diversions caused by intermittent very low or negative hourly river flow at Freeport.



Large percent diversions caused by intermittent very low or negative hourly river flow at Freeport.

Figure 18. Minimum, Maximum, and Mean Percent of Flow Diverted from the Sacramento River by the Freeport Water Intake Facility during the Entrainment Monitoring Period, WYs 2012–2014



Source: Speegle pers. comm.

Figure 19. Daily Catch of Adult Delta Smelt in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014

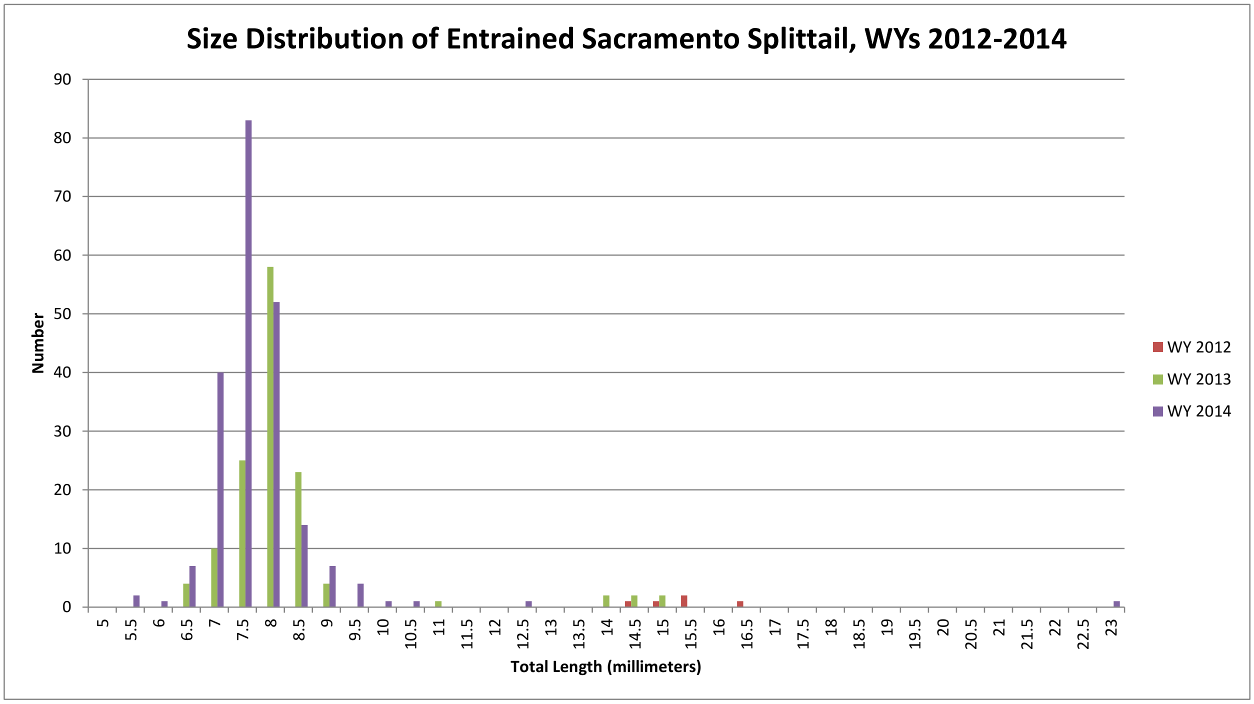
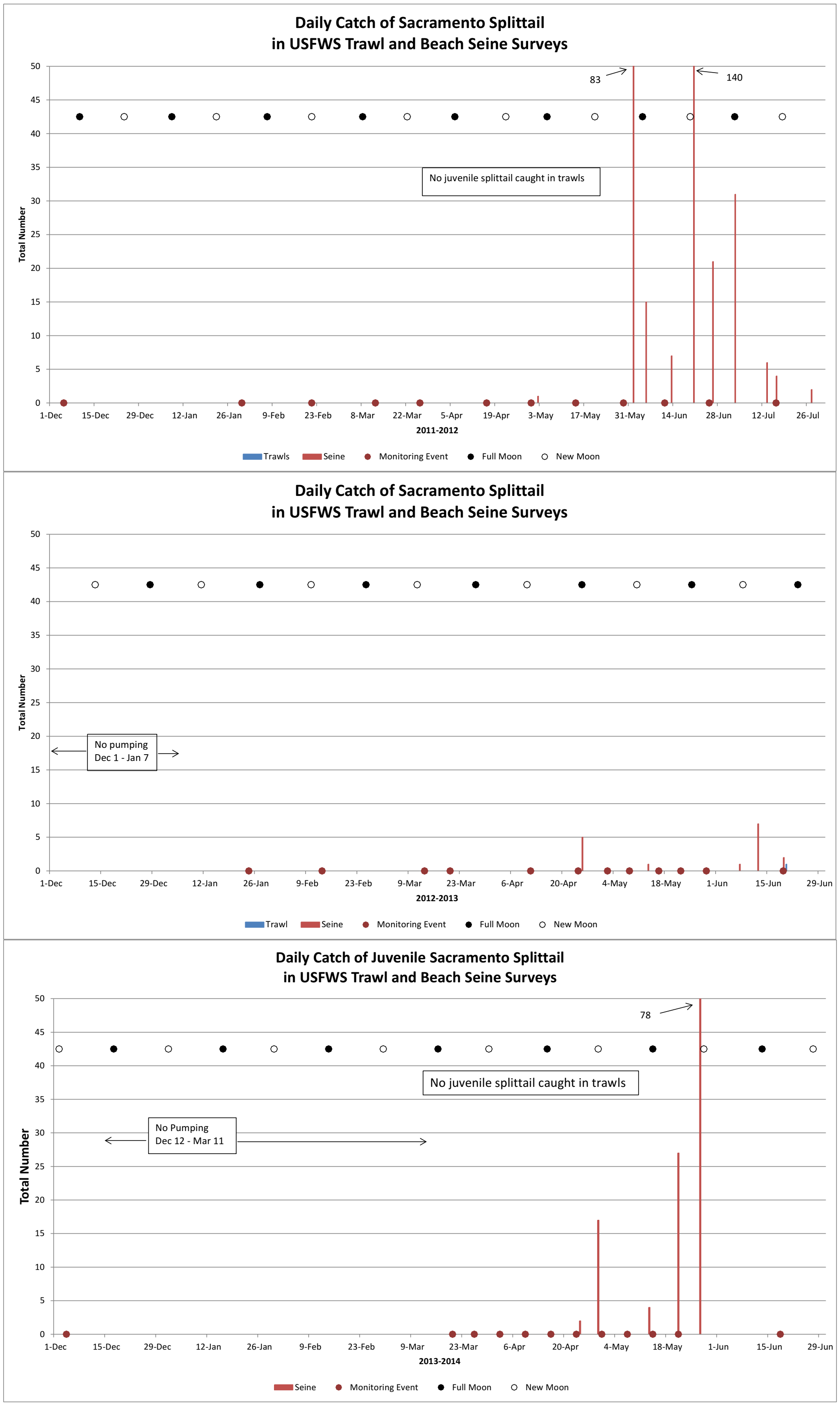
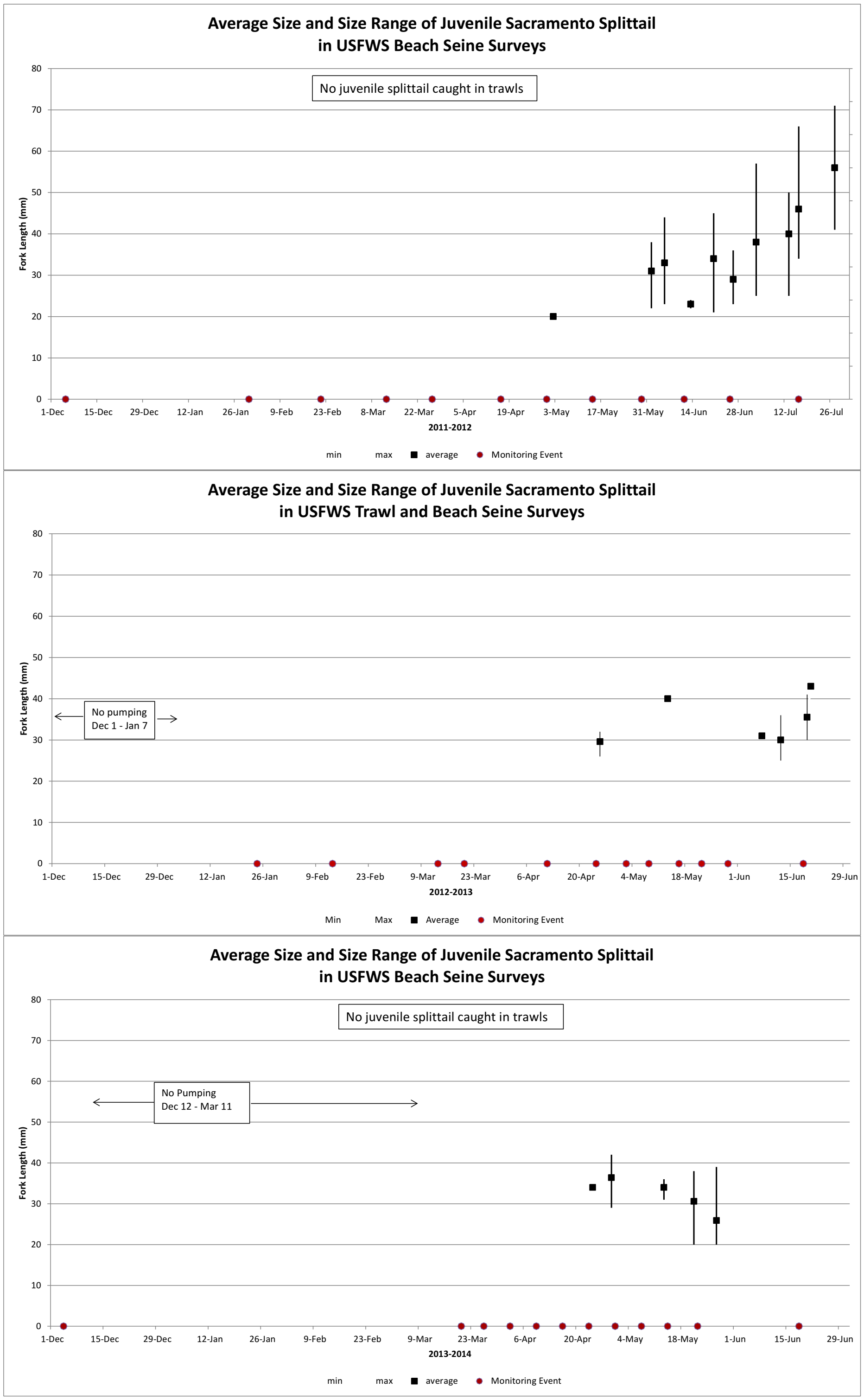


Figure 20. Size Distribution of Sacramento Splittail Detected in the Net at the VSWTP and in the Floating Larval Light Traps at the Freeport Water Intake Facility, WYs 2012–2014



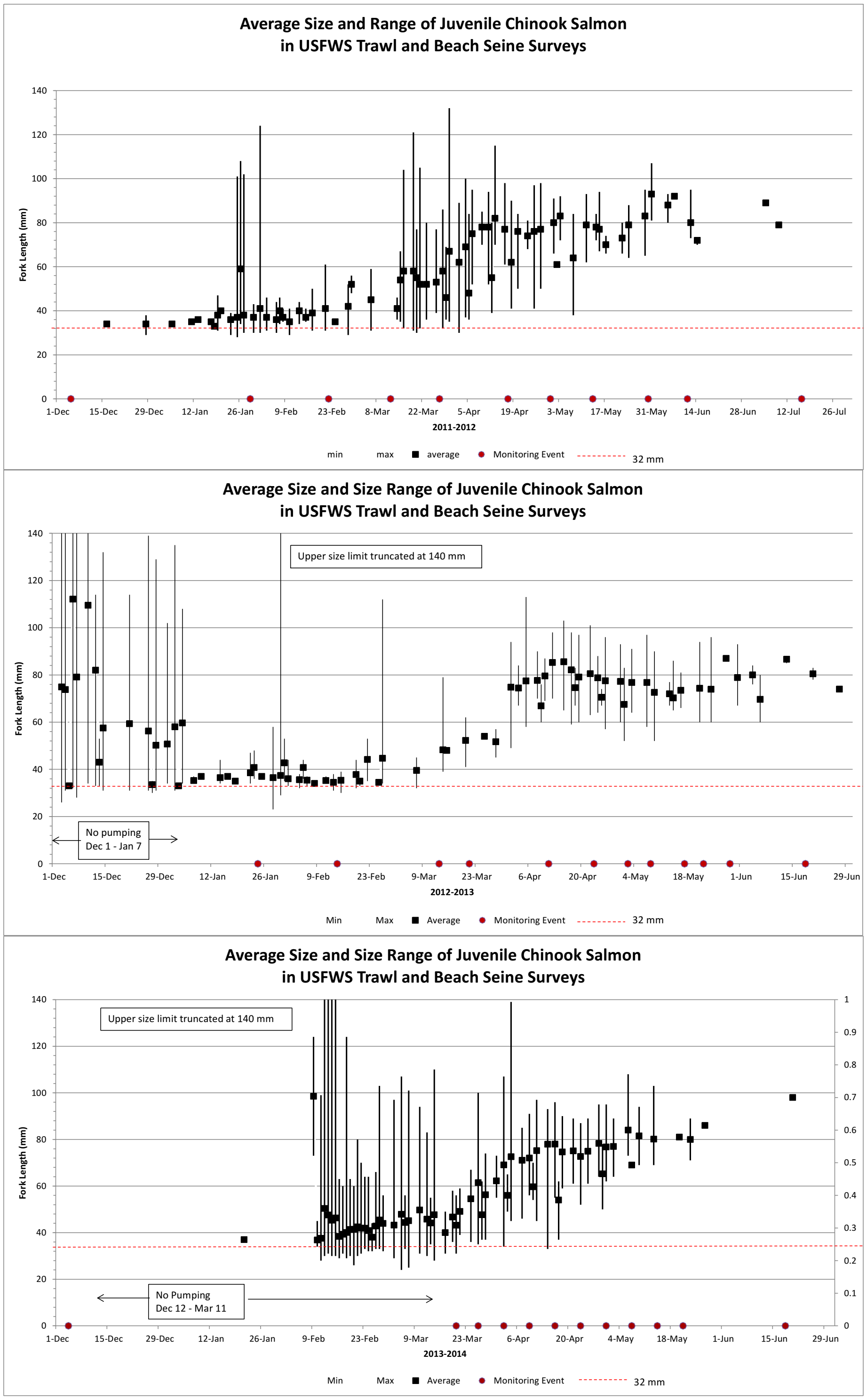
Source: Speegle pers. comm.

Figure 21. Daily Catch of Juvenile Sacramento Splittail in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014



Source: Speegle pers. comm.

Figure 22. Average Size and Size Range of Juvenile Sacramento Splittail Caught in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014



Source: Speegle pers. comm.

Figure 23. Average Size and Size Range of Juvenile Chinook Salmon Caught in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014

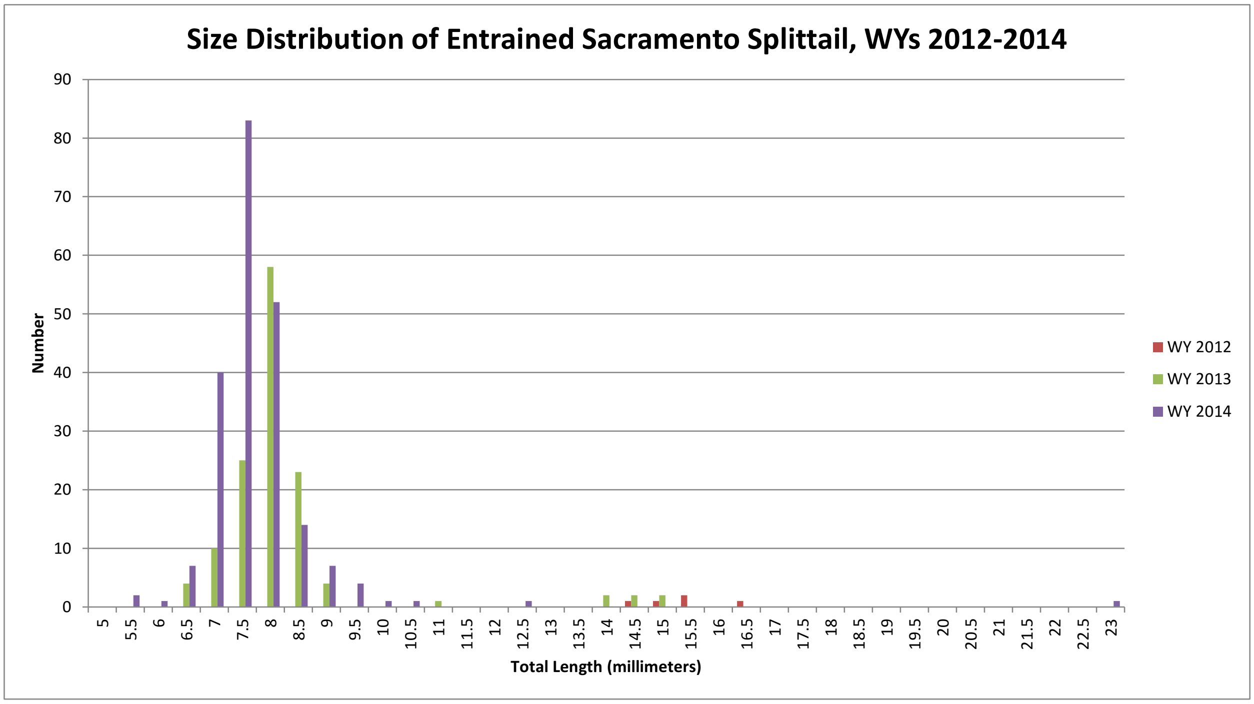
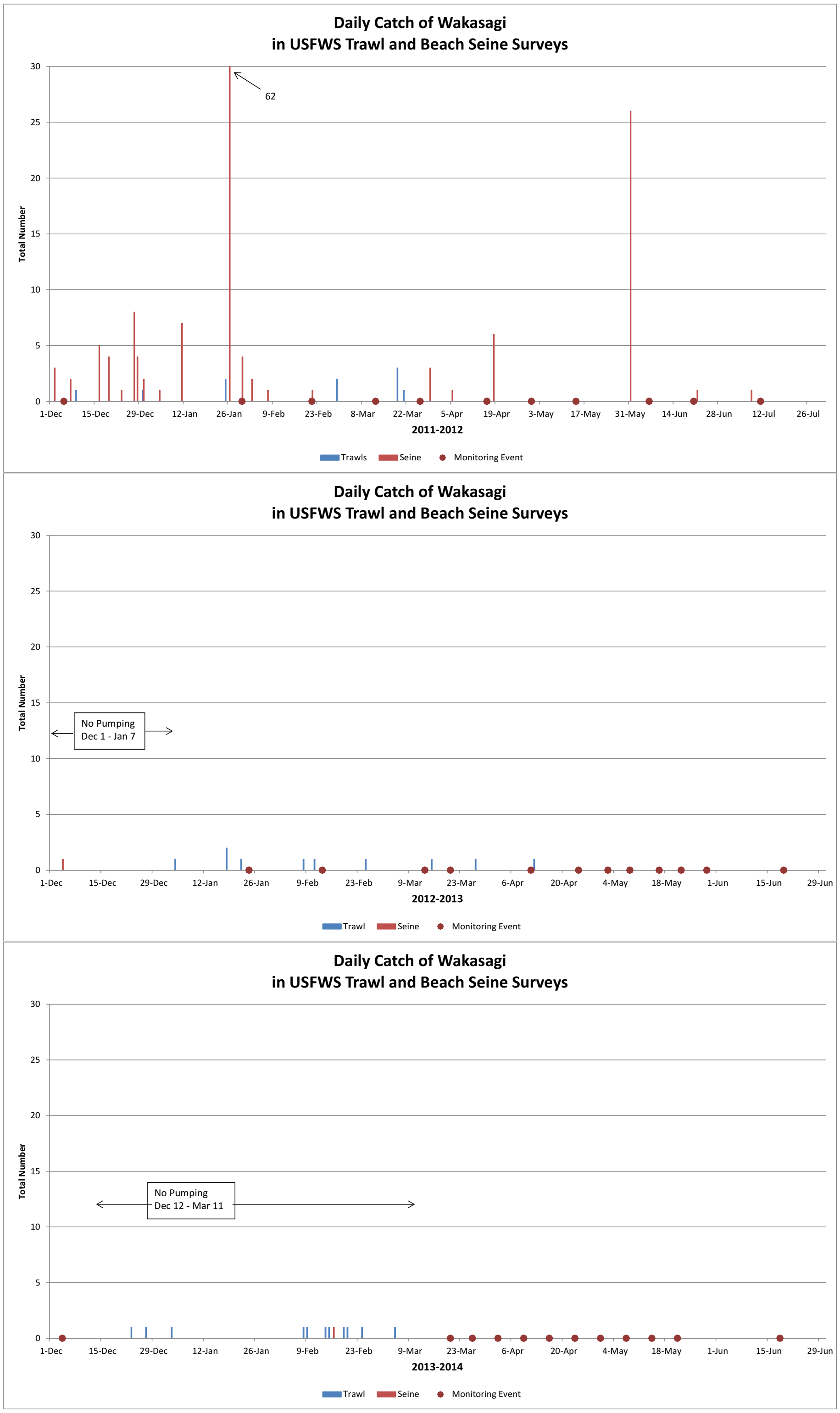
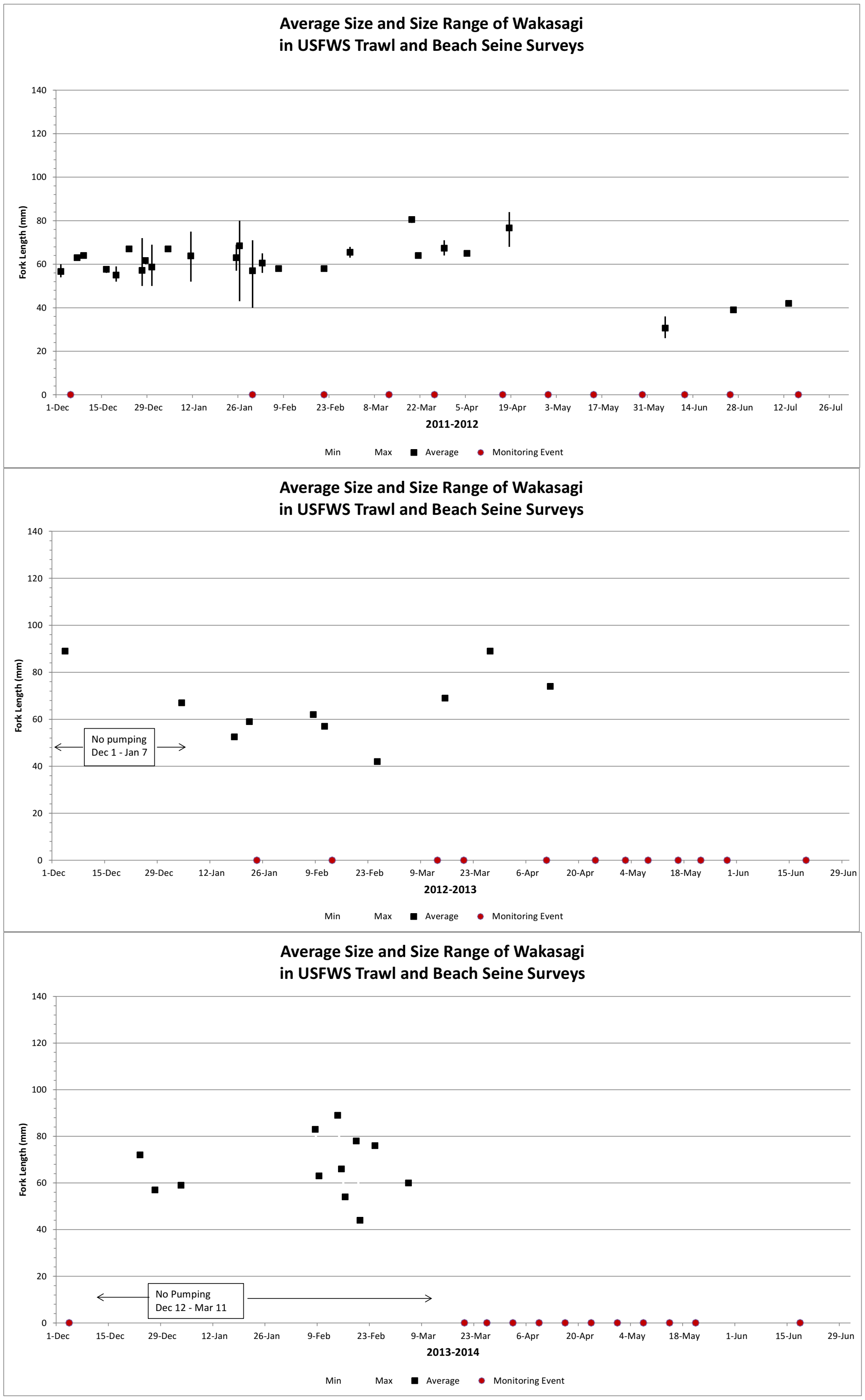


Figure 24. Size Distribution of Prickly Sculpin Detected in the Net at the VSWTP and in the Floating Larval Light Traps at the Freeport Water Intake Facility, WYs 2012–2014



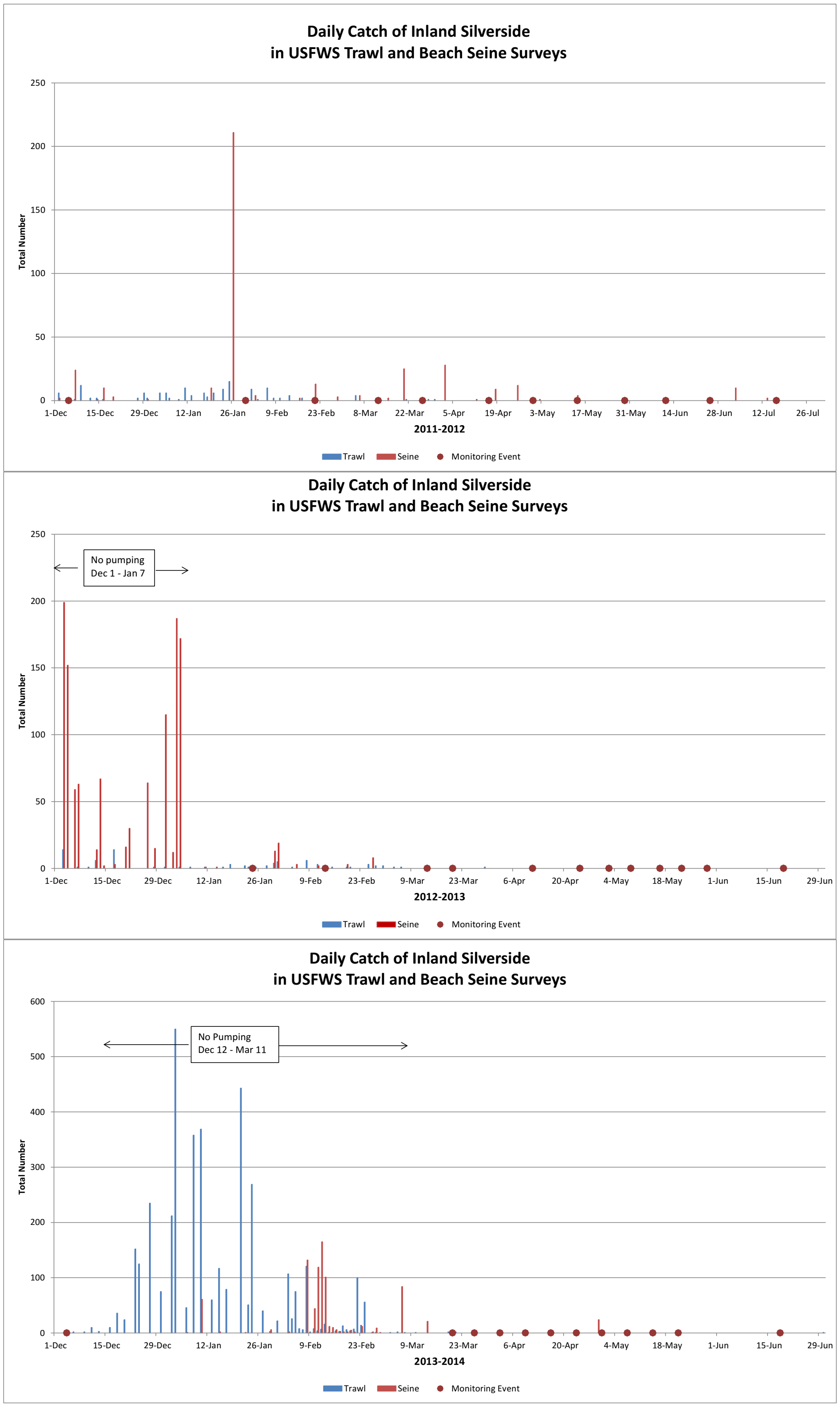
Source: Speegle pers. comm.

Figure 25. Daily Catch of Wakasagi in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014



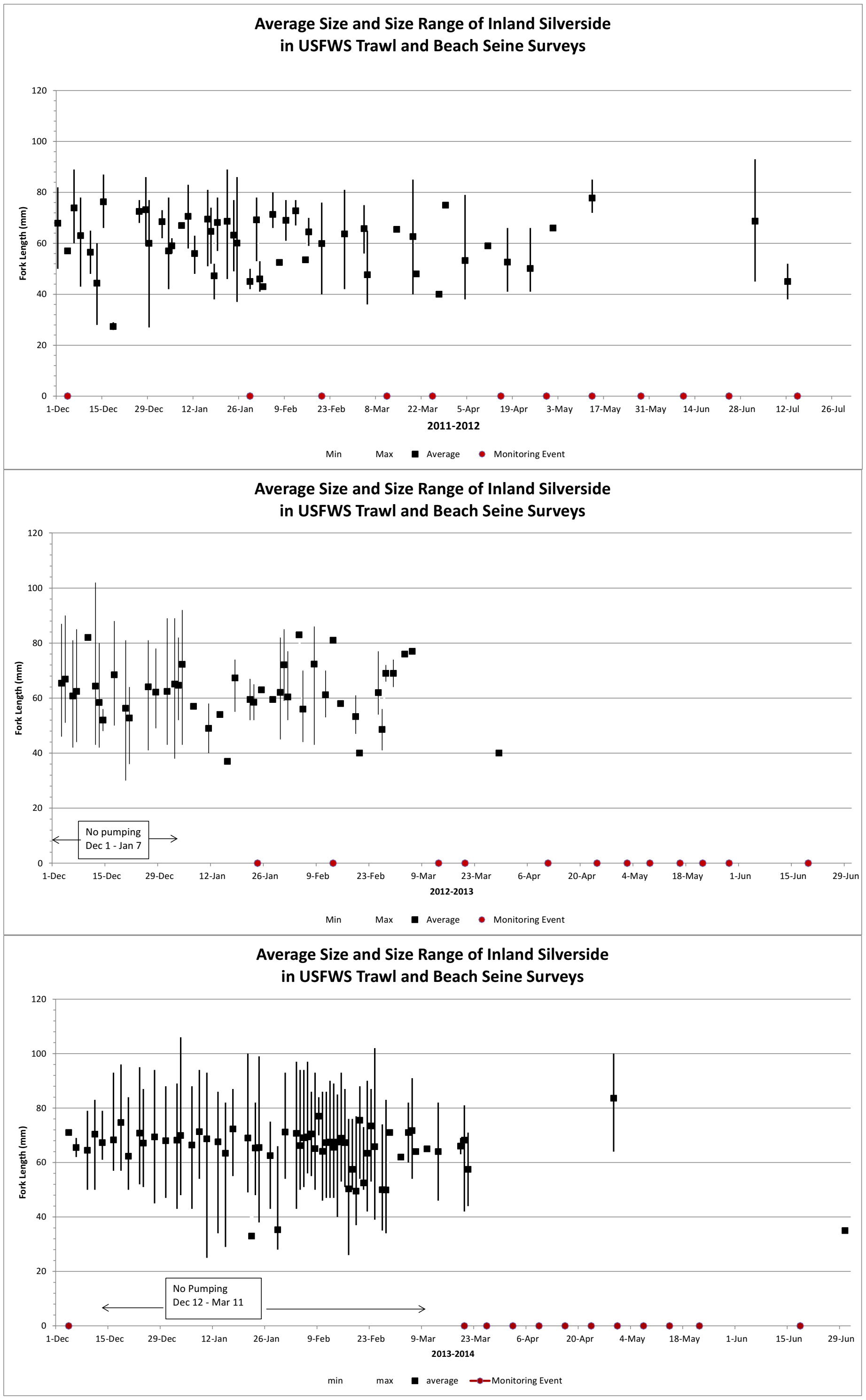
Source: Speegle pers. comm.

Figure 26. Average Size and Size Range of Wakasagi Caught in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014



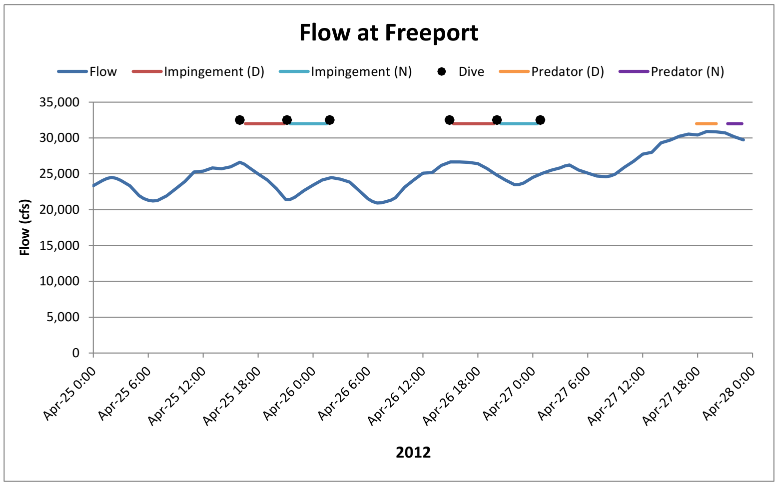
Source: Speegle pers. comm.

Figure 27. Daily Catch of Inland Silverside in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014

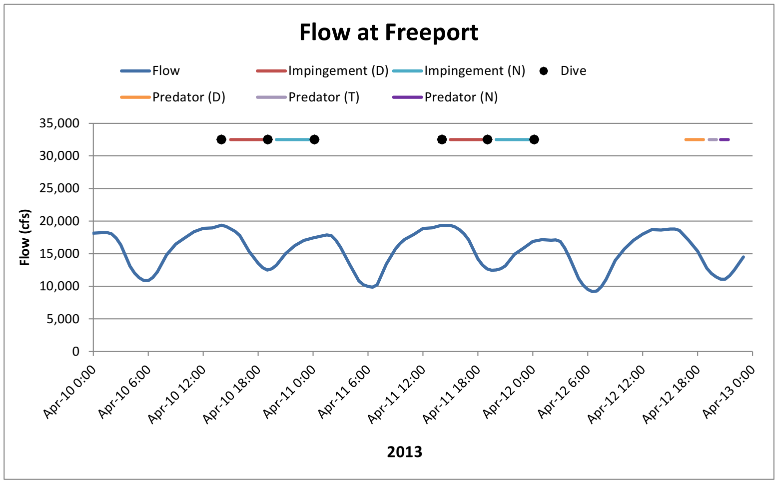


Source: Speegle pers. comm.

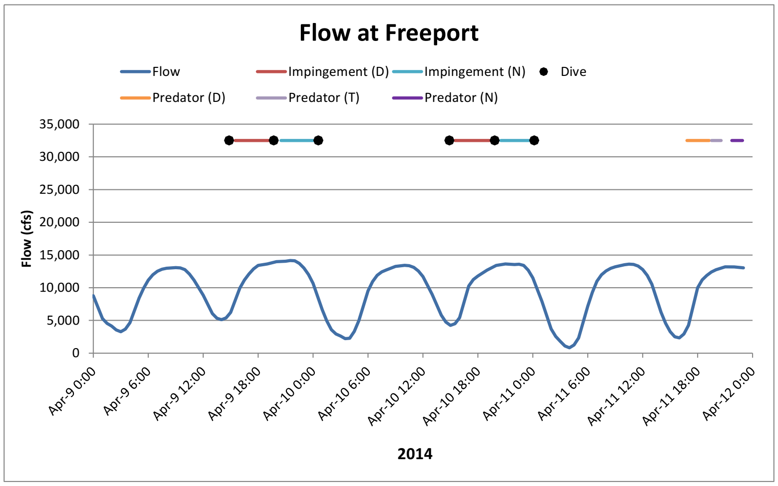
Figure 28. Average Size and Size Range of Inland Silverside Caught in the Sacramento River by USFWS Trawl (Sherwood Harbor) and Beach Seine (Garcia Bend) Surveys, WYs 2012–2014



Source: California Data Exchange Center 2012.

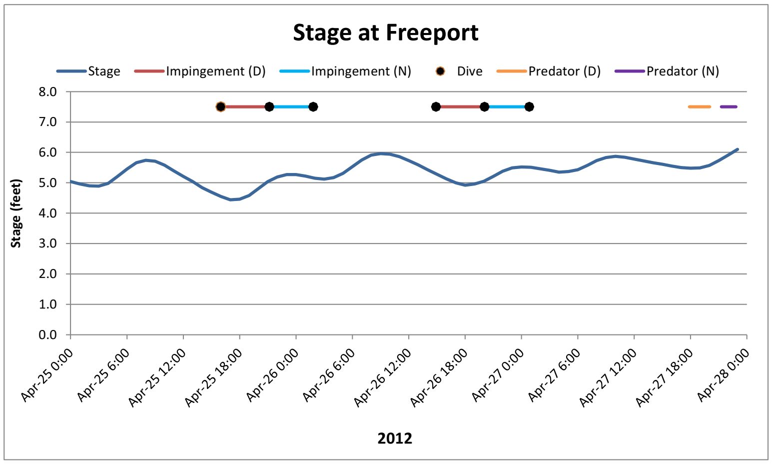


Source: California Data Exchange Center 2013.

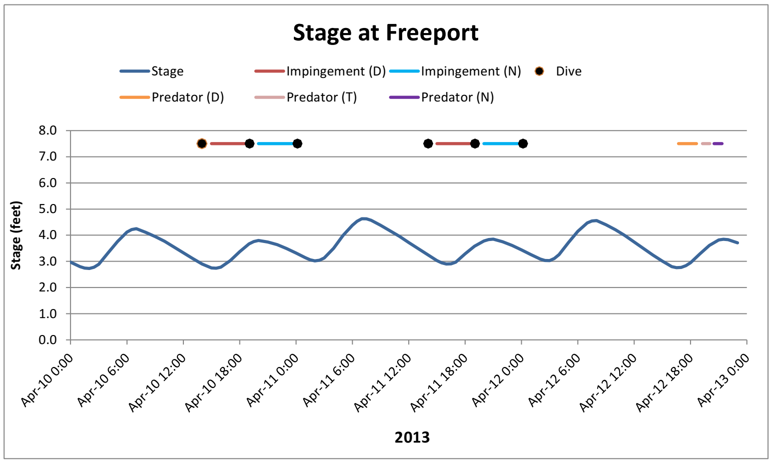


Source: California Data Exchange Center 2014.

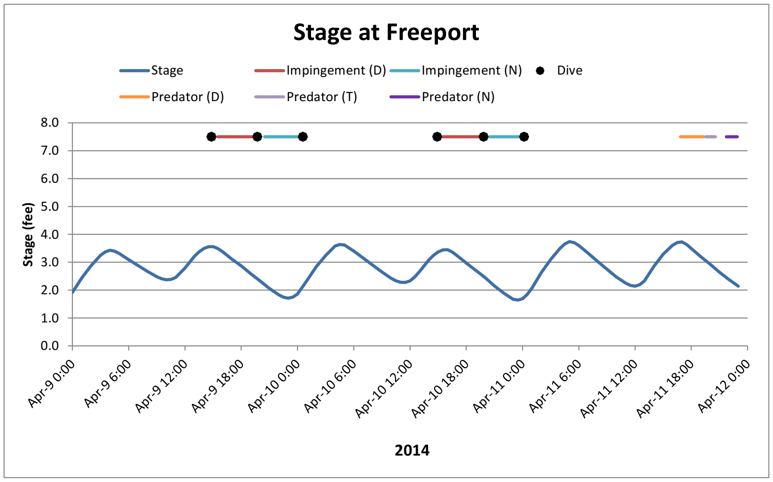
Figure 29. Hourly Sacramento River Flows at Freeport during Impingement and Predator Monitoring, WYs 2012–2014



Source: California Data Exchange Center 2012.

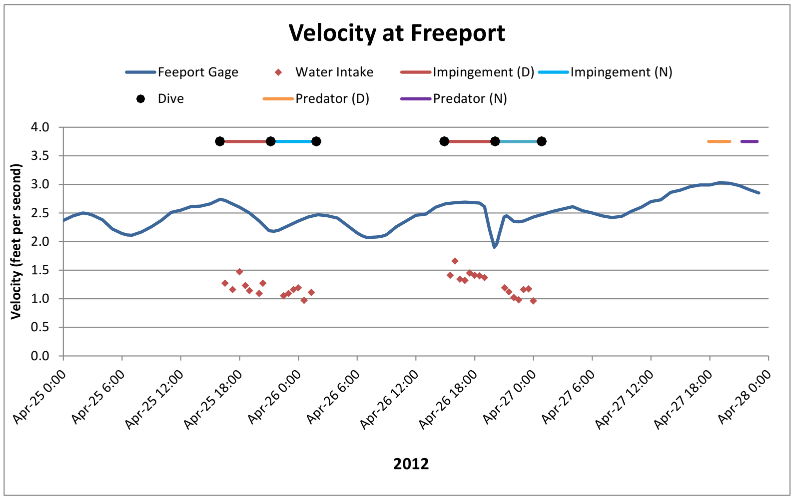


Source: California Data Exchange Center 2013.

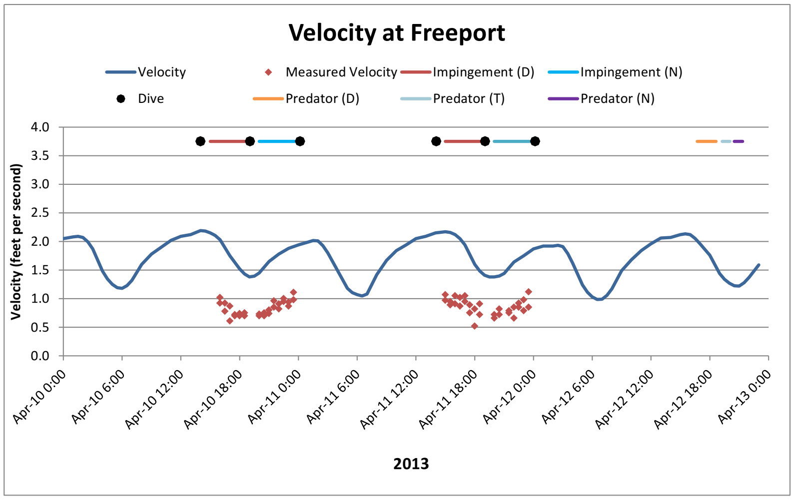


Source: California Data Exchange Center 2014.

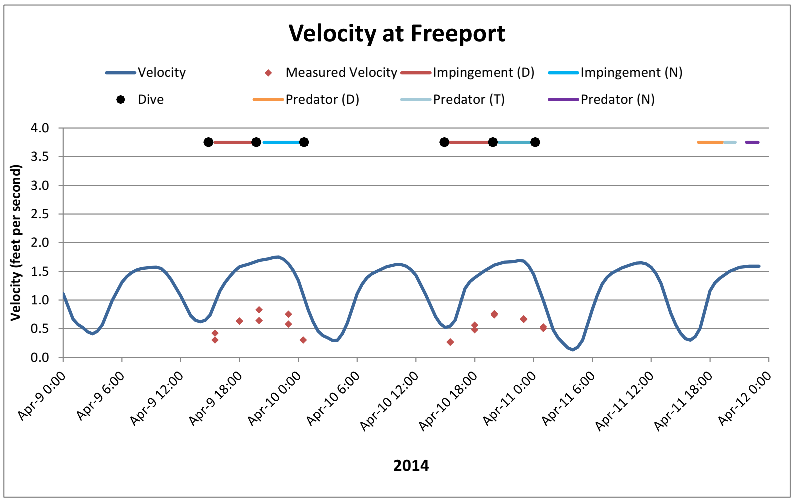
Figure 30. Hourly Sacramento River Stage at Freeport during Impingement and Predator Monitoring, WYs 2012–2014



Source: California Data Exchange Center 2012.

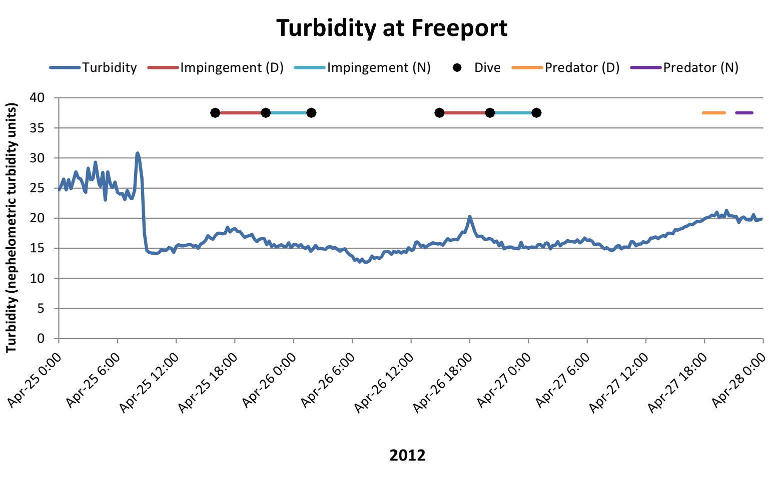


Source: California Data Exchange Center 2013.

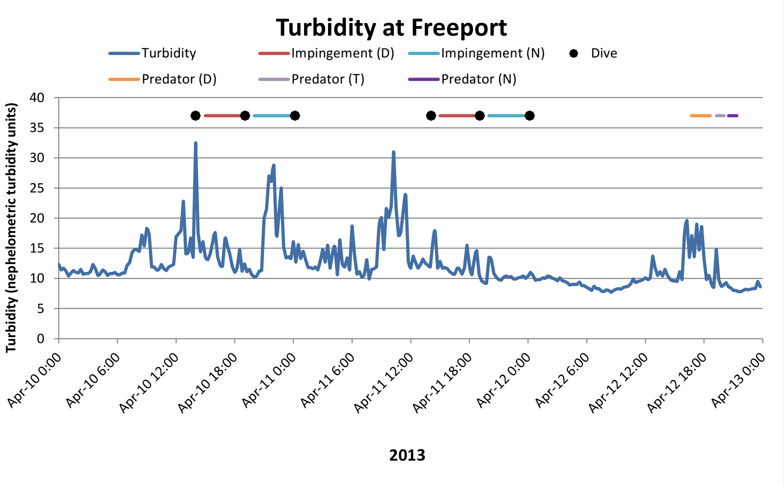


Source: California Data Exchange Center 2014.

Figure 31. Hourly Sacramento River Velocity at Freeport and Measured Water Velocity at the Freeport Water Intake Facility during Impingement and Predator Monitoring, WYs 2012–2014



Source: California Data Exchange Center 2012.



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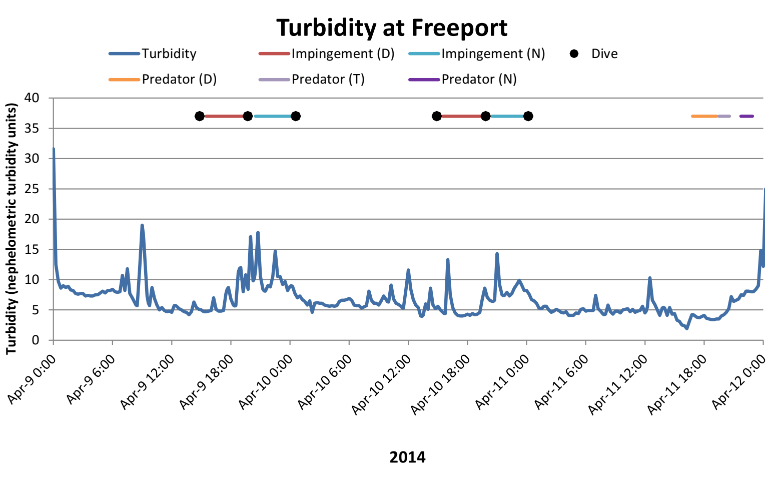
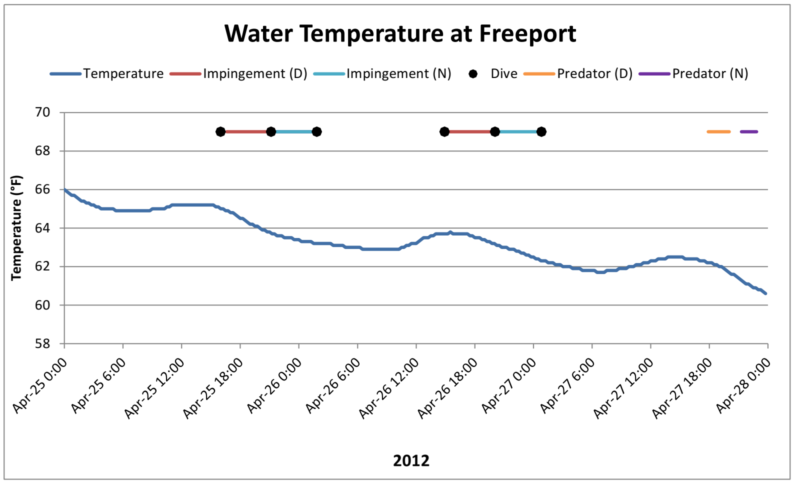
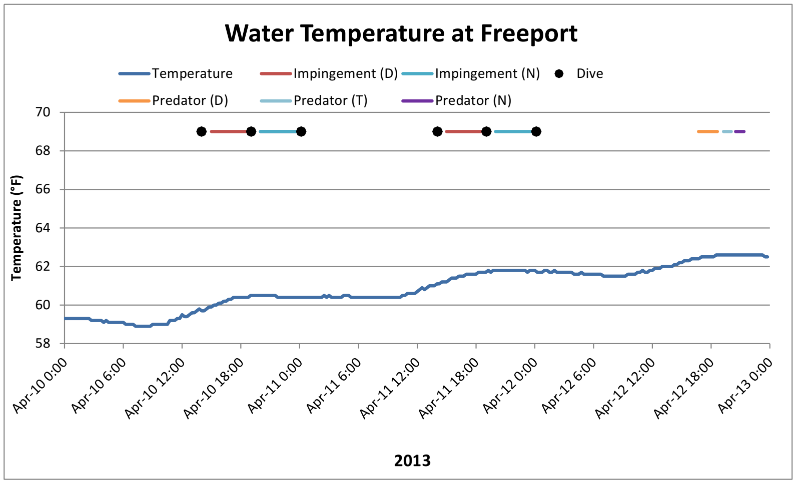


Source: California Data Exchange Center 2014.

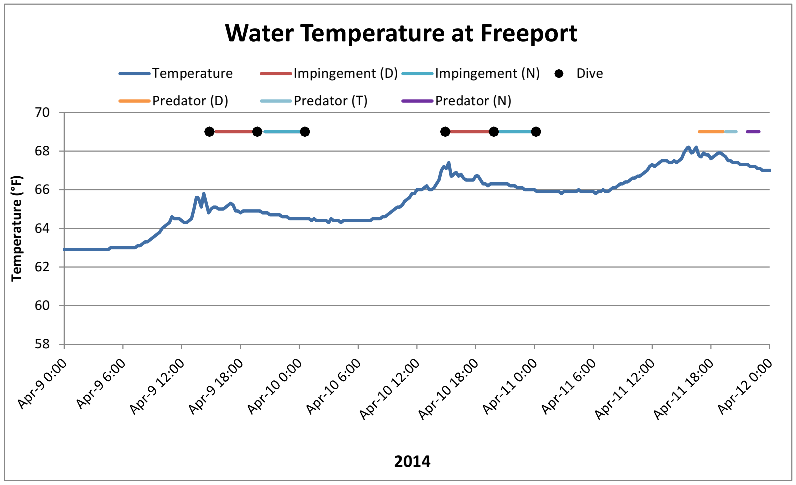
Figure 32. Hourly Sacramento River Turbidity at Freeport during Impingement and Predator Monitoring, WYs 2012–2014



Source: California Data Exchange Center 2012.

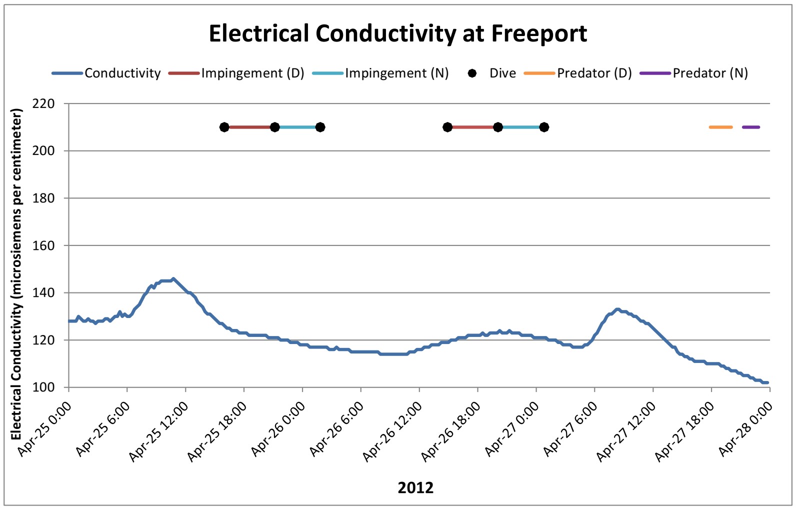


Source: California Data Exchange Center 2013.

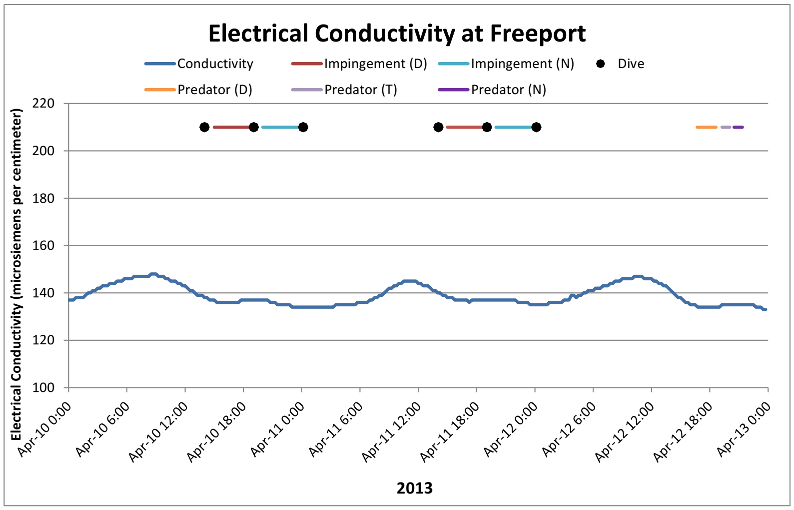


Source: California Data Exchange Center 2014.

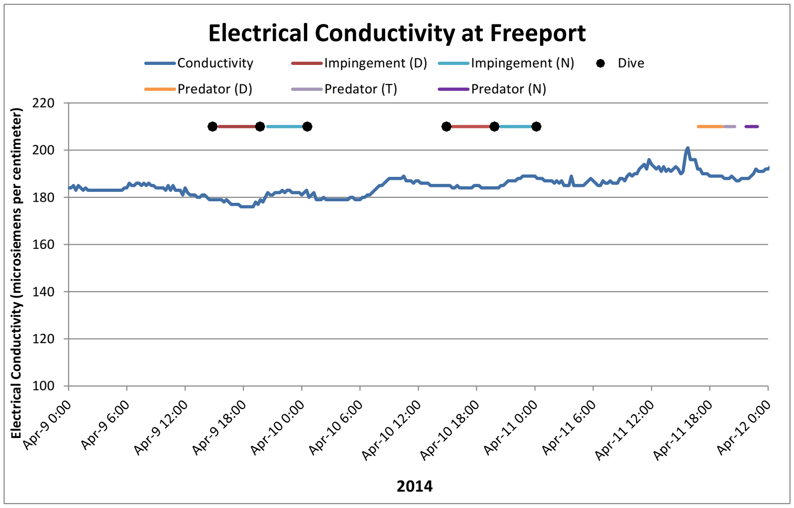
Figure 33. Hourly Sacramento River Water Temperature at Freeport during Impingement and Predator Monitoring, WYs 2012–2014



Source: California Data Exchange Center 2012.



Source: California Data Exchange Center 2013.



Source: California Data Exchange Center 2014.

Figure 34. Hourly Sacramento River Electrical Conductivity at Freeport during Impingement and Predator Monitoring, WYs 2012–2014

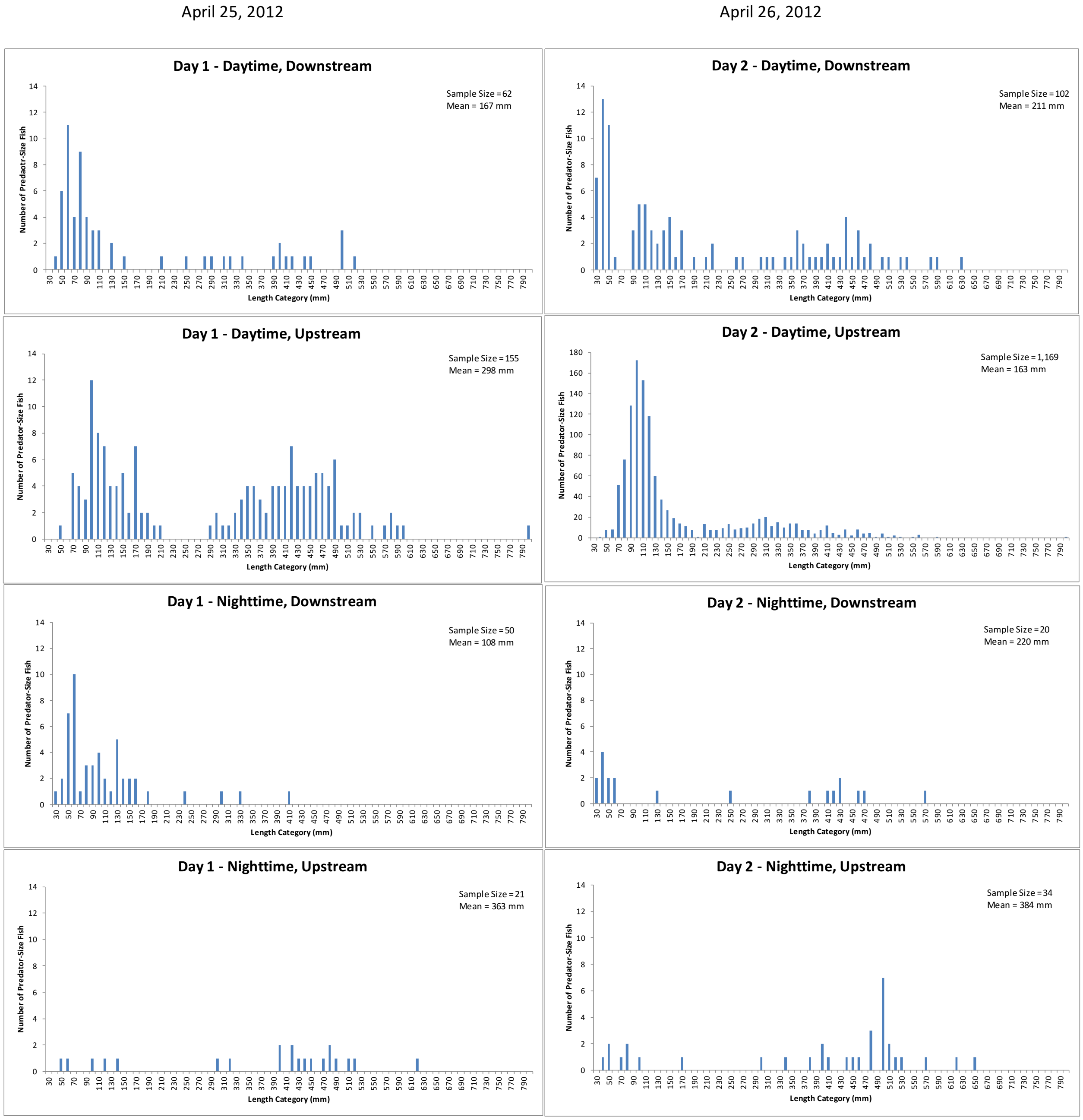


Figure 35. Length-Frequency Distribution of Fish Observed during Impingement Monitoring Using the DIDSON Sonar Camera, April 25–26, 2012

April 10, 2013 April 11, 2013

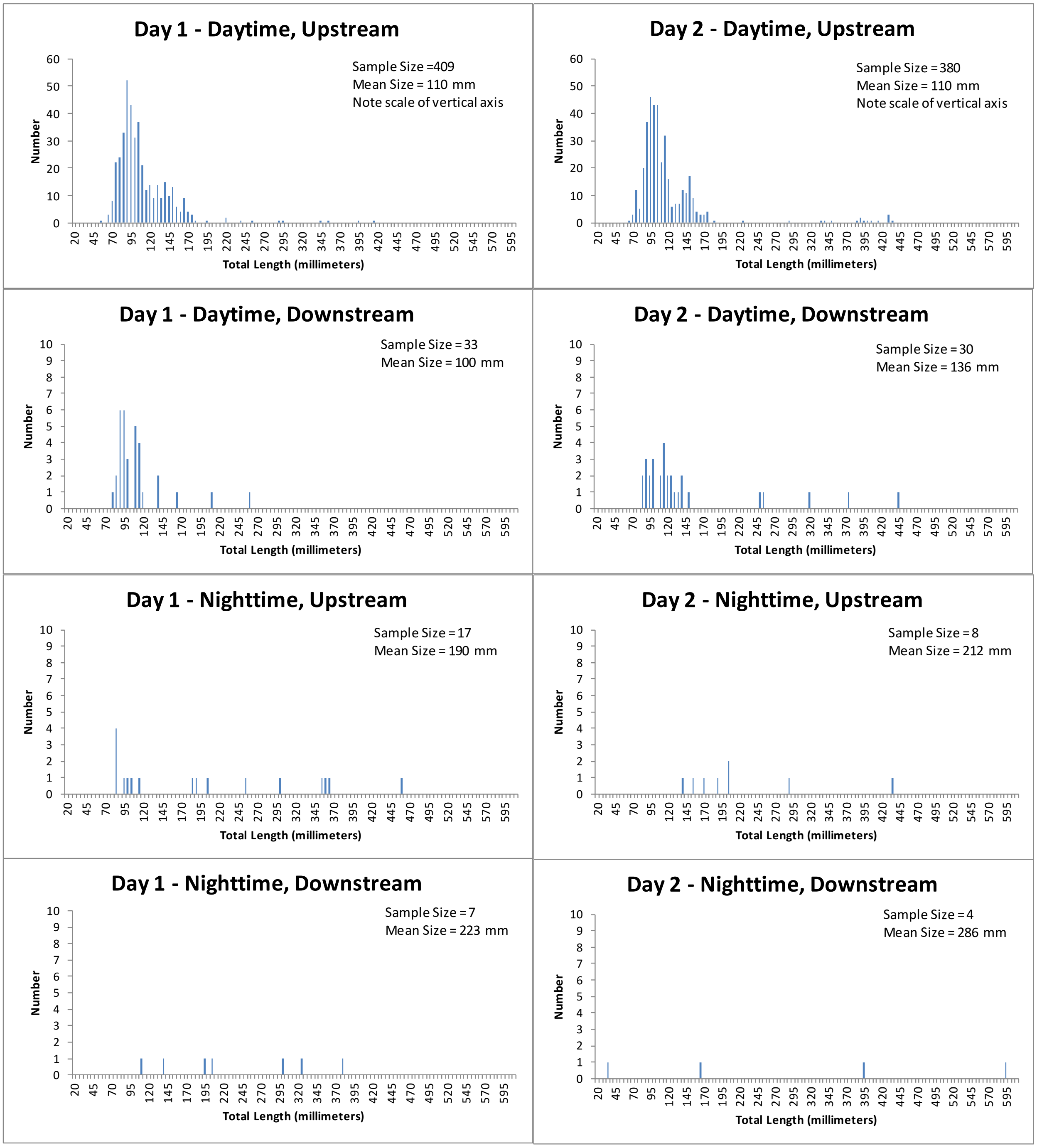
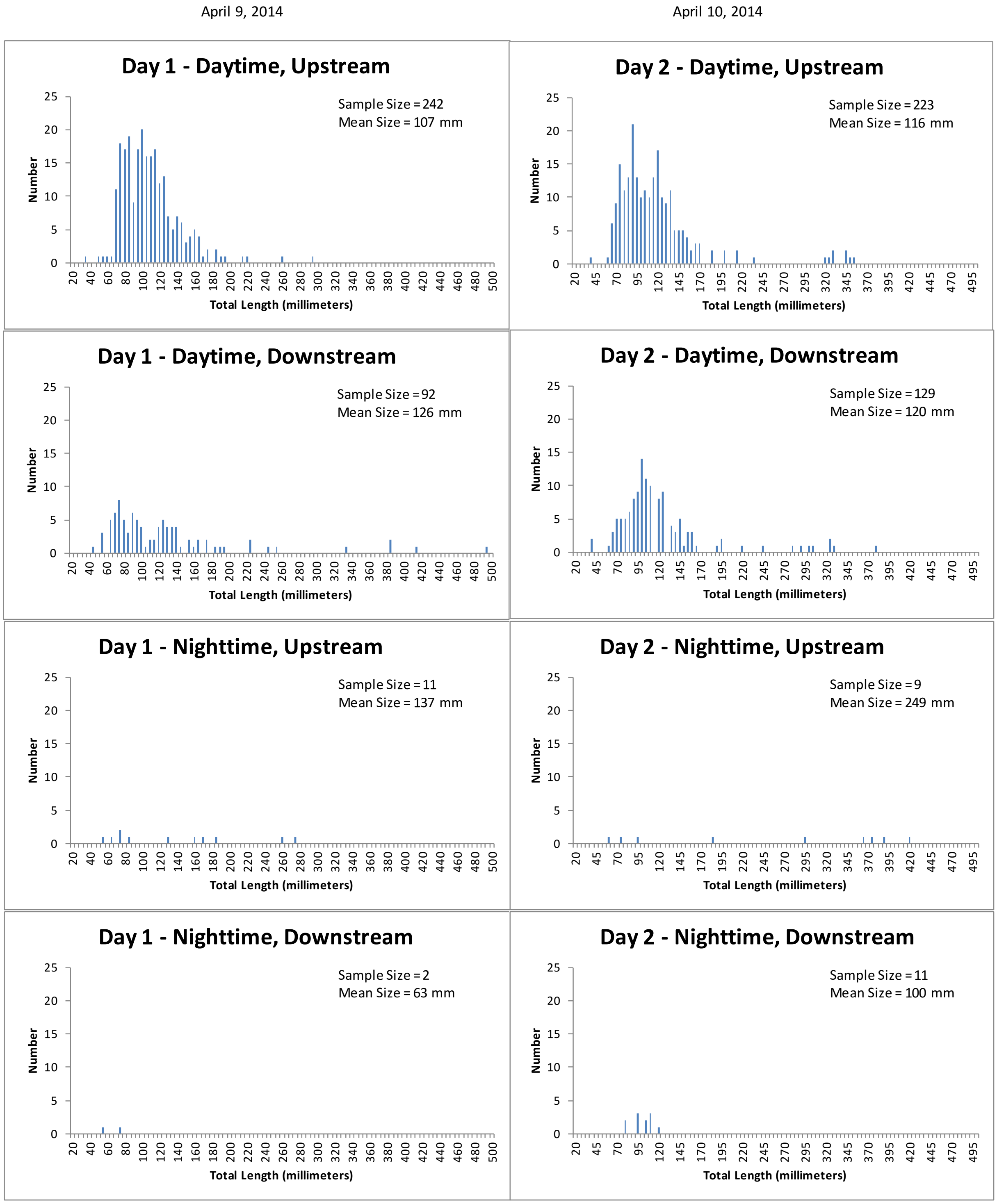


Figure 36. Length-Frequency Distribution of Fish Observed during Impingement Monitoring Using the ARIS Sonar Camera, April 10–11, 2013



April 9, 2014

April 10, 2014

Day 1 - Daytime, Upstream

Sample Size = 242
Mean Size = 107 mm

Day 2 - Daytime, Upstream

Sample Size = 223
Mean Size = 116 mm

Day 1 - Daytime, Downstream

Sample Size = 92
Mean Size = 126 mm

Day 2 - Daytime, Downstream

Sample Size = 129
Mean Size = 120 mm

Day 1 - Nighttime, Upstream

Sample Size = 11
Mean Size = 137 mm

Day 2 - Nighttime, Upstream

Sample Size = 9
Mean Size = 249 mm

Day 1 - Nighttime, Downstream

Sample Size = 2
Mean Size = 63 mm

Day 2 - Nighttime, Downstream

Sample Size = 11
Mean Size = 100 mm

Figure 37. Length-Frequency Distribution of Fish Observed during Impingement Monitoring Using the ARIS Sonar Camera, April 9–10, 2014

Figure 38

Measured Water Depths in Predator Monitoring Reaches

Monitoring Date: April 27, 2012
Monitoring Interval: 17:53–19:07

Figure 39a

Location of Predator-Size Fish Observed during Survey 1 with DIDSON Sonar Camera

Monitoring Date: April 27, 2012
Monitoring Interval: 19:10–20:02

Figure 39b

Location of Predator-Size Fish Observed during Survey 2 with DIDSON Sonar Camera

Figure 39c

Location of Predator-Size Fish Observed during Survey 3 with DIDSON Sonar Camera

Monitoring Date: April 27, 2012
Monitoring Interval: 22:10–22:50

Figure 39d

Location of Predator-Size Fish Observed during Survey 4 with DIDSON Sonar Camera

Figure 40a

Location of Predator-Size Fish Observed during Survey 1 with Mobile ARIS Sonar Camera

Figure 40b

Location of Predator-Size Fish Observed during Survey 2 with Mobile ARIS Sonar Camera

Legend

● Predator-Sized Fish (>305mm)

— Boat Path

— Reach Boundary

- - - Backwater Eddy

Monitoring Date: April 12, 2013
Monitoring Interval: 19:16–20:03

Figure 40c

Location of Predator-Size Fish Observed during Survey 3 with Mobile ARIS Sonar Camera

Monitoring Date: April 12, 2013
Monitoring Interval: 20:30–21:21

Figure 40d

Location of Predator-Size Fish Observed during Survey 4 with Mobile ARIS Sonar Camera

Figure 41a

Location of Predator-Size Fish Observed during Survey 1 with Mobile ARIS Sonar Camera

Monitoring Date: April 11, 2014
Monitoring Interval: 18:13–19:16

Figure 41b

Location of Predator-Size Fish Observed during Survey 2 with Mobile ARIS Sonar Camera

Monitoring Date: April 11, 2014
Monitoring Interval: 19:31–20:34

Figure 41c

Location of Predator-Size Fish Observed during Survey 3 with Mobile ARIS Sonar Camera

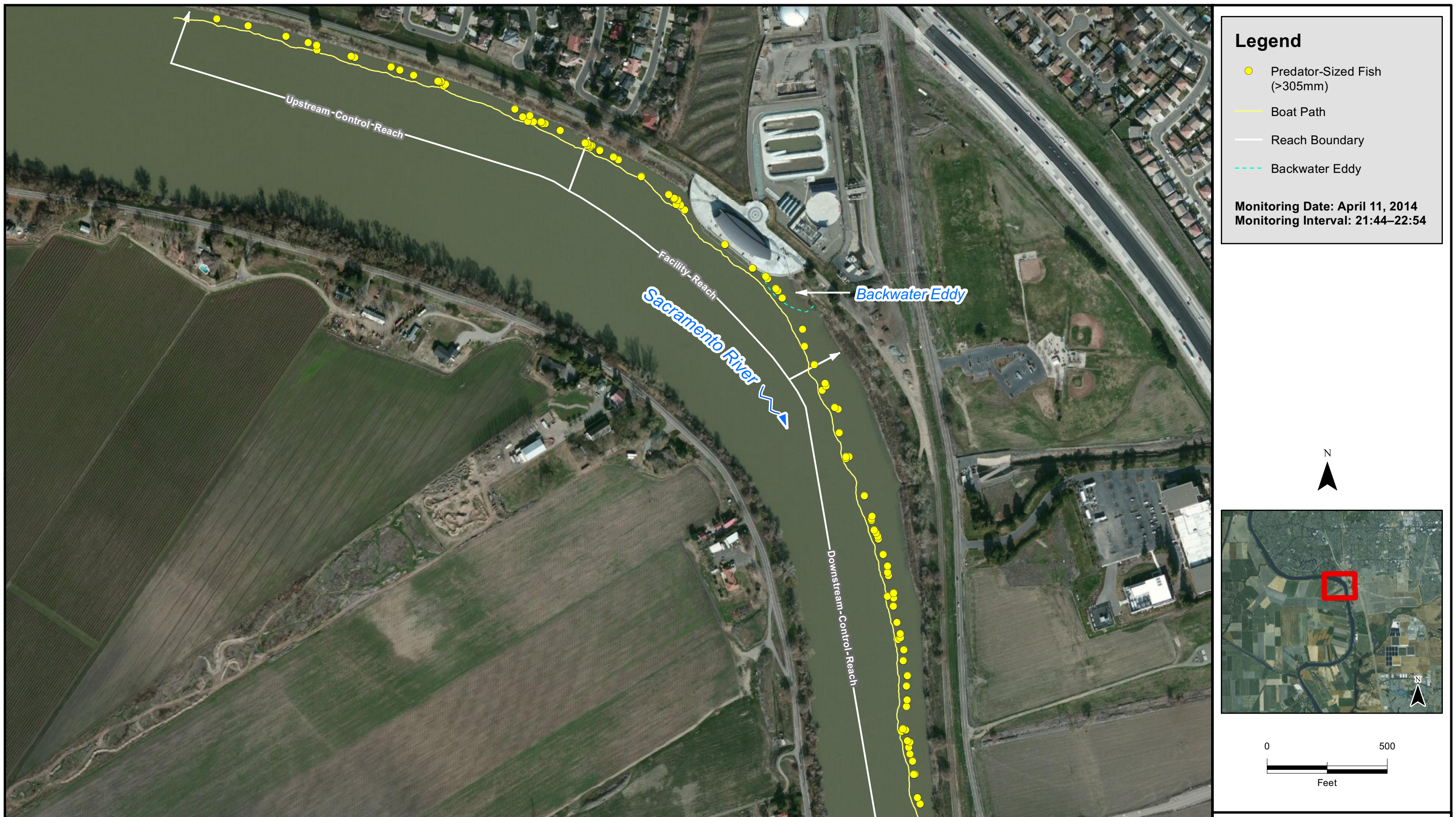


Figure 41d

Location of Predator-Size Fish Observed during Survey 4 with Mobile ARIS Sonar Camera

Legend

○ Prey-Sized Fish (<305mm)

— Boat Path

— Reach Boundary

- - - Backwater Eddy

Monitoring Date: April 12, 2013
Monitoring Interval: 16:43 - 17:31

Figure 42a

Location of Prey-Size Fish Observed during Survey 1 with Mobile ARIS Sonar Camera

Figure 42b

Location of Prey-Size Fish Observed during Survey 2 with Mobile ARIS Sonar Camera

Monitoring Date: April 12, 2013
Monitoring Interval: 19:16–20:03

Figure 42c

Location of Prey-Size Fish Observed during Survey 3 with Mobile ARIS Sonar Camera

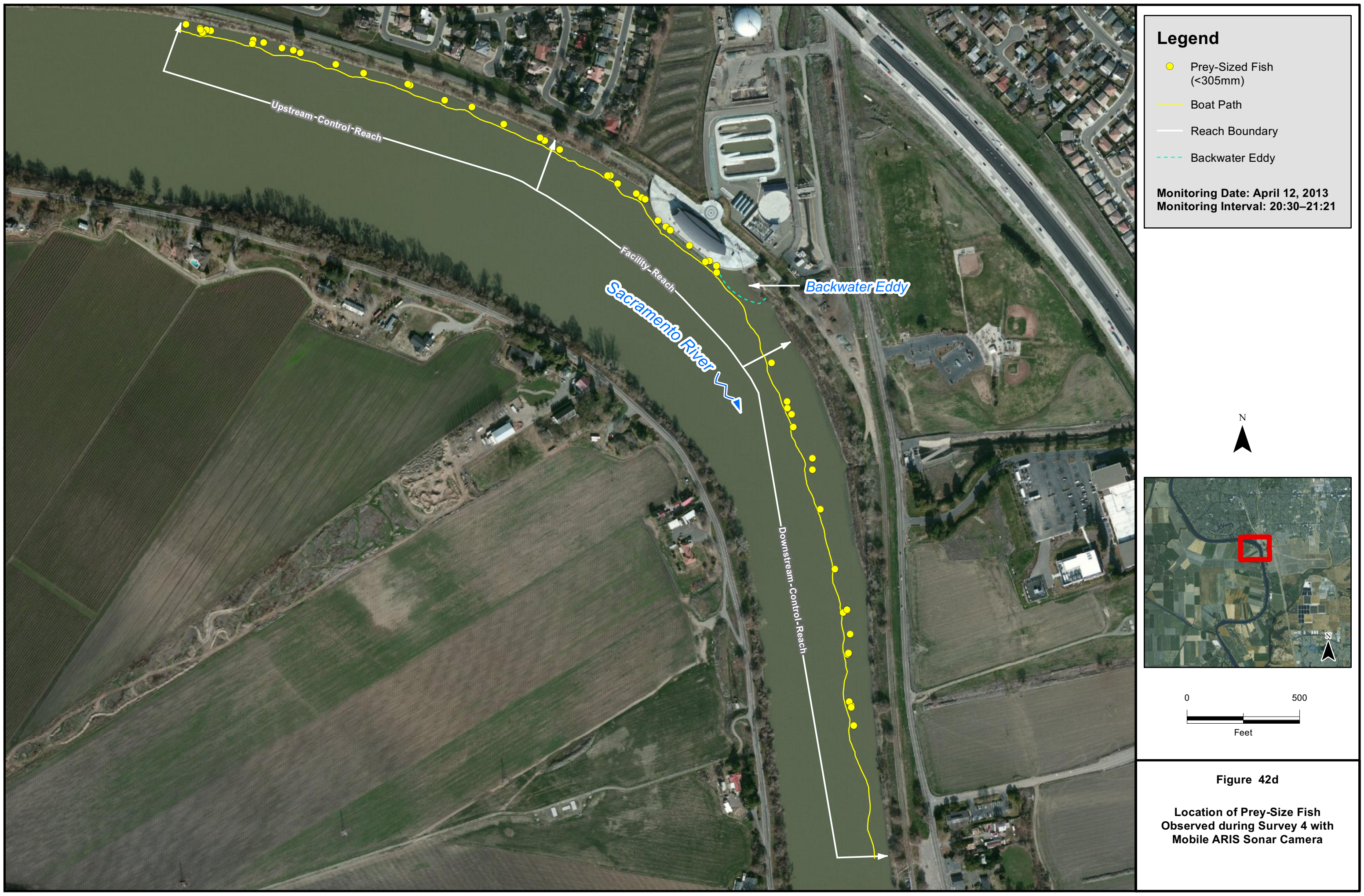


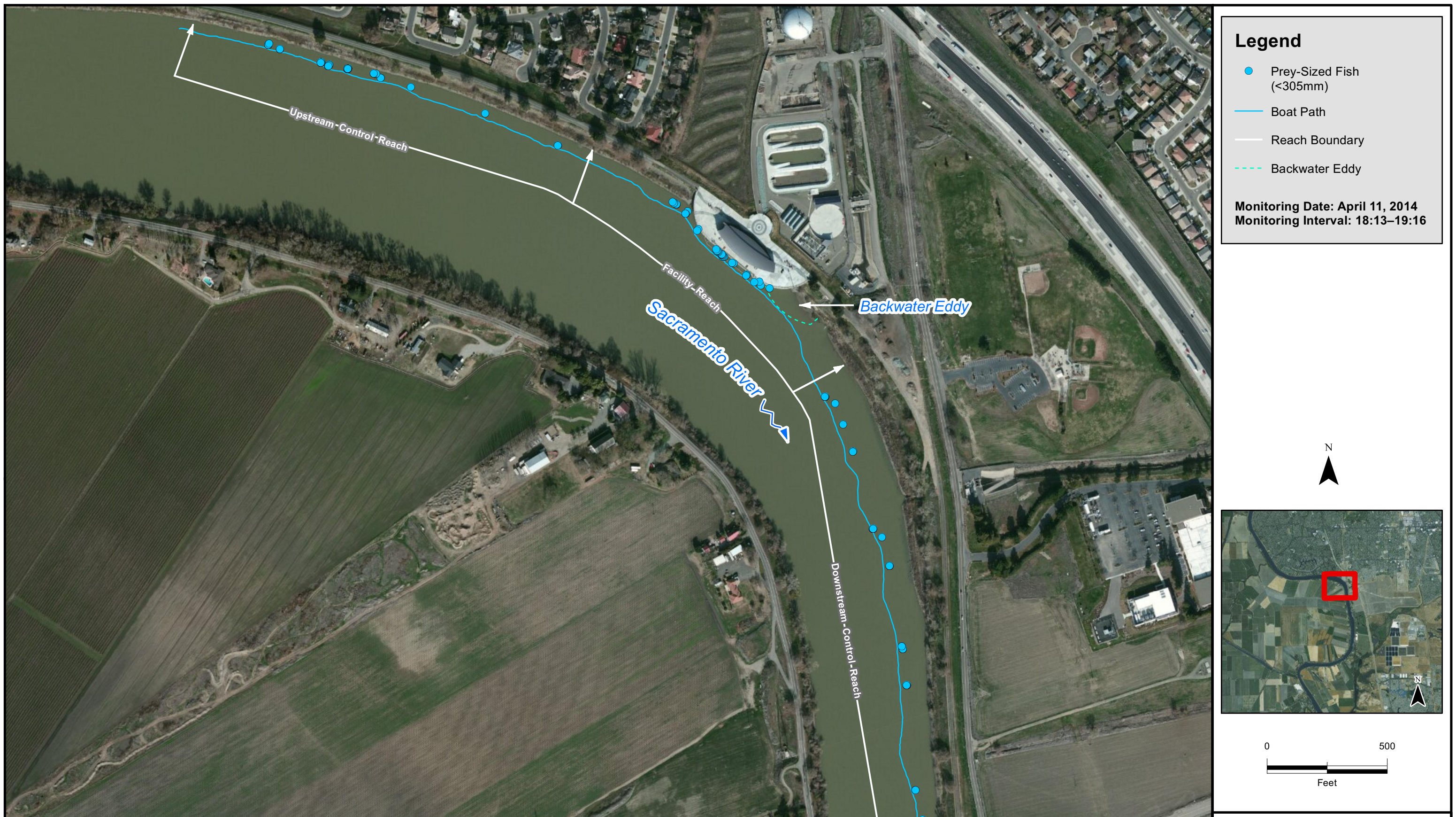
Figure 42d

Location of Prey-Size Fish Observed during Survey 4 with Mobile ARIS Sonar Camera

Monitoring Date: April 11, 2014
Monitoring Interval: 16:50 - 17:55

Figure 43a

Location of Prey-Size Fish Observed during Survey 1 with Mobile ARIS Sonar Camera



Monitoring Date: April 11, 2014
Monitoring Interval: 18:13–19:16

Figure 43b

Location of Prey-Size Fish Observed during Survey 2 with Mobile ARIS Sonar Camera

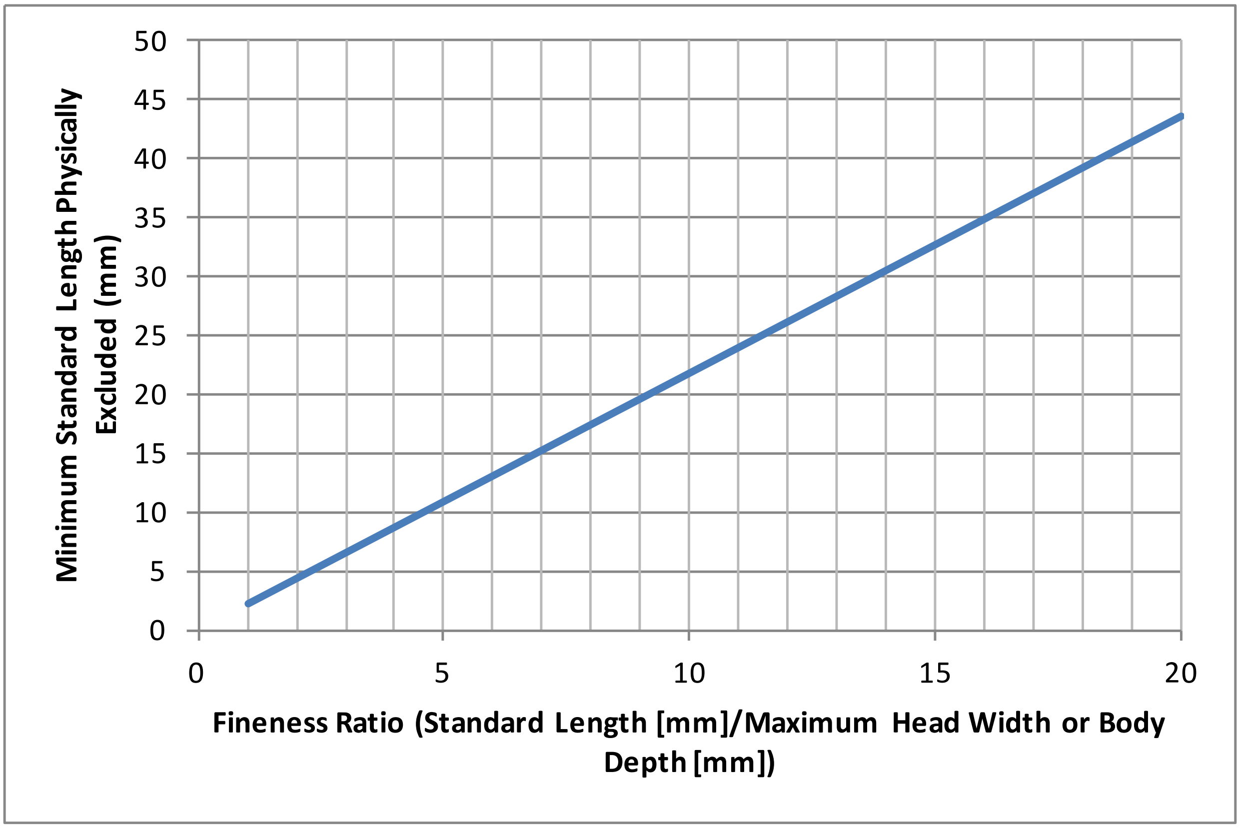
Figure 43c

Location of Prey-Size Fish Observed during Survey 3 with Mobile ARIS Sonar Camera

Monitoring Date: April 11, 2014
Monitoring Interval: 21:44–22:54

Figure 43d

Location of Prey-Size Fish Observed during Survey 4 with Mobile ARIS Sonar Camera



Based on equation provided by Young et al. 1997.

Figure 44. Minimum Standard Length of Fish Physically Excluded by 1.75-mm Vertical Profile Bar Fish Screens

Note: Fish sizes falling above the line are assumed to be physically excluded from entrainment.

Appendix A

Monitoring Plan to Evaluate the Biological Efficacy of the Freeport Regional Water Authority's New Water Intake Fish Screen, and Addendum to the Monitoring Plan to Evaluate the Biological Efficacy of the Freeport Water Authority's New Water Intake Fish Screen

MONITORING PLAN TO EVALUATE THE BIOLOGICAL EFFICACY OF THE FREEPORT REGIONAL WATER AUTHORITY'S NEW WATER INTAKE FISH SCREEN

PREPARED FOR:

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and
Sacramento County Water Agency
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PREPARED BY:

ICF International
630 K Street, Suite 400
Sacramento, CA 95814
Contact: Jeff Kozlowski
916/737-3000

April 2010

ICF International. 2010. *Monitoring plan to evaluate the biological efficacy of the Freeport Regional Water Authority's new water intake fish screen*. April. (ICF Project 00454.07.) Sacramento, CA. Prepared for Freeport Regional Water Authority and Sacramento County Water Agency, Sacramento, CA.

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6 Modified Slide Gate Used to Attach Sampling Net 6

Acronyms and Abbreviations

af	acre-feet
BO	biological opinion
cfs	cubic feet per second
DFG	California Department of Fish and Game
DIDSON	dual-frequency identification sonar
EBMUD	East Bay Municipal Utility District
fps	feet per second
FRWA	Freeport Regional Water Authority
FSC	Folsom South Canal
mgd	million gallons per day
mm	millimeters
NMFS	National Marine Fisheries Service
PVC	polyvinyl chloride
SCWA	Sacramento County Water Agency
USFWS	U.S. Fish and Wildlife Service
USGS	United States Geological Survey
VSWTP	Vineyard Surface Water Treatment Plant

Monitoring Plan to Evaluate the Biological Efficacy of the Freeport Regional Water Authority's New Water Intake Fish Screen

Introduction

The Freeport Regional Water Authority (FRWA) is constructing a new water intake on the Sacramento River near Freeport, California. Substantial completion of the new water intake and fish screen facility is expected in March 2010, with testing of the facility and the other conveyance components of the Freeport Regional Water Project extending to approximately July 2010. The new Vineyard Surface Water Treatment Plant (VSWTP), which will allow full operation of the water delivery system, is scheduled for completion in fall 2011.

The Freeport intake facility was designed to minimize fish entrainment losses associated with water diversions at the pumping facility. The Freeport intake facility has a fish exclusion system (i.e., a fish screen) that was designed to meet California Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS), and U.S. Fish and Wildlife Service (USFWS) fish screening criteria for adequate screen area, maintenance features, and facility hydraulics for the protection of delta smelt, Chinook salmon, steelhead, green sturgeon, and other fish species. Because the fish screen has been designed to meet an approach velocity of 0.2 foot per second (fps) to protect delta smelt, it exceeds NMFS's design criteria to protect juvenile salmonids.

This fish monitoring program is based on the terms and conditions included in the biological opinion (BO) for the effects of the Freeport intake facility on delta smelt (U.S. Fish and Wildlife Service 2004).

Freeport's BO from USFWS contains the following requirements (excerpted from page 129 of the BO):

1. FRWA will develop a Service-approved fish and hydraulic monitoring program prior to operation of the fish screen/intake facility to monitor the velocities and the entrainment and impingement of delta smelt at the fish screen/intake facility. Implement the Service-approved fish and hydraulic monitoring program upon the start of operations of the fish screen/intake facility and shall continue for 10 years. The Service-approved fish and hydraulic monitoring program shall include fish sampling behind the screens of the fish screen/intake facility, monthly from December 1st through July 31st, for a total of eight fish sampling efforts per year. The reporting period for the Service-approved fish and hydraulic monitoring program would be from December 1st through July 31st of each sampling year, and would be due to the Service at the end of each calendar year. The data collected by the Service-approved fish and hydraulic monitoring program shall include for all fish collected the species name, date collected, numbers of individuals, lengths, and location of collection (behind the screens).
2. Any salvaged specimens [delta smelt] taken shall be properly preserved in accordance with the Natural History Museum of Los Angeles County's policy of accessioning (10 percent formalin in a quart jar or freezing). Information concerning how the specimen was taken, length of the interval between death and preservation, the environmental conditions, the incidental take

permit number (l-1-04-F-0224), and any other relevant information shall be written on 100 percent rag content paper, with indelible ink, and included in the container with the specimen. Preserved specimens shall be delivered to the Service's Division of Law Enforcement at 2800 Cottage Way, Room W-2928, Sacramento, California 95825 (telephone: 916/414-6660).

A post-construction evaluation of fish screen operation under a range of operating scenarios will be conducted by FRWA under a separate effort to verify compliance with the fish screen hydraulic performance requirements set forth in USFWS's BO for delta smelt. Details of the fish screen hydraulic evaluations are described in the *Final Freeport Regional Water Project Fish Screen Hydraulic Evaluation Plan* (CH2MHill 2009). The hydraulic evaluation will occur during summer in the first year that EBMUD takes water. After the post-construction evaluation has been completed and the results accepted by the fisheries agencies—DFG, NMFS, and USFWS—FRWA will implement the proposed biological monitoring plan described herein to ensure continued compliance with the provisions of the BO.

The purpose of this biological monitoring plan is to meet the requirements of USFWS's BO on the effects on delta smelt from operating the Freeport intake facility, to demonstrate fish screen effectiveness for minimizing entrainment of delta smelt, and to evaluate "take" of delta smelt. In addition, USFWS has indicated that fish monitoring will provide data on life stages of fish species passing through the fish screen (Meier pers. comm.).

Biological monitoring required to address the terms and conditions of USFWS's BO is described in the following sections.

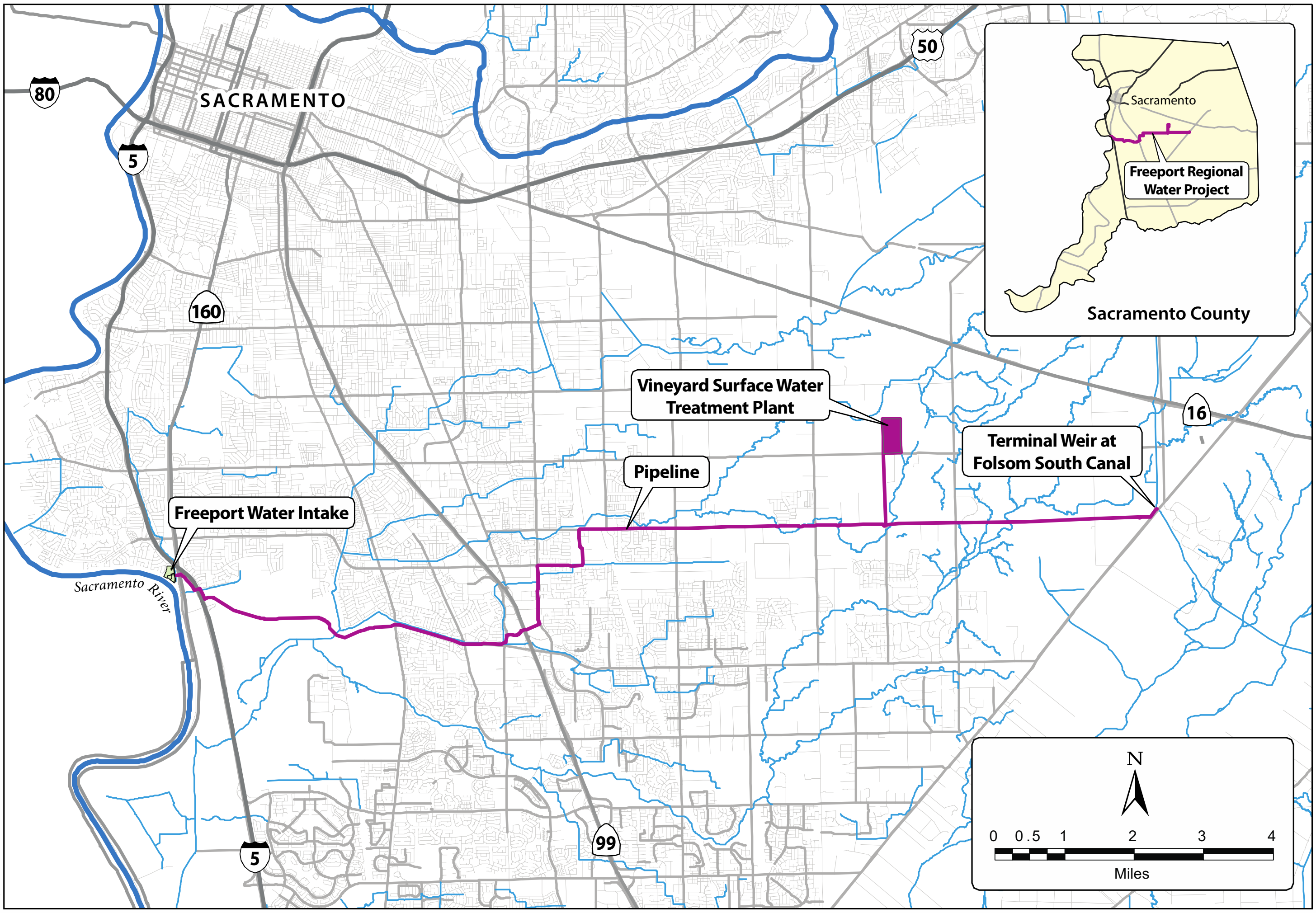
Description of the Facilities

Freeport Intake Facility

The new intake structure and pumping facility under construction are located on the east bank of the Sacramento River at Freeport Bend, a short distance upstream of the town of Freeport, California (Figure 1).

When completed and fully operational, the new intake facility will have a capacity of up to 185 million gallons per day (mgd), or 286 cubic feet per second (cfs). The new intake facility will have eight vertical pumps (seven duty pumps and one spare pump) split between two forebay chambers. Each chamber will house four pumps and eight fish screen bays (Figures 2 and 3). All the pumps will have an equal design flow rate of 26.4 mgd (40.8 cfs), and the maximum design flow rate for each chamber will be 105.7 mgd (163.5 cfs).

The intake facility's fish exclusion system was designed to meet DFG, NMFS, and USFWS criteria for adequate screen area, maintenance features, and facility hydraulics for the protection of fish. The fish screen will consist of 1.75-millimeter stainless steel wedge-wire and has been designed to meet a maximum approach velocity (i.e., velocity perpendicular to the fish screen face) of 0.2 fps. This approach velocity criterion was chosen specifically because it will protect delta smelt, which are weaker swimmers than fry and juvenile steelhead and Chinook salmon. However, because the Sacramento River at Freeport Bend is tidally influenced and subject to reverse flow, the criterion for sweeping velocity (i.e., the velocity parallel to the screen face) will not always be met. A floating log



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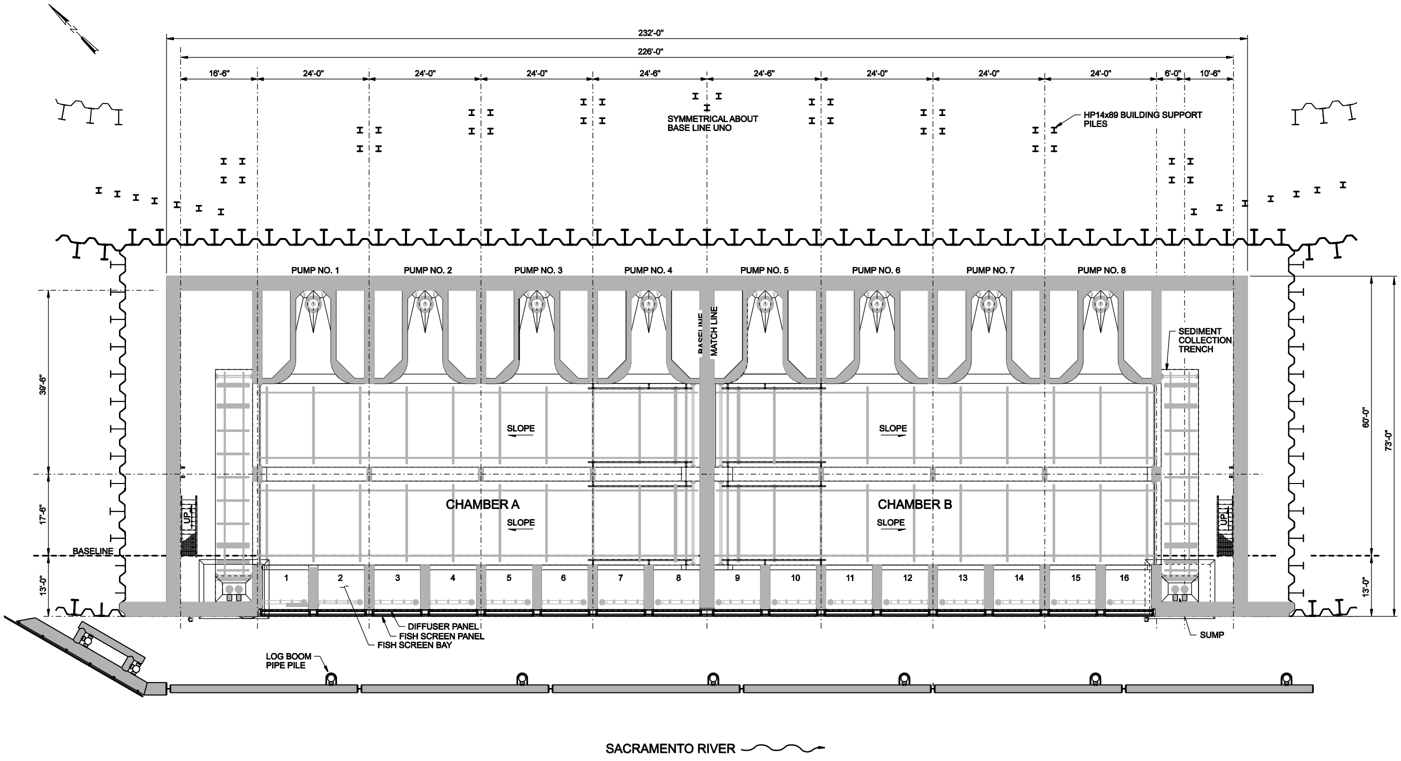
an ICF International Company

Figure 1
Freeport Regional Water Project Location



Source: CH2MHill, 6-29-06.

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Figure 2
Plan View of Freeport Water Intake Facility

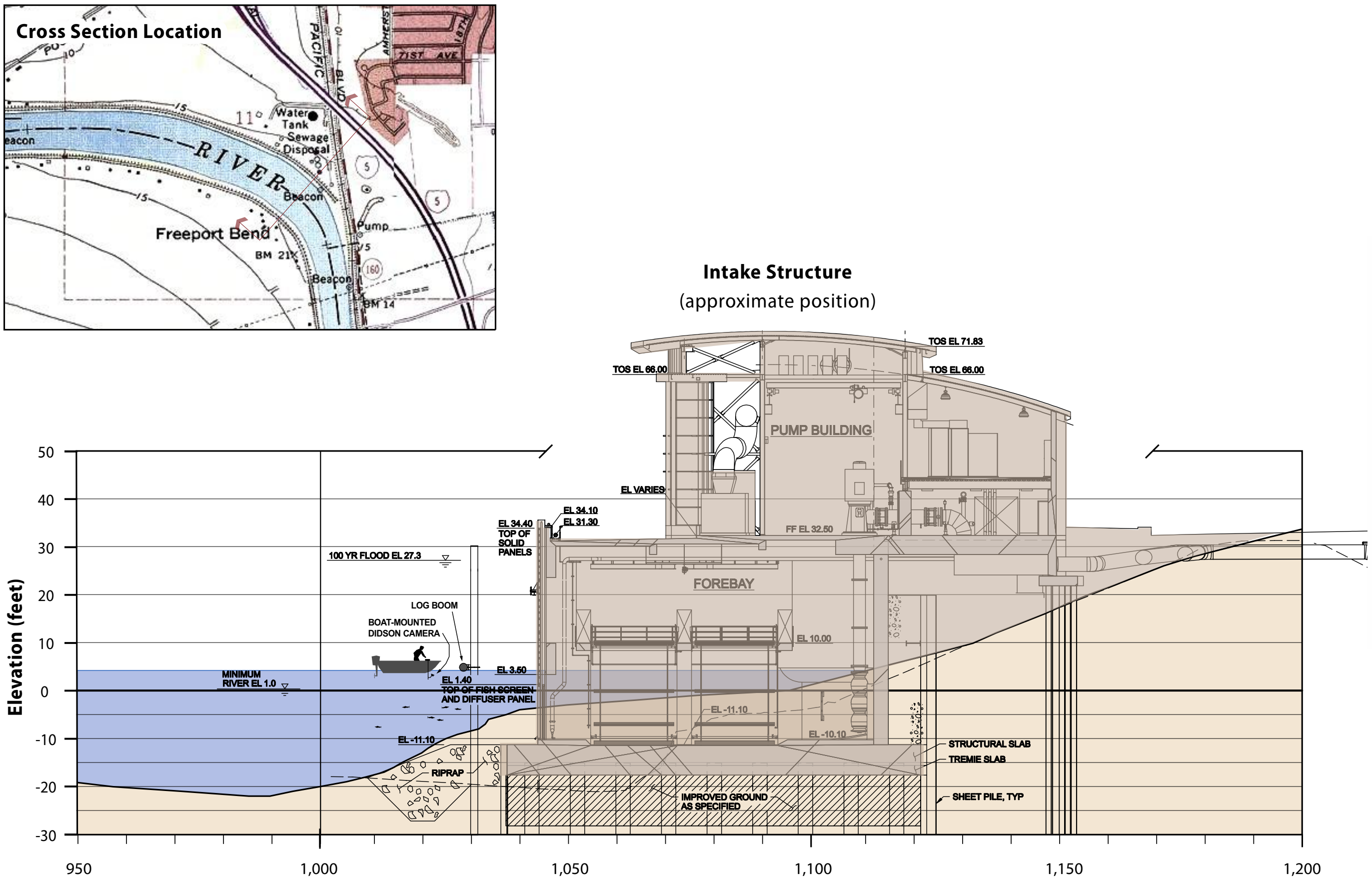

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Figure 3
Cross Section of the Sacramento River at Freeport Water Intake

boom on the river side of the intake facility will protect the fish screen from damage by floating debris and boaters (Figures 2 and 3).

Diversion water will be carried to the VSWTP (discussed below) and the Folsom South Canal (FSC) through pipelines. The 66-inch turnout pipeline to the VSWTP has been designed for a 100 mgd capacity to allow for buildout water demands of Sacramento County. The pipeline leading to the FSC will deliver East Bay Municipal Utility District (EBMUD) dry-year supplies and has been designed for a capacity of 100 mgd.

Vineyard Surface Water Treatment Plant

The VSWTP is under construction, with completion expected in 2011. The VSWTP will be owned and operated by Sacramento County Water Agency (SCWA) and will have a capacity of 50 mgd. The VSWTP will include a flushing basin, flash mix system, flocculation and sedimentation basin, filters, and a clearwell.

Before water is delivered to the VSWTP, it will pass through a sleeve valve to reduce the pressure before discharging into the flow distribution structure (Figure 4). The sleeve valve consists of an internal nozzle configured with 1-inch-diameter holes. As the water flows through these holes, it converges, causing excess pressure in the pipeline to dissipate. The flow distribution structure will consist of two separate chambers that measure approximately 25 feet by 25 feet. The chamber walls will be approximately 22 feet high. After passing through the sleeve valve, the water will enter each chamber of the flow distribution structure through a 60-inch pipe. The pipe openings will be flush with the inside chamber wall of the flow distribution structure. One of the two chambers at the flow distribution structure will be fitted with a slide gate to facilitate entrainment monitoring at the point where water enters the chamber through the 60-inch pipe. Water velocities entering the chamber will vary according to the volume of water entering the VSWTP but are expected to be around 2.4 fps (i.e., 30 mgd) when the treatment plant is initially operated.

Operations Schedule

Up to 100 mgd will be delivered to either VSWTP or EBMUD; however, the instantaneous diversion amount from the Sacramento River will not exceed 185 mgd. On average, EBMUD will take delivery of water approximately three out of every ten years.

Because VSWTP is under construction, water delivery to the VSWTP is not anticipated until 2011. Once VSWTP is operational, SCWA deliveries will be continuous but will vary by season. SCWA deliveries will increase from an initial summertime peak diversion of approximately 30 mgd in 2011 to the designed full capacity of 100 mgd 30 years later, after an anticipated phase 2 construction project.

In contrast, dry-year deliveries of EBMUD supplies may occur as early as spring 2010. In years when dry-year deliveries occur, these deliveries could begin as early as March 1 if drought conditions are declared in February. These deliveries would have to cease if an official drought was not declared on May 1. In years when an official drought is declared, dry-year deliveries of EBMUD supplies could continue through February of the following year (up to the limit of EBMUD’s maximum annual allocation 133,000 acre-feet [af]).

Scope of Biological Monitoring

The long-term biological monitoring program will consist of two elements: entrainment monitoring and impingement/predator monitoring. Entrainment monitoring will occur on a regularly scheduled basis from December through July, while impingement/predator monitoring will occur once in April or May during the first three years that entrainment monitoring is conducted. If EBMUD does not take its dry-year delivery during the first two years of entrainment monitoring and is not projected to take its deliveries during the third year of operation, impingement/predator monitoring will be delayed until dry-year deliveries to EBMUD are occurring along with deliveries to SCWA. This will ensure that at least one impingement/predator monitoring activity is conducted during a period when the Freeport intake facility is operating at a higher capacity than if only SCWA is taking delivery.

Entrainment monitoring will be conducted to determine the occurrence, timing, and magnitude of entrainment of delta smelt. Because eggs and larvae of other fish species are also likely to be entrained with water diverted by the intake facility, entrainment monitoring will provide entrainment data for fish species other than delta smelt. Impingement monitoring will be conducted to determine whether delta smelt and other fish species are being impinged (temporary or permanent contact) against the fish screen. Predator monitoring, a component of impingement monitoring, will be conducted to determine whether predator or prey species are more concentrated in the vicinity of the water intake facility and fish screen.

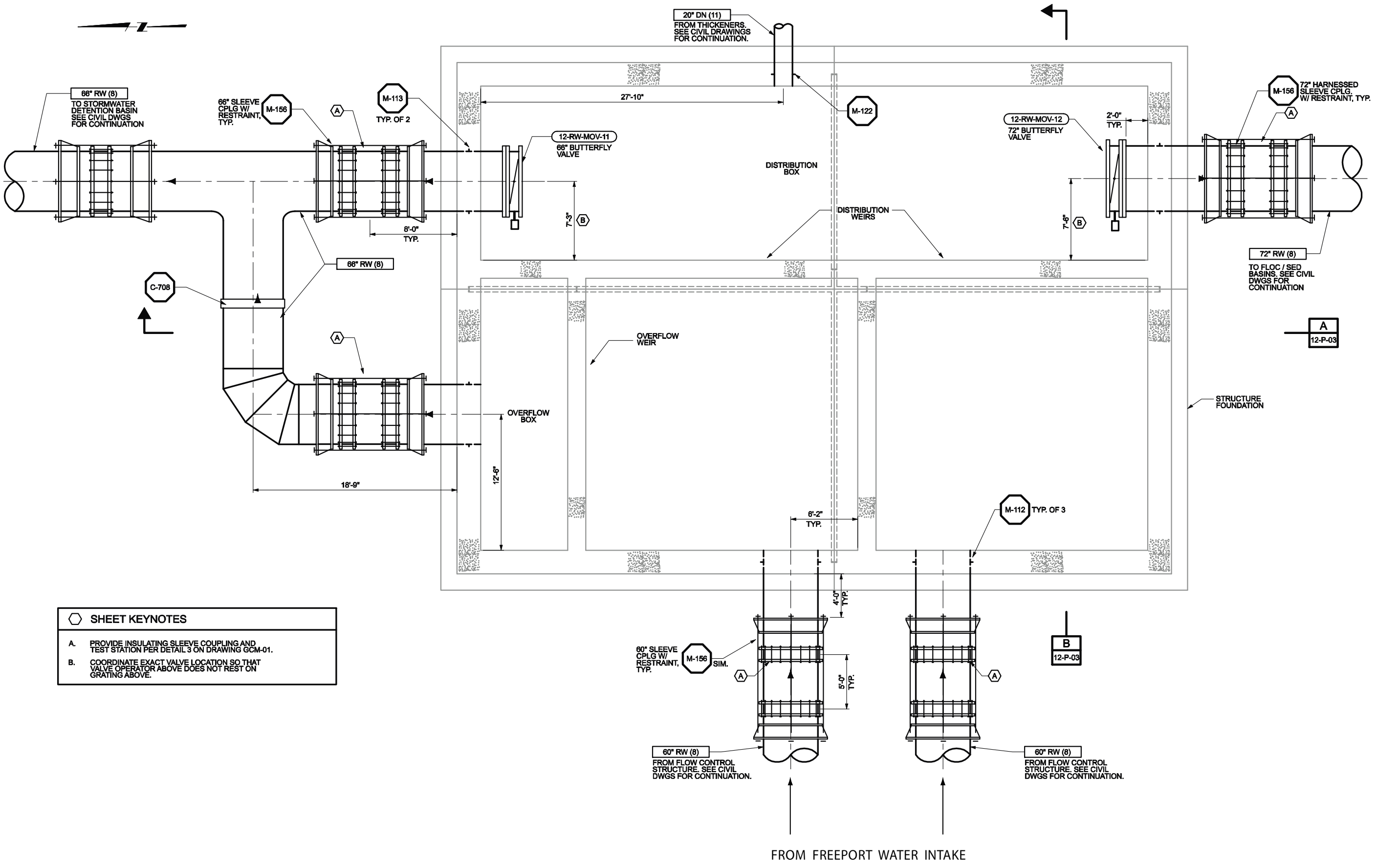
Entrainment Monitoring

Methods and Equipment

Sampling Location

Term and Condition 2 of the USFWS BO requires that fish sampling be conducted behind the screens of the fish screen/intake facility upon the start of operations of the fish screen/intake facility for a period of 10 years.

In October 2008, an ICF Jones & Stokes fish biologist visited the Freeport water intake facility site to determine the feasibility of conducting entrainment monitoring at the intake facility. Based on numerous constraints at the facility, including limited access to the forebay and concerns about the chain and flight system associated with the sediment removal system, the fish biologist concluded that using nets to conduct entrainment monitoring at this location would not be feasible. As a result, two terminal points were investigated to determine their feasibility: the flow distribution structure at VSWTP and the terminal weir at the FSC. Based on these site visits, the fish biologist concluded that the only feasible location for conducting entrainment monitoring was at the flow distribution structure at VSWTP. The feasibility of conducting entrainment monitoring directly behind the fish screens using a pump also was investigated. However, this sampling method was determined to be less desirable than net sampling at VSWTP because of the limited area that can be sampled behind the fish screen (i.e., the area being sampled at any one time is equal to the area of the pipe inlet leading to the pump). In contrast, water entering VSWTP is composed of blended water that has, theoretically, passed through all of the fish screens that are being used at the time that pumping (and entrainment monitoring) is occurring.



SHEET KEYNOTES

A. PROVIDE INSULATING SLEEVE COUPLING AND TEST STATION PER DETAIL 3 ON DRAWING GCM-01.

B. COORDINATE EXACT VALVE LOCATION SO THAT VALVE OPERATOR ABOVE DOES NOT REST ON GRATING ABOVE.

Source: MWH, 7-22-07.

Graphics ... 00454.07-007 (10-09)

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Figure 4
Flow Distribution Structure at the Vineyard Surface Water Treatment Plant

USFWS toured the facility in June 2009 and concurred that sampling with nets immediately behind the fish screens at the intake facility was not feasible. USFWS also concurred that net sampling at VSWTP was preferred over pump sampling at the water intake facility (Meier pers. comm.). Further discussions were held to determine the feasibility of conducting entrainment monitoring at VSWTP should EBMUD initiate its dry-year water deliveries in spring 2010 and/or 2011 and the VSWTP is not yet fully operational. Assuming that water can be sent to the flushing basin, it was determined that limited entrainment sampling at the VSWTP flow distribution structure may be possible if EBMUD implements its option to conduct dry-year water deliveries. If it turns out that water cannot be sent to the VSWTP flushing detention basin during EBMUD-only pumping, biological monitoring would not be initiated until VSWTP is constructed and operational in 2011.

Sampling Gear

A conical nylon net will be placed at the discharge end of the pipeline where it enters the flow distribution structure (Figure 5). The net will be engineered for relatively easy insertion and removal using a slide gate built into the inside wall of the flow distribution chamber (Figures 5 and 6). The net will be attached to a short (12-inch-long) pipe section attached to the slide gate. The diameter of the pipe section (60 inches) will match the diameter of the outlet pipe to provide a smooth transition between the outlet pipe and the mouth of the net and to facilitate sampling of the entire flow entering the flow distribution chamber. The slide gate and net will be raised and lowered using a hand-operated hoist fitted with a hand wheel (Figure 6).

The net will be 505-micron mesh plankton net constructed of nylon with a 60-inch-diameter opening. The net will be approximately 15 feet long with one or more rings located between the mouth and cod end[1] of the net to maintain the net shape. The net will taper from the 60-inch diameter at the mouth to 4 inches at the cod end. The cod end will be constructed of polyvinyl chloride (PVC) and netting made from the same material as the sampling net and will attach to the main body of the net with a connector containing a quick release mechanism to allow the easy removal and replacement of the cod end. An extra cod end will be available to facilitate the immediate redeployment of the net while fish are removed from the first cod end. The proposed design of the plankton net and cod ends are based on conversations with Research Nets, Inc., located in Bothell, Washington.

Sampling Procedures

Sampling will occur one to two days per month between December 1 and July 31 each year. During December, January, February, and July, sampling will be limited to one day per month. Sampling frequency will be increased to two days per month during March–June when delta smelt are more likely to be present in the vicinity of the water intake facility (Meier pers. comm.). For months when sampling will be limited to one day, each sample day within each month will be selected independently and at random from among the available days of the month. During March–June when sampling will occur on two days each month, the first day of entrainment monitoring in March will be selected at random from among the first 15 days in the month; subsequent sampling days for entrainment monitoring will be conducted every 2 weeks (plus or minus 1 day) thereafter through June, for a total of 12 sampling days for the entire monitoring period (December–July). For example, Table 1 lists the monitoring days for a hypothetical monitoring year.

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[1] The cod end is the collection cylinder at the closed end of the net.

Table 1. Example of Sampling Days for a Hypothetical Monitoring Year

	Monitoring Month and Date							
Sampling Day	December	January	February	March	April	May	June	July
First	December 12	January 6	February 22	March 9	April 6	May 4	June 8	July 21
Second	n/a	n/a	n/a	March 23	April 20	May 18	June 22	n/a

Note: Shading represents months when sampling will occur on two days. n/a = not applicable. The precise dates for subsequent sampling days may vary by 1 day before or after the date listed to allow flexibility in conducting the monitoring.

By monitoring every 2 weeks, FRWA will increase the likelihood that the monitoring program will capture the temporal occurrence of delta smelt that are potentially present in the river and subject to entrainment by the intake facility. This schedule also provides an opportunity to conduct entrainment monitoring under varying environmental conditions. Spawning and dispersal of Delta smelt may be linked to lunar phase and/or tidal conditions (Bennett 2005).

On the days that monitoring is conducted, sampling will be initiated between 0600 and 1200 hours and will continue for a period of 24 hours. The precise time sampling will be initiated will depend on sunrise times and the time it takes water to travel from the intake to the VSWTP (see below). Entrainment collections will be made continuously over a 24-hour period to increase the likelihood of observing a rare occurrence, to sample under variable environmental conditions (e.g., tidal and river velocity), and to account for diel variation in entrainment densities. To account for expected differences in fish movement during the day and at night, each sampling day will be divided into two separate monitoring periods. The first monitoring period will consist of sampling conducted primarily during daylight, while the second monitoring period will consist of sampling conducted primarily at night. Because of the distance separating the intake and the flow distribution structure at the VSWTP, it will be necessary to stagger the start and ending times of the sample according to the travel time of the water in the pipeline, which is dependent on pumping rate. For example, at a pumping rate of 20 mgd it will take 23.9 hours for water to travel from the intake to VSWTP; higher pumping rates will result in substantially shorter travel times (e.g., at 85 and 100 mgd, travel times will be 5.6 and 4.8 hours, respectively). Initially, sampling intervals within each day's monitoring period will be no longer than 2 hours (i.e., the net will be retrieved to collect entrained organisms and re-deployed every 2 hours) to gauge the level of debris loading and organisms entrained. Subsequent sampling intervals may be increased (e.g., every 6 hours or longer) if debris loads and fish counts are manageable and it is felt that increasing the sampling interval will not compromise monitoring results. Effort will be made to begin and end monitoring intervals around sunrise and sunset so that differences in entrainment between day and night are discernable.

At the end of each sampling interval, flow to the net will be discontinued by raising the slide gate and net. Once the net is in the fully raised position, a hose will be used to rinse the nets, allowing debris and captured fish to be flushed from the net and funneled into the cod end. Once all of the debris and fish are rinsed from the net and confined to the cod end, the cod end will be removed from the net and a second cod end will be attached in its place. Afterwards, the net will be lowered to its original position and sampling will resume. This process will be repeated, as needed, until a continuous 24-hour period of monitoring is completed.

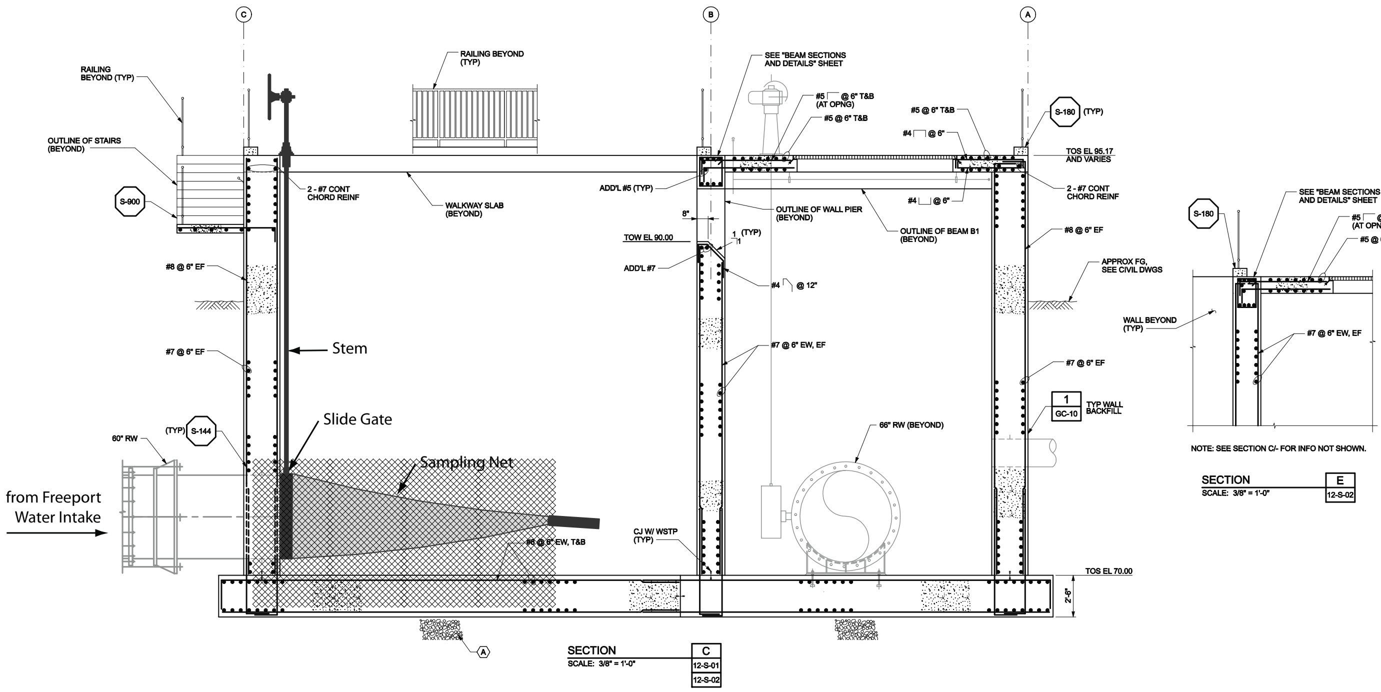
After the nets have been rinsed and the cod ends removed, captured fish and debris collected in the cod end will be transferred to a sieve with a mesh size of 500-micron or smaller where the contents

SHEET KEYNOTES

A. PROVIDE 6" COMPACTED TYPE G AGGREGATE BASE UNDER ALL STRUCTURE FOUNDATIONS AND EXTERIOR SLABS IN ACCORDANCE WITH SPEC SECTION 02200 (TYP).

GENERAL SHEET NOTES

1. SEE "FOUNDATION PLAN SHEET FOR GRIDLINE INFORMATION AND DIMENSIONS NOT SHOWN.
2. TOS = TOP OF SLAB
   TOW = TOP OF WALL OR TOP OF WEIR
3. CONTRACTOR TO CONFIRM AND COORDINATE SIZE AND LOCATION OF EQUIP AND PIPING WITH CIVIL AND PROC DWGS.



Source: MWH, 1-31-08.

Graphics … 00454.07-007 (7-09)

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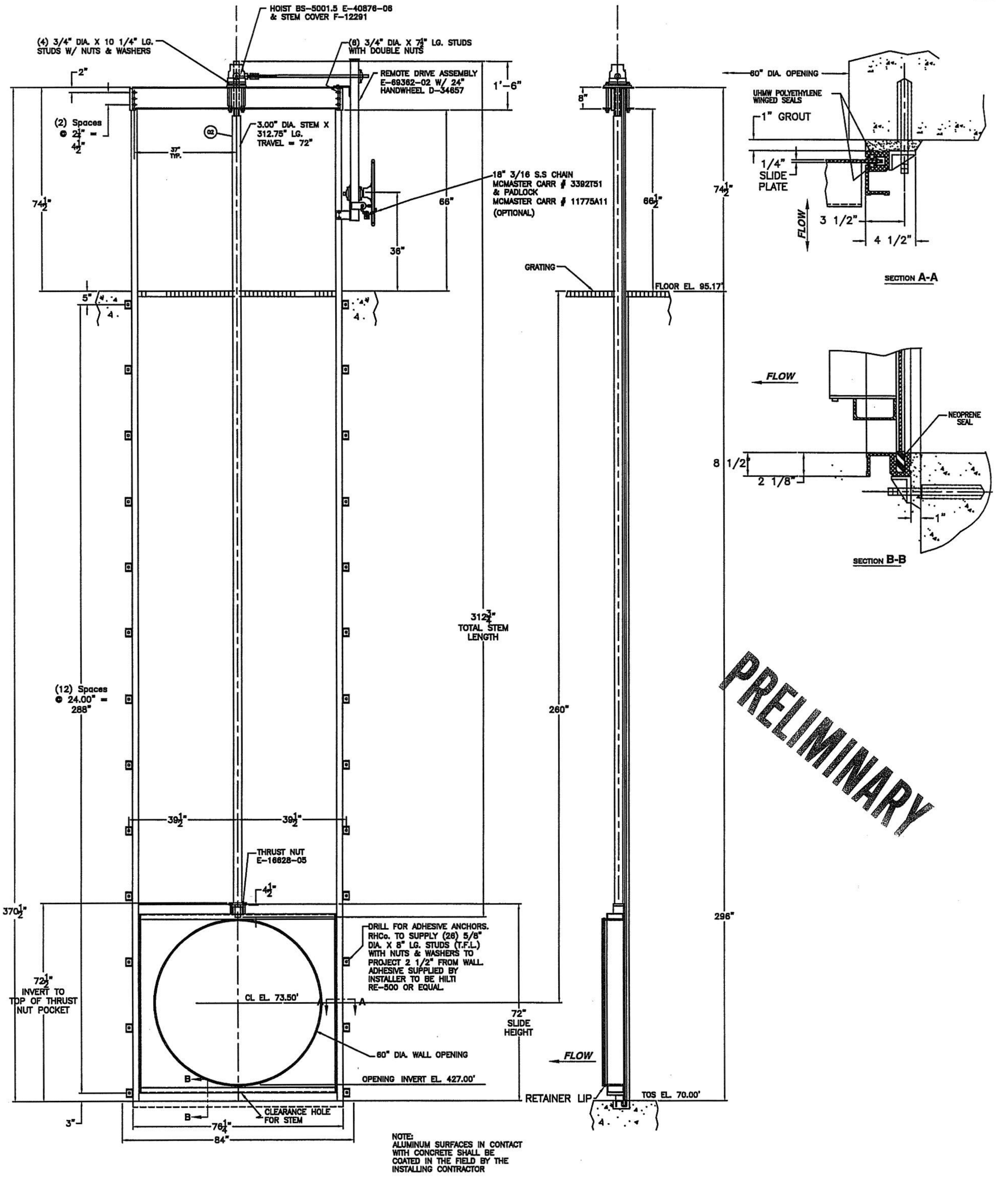
Figure 5
Flow Distribution Structure at the Vineyard Surface Water Treatment Plant and Location of Sampling Net and Slide Gate



Source: Rodney Hunt Company, 11-14-08.

Not to Scale

Graphics … 00454.07-007 (7-09)

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Figure 6
Modified Slide Gate Used to Attach Sampling Net

will be rinsed with 5% formalin. After all of the contents have been rinsed in the sieve, the sample will be transferred to a sample jar containing 5-percent formalin to preserve the sample until it can be processed in the laboratory as described below under "Sample Processing." The sample number will be written on a small slip of 100% rag content paper and included in the container with the preserved collection (sample identification is discussed below under "Sample Information").

Variables Measured and Recorded

Data that will be recorded for each sample fall into three categories: sample information, facility operating information, and environmental data. These data will be recorded on data collection forms that will be prepared prior to implementation of the monitoring program. These recorded variables and their description are provided below.

Sample Information

This information includes data associated with the collection of each entrainment sample. Sample information will be recorded on prepared data collection forms at the beginning and end of every sampling event will include:

- Start date and time of sample
- End date and time of sample
- Unique sample number (last two digits of calendar year, month, day, start time [military time], end time [military time], and sample jar number [e.g., 01, 02, etc.]). For example, for a sample event starting at 10:00 p.m. on December 29, 2013, and ending at 4:00 a.m. the next morning the sample number would be: 131229_2200-0400_01. If a second sample jar was required to preserve the collection, the sample number for that jar would be 121229_2200-0400_02.
- Number of containers used to preserve sample
- Sampling location (VSWTP)

Water Intake and Flow Distribution Structure Operating Information

This information includes data on the operation of the intake facility and the flow distribution structure at VSWTP during the collection of the entrainment samples. In instances where this information is not readily available at the time that samples are collected, SCWA's program manager overseeing the biological monitoring will obtain the information and enter the data on data collection forms as soon as possible following collection of the sample. Intake operating information to be recorded for each sampling event will include:

- The intake pumps operating and their operating speed (e.g., mgd)
- The intake forebay chambers operating
- Total volume of flow through the fish screens while the net was fished
- Total volume of flow sampled by the net at VSWTP

Environmental Data

This information includes environmental data measured coincident with each entrainment sample or obtained from the Internet during data analysis for the day that samples were collected and, in some cases, for one or more of the days before the entrainment samples were collected. For example, it may be useful for data analysis purposes, to obtain turbidity, temperature, and flow data for a several-day period leading up to and including the day entrainment samples are collected. Because environmental conditions (e.g., water temperature) often vary over the course of the day, these data may need to be collected several times during the sampling event or come from continuous monitoring equipment (e.g., water temperature data loggers). In addition, because it can take up to 24 hours for water diverted at the pumps to reach the flow distribution structure at VSWTP, it will be necessary to record environmental data for the times that correspond to when the sample water was diverted from the river.

The following environmental data will be recorded by VSWTP personnel conducting entrainment sampling for each sampling interval:

- Sunrise and sunset times (necessary for knowing when to initiate and terminate entrainment sampling)
- General weather conditions (e.g., clear, cloudy, dry, rain)

The following environmental data will be obtained from the Internet and other appropriate sources by personnel conducting the data analysis phase:

- Intake water temperature (preferably from continuous monitoring equipment)
- Water clarity/turbidity
- River flow and stage
- Sacramento River water velocity
- Moonrise and moonset times, and moon phase

Information on river flow, river stage, and water velocity will be obtained from the United States Geological Survey (USGS) stream gage (No. 11447650), for the Sacramento River located near Freeport. Information on rise and set times for the sun and moon and moon phase will be obtained from the Internet. All other environmental data either will be measured at the time samples are taken or will come from continuous monitoring equipment (e.g., water temperature data loggers).

Sample Processing

Following sample collection, entrainment samples will be processed in the laboratory to identify species, relative abundance, and sizes of fish entrained. Laboratory processing of entrainment samples will consist of two distinct steps: sorting fish and eggs from detritus and other materials and analyzing the species, life stages, and sizes of the species collected.

Sorting

To facilitate sorting, the entrainment sample will be placed on a sieve with a mesh size equal to or smaller than the sampling net and washed with clean water before being transferred to a shallow container partially filled with clean water. All detritus will be carefully teased apart and inspected for fish and fish eggs before being discarded. Sorting will be conducted by eye with the aid of a magnifying glass as appropriate. All sorting will be done in an appropriately ventilated area to minimize worker exposure to preservative fumes. After all detritus has been inspected and removed from the sorting tray, the sorter will visually inspect the entire sorting tray to locate and remove all fish and fish eggs.

While fish and fish eggs are being removed from the sorting tray, the sorter will place the retrieved specimens into separate sample jars or vials, according to group based on size and/or life stage, along with sufficient fresh preservative (e.g., 5% formalin). For example, all juvenile fish (post-larval stage) will make up one group, and larval fish and fish eggs will make up the remaining two groups. All vials will be carefully labeled, both inside and out, and retained for subsequent analysis (i.e., species identification). All relevant information for the entrainment sample will be recorded in an appropriate laboratory log book. At a minimum, this information will include the person conducting the sorting, the dates the sample was collected and sorted, the identification number of the entrainment sample that was sorted, and the identification numbers of the sample jars/vials to which the specimens were transferred.

Identification and Analysis of Fish and Fish Eggs Collected

If the number of organisms in any of the vials makes it impractical to enumerate and identify all fish, it may be necessary to take a subsample of the catch before the sample is processed. If subsampling is necessary, standard methods for taking subsamples of the catch should be employed to ensure that the organisms selected for identification are chosen randomly. Random selection ensures that the species represented in the subsample are representative of the entire collection. Following subsampling, the portion of the catch not subsampled will be returned to the sample jar or vial, along with fresh preservative, and retained for subsequent analysis (if necessary).

All fish and fish eggs in the sample (or subsample) will be identified to the lowest practical taxon using a dissecting scope, as appropriate. Analysis of the samples will be conducted only by qualified individuals who are familiar with fish species identification, including post-larval fish and fish eggs. Once all fish in the entrainment samples are identified to the appropriate taxonomic category (family, genus, or species) and life stage, they will be counted, measured for total length (to nearest 0.1mm for larvae and 1.0 mm for juvenile and larger fish), and recorded. In addition, all individuals from each taxonomic group and life stage will be measured for total length. If necessary, subsamples of 25 to 30 individual lengths per taxon and life stage will be measured, provided that specimens collected in the sampling net are sufficiently intact[2].

Taxonomic keys to early life stages of Sacramento River fish will be used to identify fish and fish eggs caught by the plankton nets. Alternatively, sorted samples will be sent to a specialist for species identification and life stage confirmation.

Following identification and analysis, fish (with the exception of delta smelt) will be stored in sample jars filled with fresh preservative and appropriately labeled as described above. Any delta smelt identified in samples will be preserved separately as discussed below. Preserved samples will be retained by SCWA or their designee for the duration of the monitoring program.

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[2] Prior to entering the flow distribution structure at VSWTP, water (and fish) will pass through a flow control valve (sleeve valve) to reduce the water pressure in the pipeline. Fish entrained with water passing through the sleeve valve may be damaged in the process, making measurements difficult.

Preservation of Delta Smelt and Delivery to U.S. Fish and Wildlife Service

Any delta smelt identified in samples during sample identification and analysis will be preserved. As described in the BO, information concerning how the specimen was taken, length of the interval between death and preservation, the environmental conditions, the incidental take permit number (l-1-04-F-0224), and any other relevant information will be written with indelible ink on 100% rag content paper and included in the container with the specimen. Preserved specimens will be delivered to the U.S. Fish and Wildlife Service, Division of Law Enforcement, at 2800 Cottage Way, Room W-2928, Sacramento, CA 95825 (telephone: 916/414-6660).

Impingement and Predator Monitoring

Impingement monitoring will consist of two components: monitoring for fish impingement on the fish screen using a combination of close-range, dual-frequency identification sonar (DIDSON) monitoring and SCUBA diving. The purpose of this monitoring will be to document whether fish are being impinged on the face of the fish screen, where impingement is defined as the temporary or permanent contact of the fish screen by fish. Predator monitoring will consist of long-range DIDSON monitoring of predator and prey fish in front and within the vicinity of the fish screen. The purpose of this monitoring will be to evaluate whether the fish screen may be concentrating predators, increasing predator activity, concentrating prey, or causing prey species to become disoriented—all of these factors can lead to increased predation. These monitoring components are described in the following sections.

Methods and Equipment

Impingement Monitoring

Sampling Location

Close-range DIDSON monitoring will focus on one or more of the 16 fish screen panels along the outside (i.e., river side) of the fish screen. The precise location of the DIDSON monitoring will be determined based on operation of the intake facility and the results of observations of the face of the fish screen by SCUBA divers (dive surveys are described below). Close-range inspection of the fish screen by SCUBA divers will be conducted along the entire length of the fish screen concurrent with DIDSON monitoring. Divers will systematically cover the entire area of each fish screen panel, from top to bottom. Conducting such inspections of the fish screen during DIDSON monitoring will provide an opportunity for divers to validate any observations made using the DIDSON camera.

Sampling Gear

A boat-mounted DIDSON system will be used to monitor for fish impingement. The DIDSON system will be deployed from an adjustable pole mount attached to the side of the boat. The pole mount will provide precise pan and tilt capabilities and will allow the transducer to be moved up or down to allow optimal viewing of the fish screen panel. The boat will be located approximately 15 feet (horizontal distance) from the fish screen and sufficiently anchored to stabilize the DIDSON system to the maximum extent practical. The boat operator will ensure that all standard safety precautions are followed, including ensuring that U.S. Coast Guard–approved life jackets are on board for every occupant of the boat. Because DIDSON monitoring will occur during dusk and at night, the boat will need proper navigation lighting. The boat also will need to be equipped with 110 volt power to operate the DIDSON equipment. Alternatively, a portable Honda generator can be used to supply the necessary power.

Divers will use standard SCUBA equipment and will be outfitted with a diver's slate for taking notes underwater and fine-mesh bags for collecting fish found impinged on the fish screen. Divers will access the downstream end of the water intake facility by boat. Three safety flags displaying the universal sign for diving will be deployed during times when the divers are in the water. The flags will be deployed at the middle, upstream end, and downstream end of the water intake facility, on the river side of the log boom where they will be visible to boaters. Underwater flashlights will be used during nighttime dives to facilitate observations in the dark. If a boat is used to conduct diver inspections, the boat operator will ensure that the boat is properly outfitted with standard safety equipment and navigation lighting, as described above.

Sampling Procedures

Impingement monitoring will occur over two days in April or May during each of the first three years that entrainment monitoring is initiated. This period coincides with the time of year when delta smelt are most likely to be present in the vicinity of the intake facility and at risk of impingement as a result of changing environmental conditions (e.g., reverse flow). If practical, impingement monitoring will be conducted concurrent with entrainment monitoring to detect any relationships between impingement and entrainment observations. If weather or environmental conditions (e.g., high flows or turbid conditions) result in poor viewing or unsafe diving conditions, diver inspections will be postponed until the next suitable entrainment-monitoring day.

If dry-year deliveries to EBMUD are not occurring when monitoring for impingement is initiated in the first two years of monitoring, the third impingement monitoring effort will be postponed until a time when the Freeport intake facility is pumping to meet both EBMUD and SCWA deliveries. By conducting impingement monitoring when both EBMUD and SCWA deliveries are occurring, FRWA will be able to inspect the fish screens for impinged fish at a time when the Freeport intake facility is operating at a higher capacity than it would be if only SCWA or EBMUD demands were being met.

Diver Inspections

On the days that impingement monitoring is conducted, two divers will systematically inspect each screen panel for impinged fish on two separate occasions. Up to three divers will be used to perform the dive inspections; however, divers will work in pairs for safety and to maximize efficiency, rotating the divers using the third diver as a substitute as needed to ensure that divers are provided sufficient rest periods. Diver inspections will occur during the two DIDSON monitoring periods. The first inspection will occur shortly after commencement of the daylight portion of the afternoon DIDSON monitoring, and the second inspection will commence 2 hours after sunset during the nighttime DIDSON monitoring.

Immediately before a diver inspection, the fish screen brush cleaning system will be turned off for diver safety and to allow the divers to be able to observe and collect any fish that have been impinged. The brush cleaning system will be disabled just long enough for divers to complete their inspections of the fish screen. However, if debris accumulates on the fish screen panels to the point that it compromises the integrity or normal operation of the fish screen or brush cleaning system, or affects the hydraulics of the fish screen in such a way that it biases the impingement monitoring results (e.g., causes more fish to be impinged than would occur under normal brush cleaning operations), diver inspections will cease temporarily. The brush cleaning system will be reactivated once divers are notified (using a prearranged signal that is audible to the divers) and have returned to shore or the boat. After accumulated debris has been removed by the brush cleaning system, the cleaning system once again will be deactivated and diver inspections will resume. The process will be repeated, as necessary, until all screen panels have been inspected.

After the dive flags are deployed, the divers will enter the water from shore or from a boat at the downstream end of the intake facility and swim upstream to the Number 8 and/or Number 16 fish screen panel depending on operation status of the two intake forebay chambers (Figure 2). Prior to beginning the dive, divers will note on their dive slates the date and time. The two divers will thoroughly and systematically inspect the entire surface of the screen panel for impinged fish. The species (if possible), size, and location of impinged fish will be noted. To note location of impinged fish on individual fish screen panels, divers will visually divide each fish screen panel into nine equal subsections (i.e., subsections A–I). Subections A–C will make up the top row of the fish screen panel subsections from left to right, followed by the middle row of subsections (D–F) and the bottom row of subsections (G–I). Impinged fish that can be collected from the face of the fish screen will be placed in a marked mesh bag for later identification and measurement. One diver from each dive team will have 16 pre-marked bags numbered in sequence from 1 to 8 or 9 to 16. Divers will place all impinged fish collected from the fish screen panel into the bag that corresponds to the numbered fish screen panel being surveyed. The process will be repeated until all of the fish screen panels are observed. Only the screen panels covering operating chamber forebays will be inspected. During the time that the divers are in the water, the automated brush cleaning system for the fish screen will be turned off for safety and to allow the divers to be able to observe and collect any fish that have been impinged (see above).

Following completion of each dive, the divers will tally the results (grouped by screen panel) on their dive slates and record these results on prepared data sheets. Impinged fish collected from each fish screen panel will be transferred to a labeled sample jar filled with 5% formalin for later identification and measurement. Each sample jar will contain the date and time of the inspection and the number of the fish screen panel from which collections were made.

DIDSON Monitoring

On the day DIDSON monitoring is conducted, monitoring will occur over two 4-hour periods. The first 4-hour monitoring period will occur during daylight and will end at dark, approximately 30 minutes after sunset. The second 4-hour monitoring period will occur at night and will begin shortly after the daylight monitoring period has concluded. The DIDSON monitoring crew will randomly select one of the fish screen panels in front of an operating forebay chamber for observation.

Once a fish screen panel is selected for monitoring, the boat will be positioned approximately 15 feet in front of the fish screen and held in place with several anchors to minimize movement of the boat and the DIDSON system (Figure 3). However, the precise distance that the boat will be positioned from the fish screen will depend on the need to achieve sufficient detection capabilities and resolution to detect small fish and their proximity to the screen. At most, it is expected that only one or two fish screen panels will be viewable because of the need to have the DIDSON system close to the fish screen.

The DIDSON system will be suspended from the boat and positioned at an oblique angle (looking upstream) relative to the fish screen to maximize the opportunity of observing fish that are close to the fish screen. Once they are positioned, the boat and DIDSON system will remain in place for the duration of both 4-hour monitoring periods unless environmental conditions or other factors require repositioning of the boat or the DIDSON system. The DIDSON system will be operated continuously during each 4-hour monitoring period, including when divers are conducting underwater inspections of the fish screen.

Water velocity will be measured from the boat at the beginning of impingement monitoring and every ½ hour thereafter while the DIDSON monitoring is being conducted. A Marsh-McBirney flow meter (or similar device) will be used to measure velocity. Water velocity (in feet per second) will be measured approximately 3 feet below the water surface on the river side of the boat (i.e., away from the influences of the fish screen log boom and DIDSON monitoring equipment). Velocity measurements will be recorded on prepared data sheets.

Predator Monitoring

Sampling Location

Predator monitoring will be conducted on the left bank[3] of the Sacramento River in the vicinity of the water intake facility. Specifically, monitoring will focus on the nearshore area from 300 feet downstream to 300 feet upstream of the intake facility, and along the face of the intake structure, for a total of about 900 linear feet of river.

Sampling Gear

The same boat-mounted DIDSON system used for impingement monitoring will be used to monitor predator activity upstream and downstream and in front of the water intake facility. As discussed above for impingement monitoring, the boat operator will ensure that the boat is properly outfitted with standard safety equipment and navigation lighting, as described above.

Sampling Procedures

Broad-range DIDSON monitoring will be conducted on either the day before or the day after close-range impingement monitoring is conducted (i.e., once in April or May for each of the three years impingement monitoring is conducted). On the day of predator monitoring, four sweeps of the river with the DIDSON system will be conducted. Two sweeps of the river will occur during daylight hours (morning and afternoon), one sweep will occur during dusk (approximately from 45 minutes before sunset to 45 minutes after sunset), and one sweep will be conducted at night (beginning 2 hours after sunset).

Predator monitoring will be initiated at the downstream end of the monitoring reach. The boat will be positioned offshore, and the DIDSON system will be facing toward the bank. The boat will travel slowly upstream into the current at a constant speed. The distance separating the boat and the shoreline will remain constant over the duration of the survey. The precise distance that the boat will remain offshore will be determined in the field and will be based on the need to achieve sufficient detection capabilities and resolution to detect fish. Monitoring will continue until the entire monitoring reach is surveyed. If necessary, at the conclusion of the first pass, a second, closer pass along the face of the fish screen will be conducted to look for smaller fish in the vicinity of the

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[3] The left bank is relative to an observer facing downstream.

fish screen. In addition, if these passes reveal that predators and/or prey species are concentrated in the vicinity of the intake facility, an additional survey of a reference sampling location away from the intake facility will occur along a similar bend in the river. The purpose of this monitoring will be to evaluate whether predator/prey abundance is more a function of the specific location along the river bend rather than an effect of the fish screen. A similar river bend relatively close in proximity to the intake facility is located along the left bank of the Sacramento River about 2.5 miles downstream from the intake facility (Figure 1).

Processing of DIDSON Data

DIDSON images will be processed either manually by playing back all of the frames stored to identify those frames where fish movement is detected or by using the fish counting component of the DIDSON software to fully or partially automate the detection process. The specific method that will be used will depend on the resolution of the data, the frequency of frames with detectable movement of fish, the accuracy and efficiency associated with each approach, and possibly other factors. Once DIDSON data have been processed, the remaining frames will be evaluated and interpreted to determine fish species (if possible), size, and behavior.

Variables Measured and Recorded

Sample Information

As discussed above, impinged fish collected by divers would be preserved for later identification and measurement. These samples would be placed into collection jars, grouped by fish screen panel, for each diver inspection survey. Sample jars will be labeled with sample number (described below) written on a small slip of 100% rag content paper and included in the container with the preserved collections. Sample information also will be recorded on prepared data collection forms summarizing the results of diver inspections. The following information will be included on the data collection forms:

- Start date and time of diver inspection
- End date and time of diver inspection
- Unique sample number (last two digits of calendar year, month, day, start time [military time], end time [military time], and fish screen panel number [i.e., 1–16]). For example, fish collected from fish screen bay No. 5 during a diver inspection event starting at 2:15 p.m. and ending at 3:45 p.m. on March 23, 2011, the sample number would be: 110323_1415-1545_05.
- Sampling location (Freeport)

Water Intake Operating Information and Environmental Data

The same information with respect to water intake facility operations and environmental conditions collected under entrainment monitoring at the flow distribution structure at VSWTP will be collected as part of impingement monitoring (see *Variables Measured and Recorded* under *Entrainment Monitoring*). In addition, water velocity measurements in the vicinity of the fish screen will be collected from the boat during DIDSON monitoring. In instances where impingement monitoring is not conducted concurrently with entrainment monitoring, these data (facility operations and environmental conditions) will be collected as described as part of entrainment monitoring.

Data Management, Evaluation, and Reporting

Implementation of the entrainment monitoring program potentially will result in the collection of large quantities of monitoring data and information over a time period that could span 10 years. These data will be used to perform analyses and to generate tables and figures necessary to create annual monitoring reports. The reports will be submitted to USFWS by December 31 of each year.

Data Management

Sample data and variable information will be entered into spreadsheets (e.g., Excel) or a database program (e.g., Access) immediately following sample processing. Entered data will be checked for quality control.

Data Evaluation

Entrainment Monitoring

Tables and graphs will be used to summarize entrainment monitoring data and illustrate any relationships between the number of fish collected and environmental conditions (e.g., water temperature, flow, moon phase) or facility operations (e.g., volume of flow diverted, pumps or intake forebay chambers operating). At a minimum, the following information will be summarized:

- total number of fish collected by species and life stage by sample date;
- total number of fish collected by species and life stage for the monitoring period (December 1–July 31);
- size range and mean lengths of all species collected by date (total length to nearest 0.1 mm [larvae] and 1.0 mm [post larvae, juveniles, and adults]);
- total volume of water sampled by date and during monitoring period; and
- total volume of water passing through screen by date and monitoring period.

Impingement and Predator Monitoring

Evaluation of impingement and predator monitoring data will be both quantitative (when possible) and qualitative. Fish that are impinged and that have been collected by divers will be identified to species, measured, and enumerated. Fish occurrence and behavior in front of the screen as well as observed impingement will be qualitatively examined in relation to environmental conditions, facility operations, and structural components of the facility to identify any relationships between these variables. Fish behavior observed by the DIDSON system during predator monitoring will be similarly analyzed. If possible, the distribution and density of potential predators and prey relative to the intake facility will be described by comparing the number of potential predators and prey (standardized by river length) observed in the vicinity of the water intake structure to the number observed in the river along unaffected portions of the river bank upstream and downstream of the intake facility.

Reporting

An annual progress report that briefly summarizes the monitoring year's entrainment and impingement/predator monitoring results and that includes preliminary recommendations will be prepared and submitted to USFWS by September 30 each year that monitoring is conducted. This progress report will provide a mechanism for implementing changes to the monitoring methods and monitoring program components prior to the next year's monitoring activities (see additional discussion below under "Adaptive Management"). In addition, an annual report that includes final recommendations for refinement to the monitoring program will be prepared and submitted to USFWS by December 1 each year that monitoring is conducted. At a minimum, the report will include sampling methods and protocol; name of operators conducting entrainment and impingement monitoring and sample processing; the species name, date collected, number of individuals by species, and lengths (ranges and means) for all species collected; and the location of collection (i.e., from the screens at the intake facility or at the VSWTP). Monitoring reports in subsequent years will evaluate the current year's monitoring results in the context of results from previous monitoring years to determine overall trends in entrainment, impingement, and predator occurrence.

Adaptive Management

This monitoring plan represents a proposed maximum level of effort to document entrainment and impingement of delta smelt and other species that may occur as a result of operation of the Freeport water intake facility. Because entrainment will be monitored repeatedly within a single monitoring year, adaptive management will be used to reevaluate the methods, timing, and duration of the entrainment monitoring program and to potentially refine and focus the monitoring effort to evaluate specific patterns observed with respect to entrainment, impingement, and predator occurrence. Year 1 of the entrainment and impingement/predator monitoring program will be treated as a pilot study where monitoring methods will be refined. Key to the adaptive management process will be the preparation and submittal of an annual progress report that briefly summarizes entrainment monitoring results and includes preliminary recommendations for refinement of the methods. This progress report will be submitted to USFWS by September 30 each year to allow time for USFWS to consider and refine the preliminary recommendations so that recommended changes to the monitoring methods and monitoring program components can be implemented before commencement of the next year's entrainment and impingement/predator monitoring activities on December 1. At the conclusion of Year 3 of the entrainment and impingement/predator monitoring program, the entire monitoring program will be assessed to determine whether entrainment and/or impingement/predator monitoring should continue. Table 2 shows the monitoring schedule for the first three years of the entrainment and impingement/predator monitoring program.

Table 2. Likely Monitoring Schedule Assuming Vineyard Surface Water Treatment Plant Is Operational in 2011

	Monitoring Month and Component[1]							
Monitoring Year	December	January	February	March	April	May	June	July
2011–2012	E	E	E	EE	EE/I[2]	EE/I[2]	EE	E
2012–2013	E	E	E	EE	EE/I[2]	EE/I[2]	EE	E
2013–2014	E	E	E	EE	EE/I[2,3]	EE/I[2,3]	EE	E

[1] E = Entrainment monitoring, I = Impingement/predator monitoring. The number of letters corresponds to the number of monitoring events within the month.

[2] Impingement/predator monitoring will be conducted once over 2 days in April or May.

[3] If East Bay Municipal Utility District (EBMUD) has not taken its dry-year deliveries during the previous two impingement/predator monitoring events, this impingement/predator monitoring event will be postponed until a future year when EBMUD is taking its dry-year deliveries so that impingement monitoring can be conducted when the Freeport intake facility is pumping at a higher capacity than during Sacramento County Water Agency–only pumping.

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Personal Communications

Meier, Dan. Program manager. U.S. Fish and Wildlife Service, Anadromous Fish Screen Program, Sacramento, CA. October 21, 2008—telephone conversation. June 8, 2009—meeting and site tour at Freeport water intake. July 2, 2009—email to Jeff Kozlowski, ICF Jones & Stokes. July 10, 2009—meeting at ICF Jones & Stokes with Jeff Kozlowski and Bill Mitchell.

Addendum to the Monitoring Plan to Evaluate the Biological Efficacy of the Freeport Water Authority's New Water Intake Fish Screen

Prepared for Freeport Regional Water Authority and
Sacramento County Water Agency,
Prepared by ICF International
October 2011

The Freeport Regional Water Authority (FRWA) is constructing a new water intake facility on the Sacramento River near Freeport, California. The new Vineyard Surface Water Treatment Plant (VSWTP), which will allow full operation of the water delivery system, is scheduled for completion in fall 2011. The Freeport intake facility was designed to minimize fish entrainment losses associated with water diversions at the pumping facility. The Freeport intake facility has a fish exclusion system (i.e., a fish screen) that was designed to meet California Department of Fish and Game (DFG), National Marine Fisheries Service (NMFS), and U.S. Fish and Wildlife Service (USFWS) fish screening criteria for adequate screen area, maintenance features, and facility hydraulics for the protection of delta smelt, Chinook salmon, steelhead, green sturgeon, and other fish species. In accordance with the terms and conditions set forth in USFWS' biological opinion (September 2004) for the effects of the Freeport water intake facility on delta smelt, FRWA prepared the *Monitoring Plan to Evaluate the Biological Efficacy of the Freeport Regional Water Authority's New Water Intake Fish Screen* (ICF International 2010) to demonstrate the fish screen's effectiveness at minimizing entrainment of delta smelt and other listed fish species, and to evaluate "take" of delta smelt. The monitoring plan was approved by the USFWS in April 2010.

In 2009, longfin smelt were listed by DFG as a threatened species under the California Endangered Species Act (CESA). In 2010, FRWA prepared an ITP application and DFG issued an incidental take permit for the project. Provision 8.4 of the CESA Incidental Take Permit No. 2081-2010-031-03 for the Freeport Regional Water Project states that DFG will coordinate with the USFWS and provide any comments or requested changes to the USFWS-approved biological monitoring plan that was prepared previously by FRWA in compliance with the USFWS's 2004 biological opinion.

FWRA received comments on the biological monitoring plan from DFG via email on March 1, 2011. Bill Mitchell and Jeff Kozlowski (ICF International) met with Dan Meier (USFWS), Jim Starr (DFG) and Marty Gingras (DFG) on May 18, 2011 to discuss DFG's comments on the biological monitoring plan. In response to these comments, FRWA has agreed to several changes in the monitoring procedures and equipment described in the original biological monitoring plan. After their initial review of the monitoring plan, DFG requested that FRWA conduct fish sampling in the Sacramento River in addition to the fish monitoring activities described in the original plan to assist in the evaluation of the effectiveness of the fish screen in excluding delta smelt, longfin smelt, and other fish species. However, USFWS was reluctant to grant a permit for in-river sampling and suggested that existing survey programs in the area may provide the information needed to evaluate the general timing of larval fish occurrence at the Freeport intake. In subsequent communications, Jim Starr of DFG agreed that FRWA did not need to conduct additional in-river sampling, and that the USFWS's existing trawl/beach seine programs could be of assistance in providing this information.

Changes to the original biological monitoring plan are presented below, and include changes that were made in response to comments received from DFG and USFWS on the draft addendum dated June 2011, and subsequent discussions in September 2011 regarding in-river sampling. Text being removed from the original monitoring plan is shown as ~~strikethrough~~, while new text is <u>underlined</u>.

Entrainment Monitoring—Sampling Dates Will Be Flexible to Accommodate Variation in Operations (e.g., Pumping Rates) and Timing in Other Fish Sampling Programs, and to Cover a Broad Range of Tidal Conditions (e.g., Neap and Spring Tides)

Text beginning on page 5 of the original biological monitoring plan under section *Entrainment Monitoring, Methods and Equipment, Sampling Procedures* will be revised as follows.

Sampling Procedures

Sampling will occur one to two days per month between December 1 and July 31 each year. During December, January, February, and July, sampling will be limited to one day per month. Sampling frequency will be increased to two days per month during March–June when delta smelt are more likely to be present in the vicinity of the water intake facility (Meier pers. comm.). ~~For months when sampling will be limited to one day, each sample day within each month will be selected independently and at random from among the available days of the month. During March–June when sampling will occur on two days each month, the first day of entrainment monitoring in March will be selected at random from among the first 15 days in the month; subsequent sampling days for entrainment monitoring will be conducted every 2 weeks (plus or minus 1 day) thereafter through June, for a total of 12 sampling days for the entire monitoring period (December–July).~~ <u>Sampling dates will be flexible to accommodate variation in operations (e.g., pumping rates), tidal conditions, and larval fish abundance. For example, spawning and dispersal of delta smelt may be linked to lunar phase and/or tidal conditions (Bennett 2005). Therefore, an effort will be made to include a broad range of lunar and tidal conditions during the 8-month sampling period. To further improve the likelihood of encountering delta smelt and longfin smelt, an effort will also be made to schedule sampling when other fish sampling programs are detecting significant numbers of larvae in the north delta (USFWS Sacramento Trawl and lower Sacramento Beach Seine surveys).</u>

Table 1 lists the monitoring days for a hypothetical-monitoring year.

Table 1. Example of Sampling Days for a Hypothetical Monitoring Year

	Monitoring Month and Date							
Sampling Day	December	January	February	March	April	May	June	July
First	December 12	January 6	February 22	March 9	April 6	May 4	June 8	July 21
Second	n/a	n/a	n/a	March 23	April 20	May 18	June 22	n/a

Note: Shading represents months when sampling will occur on two days. n/a = not applicable. The precise dates for subsequent sampling days may vary by 1 day before or after the date listed to allow flexibility in conducting the monitoring.

By monitoring every 2 weeks, FRWA may increase the likelihood that the monitoring program will capture the temporal occurrence of delta smelt that are potentially present in the river and subject to entrainment by the intake facility. This schedule also provides an opportunity to conduct entrainment monitoring under varying environmental conditions. Spawning and dispersal of Delta smelt may be linked to lunar phase and/or tidal conditions (Bennett 2005).

Entrainment Monitoring—Changes in Sorting, Staining, and Preservation Methods

Text beginning on page 8 of the original biological monitoring plan under section *Entrainment Monitoring, Methods and Equipment, Sample Processing* will be revised as follows.

Sample Processing

Following sample collection, entrainment samples will be processed in the laboratory to identify species, relative abundance, and sizes of fish entrained. Laboratory processing of entrainment samples will consist of two distinct steps: sorting fish and eggs from detritus and other materials and analyzing the species, life stages, and sizes of the species collected.

Sorting

Prior to sorting of the sample, a protein stain (e.g., Rose Bengal) will be applied to the sample to aide in the identification of fish eggs and larvae. To facilitate sorting, the entrainment sample will be placed on a sieve with a mesh size equal to or smaller than the sampling net and washed with clean water before being transferred to a shallow container partially filled with clean water. All detritus will be carefully teased apart and inspected for fish and fish eggs before being discarded. Sorting will be conducted by eye with the aid of a magnifying glass as appropriate. All sorting will be done in an appropriately ventilated area to minimize worker exposure to preservative fumes. After all detritus has been inspected and removed from the sorting tray, the sorter will visually inspect the entire sorting tray to locate and remove all fish and fish eggs.

While fish and fish eggs are being removed from the sorting tray, the sorter will place the retrieved specimens into separate sample jars or vials, according to group based on size and/or life stage, along with sufficient fresh preservative (e.g~~., 5%~~ 10% formalin). For example, all juvenile fish (post-larval stage) will make up one group, and larval fish and fish eggs will make up the remaining two groups. Larval fish will be further subdivided: Long, skinny larvae will be sorted separately from the sample, and grouped by similarity. All vials will be carefully labeled, both inside and out, and retained for subsequent analysis (i.e., species identification). All relevant information for the entrainment sample will be recorded in an appropriate laboratory log book. At a minimum, this information will include the person conducting the sorting, the dates the sample was collected and sorted, the identification number of the entrainment sample that was sorted, and the identification numbers of the sample jars/vials to which the specimens were transferred.

Identification and Analysis of Fish and Fish Eggs Collected

If the number of organisms in any of the vials makes it impractical to enumerate and identify all fish, it may be necessary to take a subsample of the catch before the sample is processed. If subsampling is necessary, standard methods for taking subsamples of the catch should be employed to ensure that the organisms selected for identification are chosen randomly. Random selection ensures that the species represented in the subsample are representative of the entire collection. Following subsampling, the portion of the catch not subsampled will be returned to the sample jar or vial, along with fresh preservative, and retained for subsequent analysis (if necessary).

All fish and fish eggs in the sample (or subsample) will be identified to the lowest practical taxon using a dissecting scope, as appropriate. Analysis of the samples will be conducted only by qualified individuals who are familiar with fish species identification, including post-larval fish and fish eggs. Once all fish in the entrainment samples are identified to the appropriate taxonomic category (family, genus, or species) and life stage, they will be counted, measured for total length (to nearest 0.1mm for larvae and 1.0 mm for juvenile and larger fish), and recorded.

In addition, all individuals from each taxonomic group and life stage of target species will be measured for total length. If necessary, subsamples of 25 to 30 individual lengths per taxon and life stage for non-target species (e.g., threadfin shad) will be measured, provided that specimens collected in the sampling net are sufficiently intact[1].

Taxonomic keys to early life stages of Sacramento River fish will be used to identify fish and fish eggs caught by the plankton nets. Alternatively, sorted samples will be sent to a specialist for species identification and life stage confirmation.

Following identification and analysis, fish (with the exception of delta smelt) will be stored in sample jars filled with fresh preservative (10% formalin) and appropriately labeled as described above. Any delta smelt identified in samples will be preserved separately as discussed below. Preserved samples will be retained by SCWA or their designee for the duration of the monitoring program.

Preservation of Delta Smelt and Delivery to U.S. Fish and Wildlife Service

Any delta smelt identified in samples during sample identification and analysis will be preserved in 10% formalin. As described in the BO, information concerning how the specimen was taken, length of the interval between death and preservation, the environmental conditions, the incidental take permit number (l-1-04-F-0224), and any other relevant information will be written with indelible ink on 100% rag content paper and included in the container with the specimen. Preserved specimens will be delivered to the U.S. Fish and Wildlife Service, Division of Law Enforcement, at 2800 Cottage Way, Room W-2928, Sacramento, CA 95825 (telephone: 916/414-6660).

Impingement and Predator Monitoring—Use of a Fixed Mount to Stabilize the DIDSON System for Close-Range Monitoring; Change in the Sequence and Timing of Diver Inspections to Avoid Disturbance of Fish during DIDSON Monitoring

Text beginning on page 10 of the original biological monitoring plan under section *Impingement and Predator Monitoring, Monitoring, Methods and Equipment, Impingement Monitoring* will be revised as follows.

Impingement Monitoring

Sampling Location

Close-range DIDSON monitoring will focus on one or more of the 16 fish screen panels along the outside (i.e., river side) of the fish screen. The precise location of the DIDSON monitoring will be determined based on operation of the intake facility and the results of observations of the face of the fish screen by SCUBA divers (dive surveys are described below). Close-range inspection of the fish screen by SCUBA divers will be conducted along the entire length of the fish screen ~~concurrent with~~ on the days DIDSON monitoring is conducted. Divers will systematically cover the entire area of each fish screen panel, from top to bottom. Conducting such inspections of the fish screen ~~during~~ on the days DIDSON monitoring is conducted will provide an opportunity for divers to validate any observations made using the DIDSON camera.

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[1] Prior to entering the flow distribution structure at VSWTP, water (and fish) will pass through a flow control valve (sleeve valve) to reduce the water pressure in the pipeline. Fish entrained with water passing through the sleeve valve may be damaged in the process, making measurements difficult.

Sampling Gear

~~A boat-mounted DIDSON system will be used to monitor for fish impingement. The DIDSON system will be deployed from an adjustable pole mount attached to the side of the boat. The pole mount will provide precise pan and tilt capabilities and will allow the transducer to be moved up or down to allow optimal viewing of the fish screen panel. The boat will be located approximately 15 feet (horizontal distance) from the fish screen and sufficiently anchored to stabilize the DIDSON system to the maximum extent practical. The boat operator will ensure that all standard safety precautions are followed, including ensuring that U.S. Coast Guard–approved life jackets are on board for every occupant of the boat. Because DIDSON monitoring will occur during dusk and at night, the boat will need proper navigation lighting. The boat also will need to be equipped with 110 volt power to operate the DIDSON equipment. Alternatively, a portable Honda generator can be used to supply the necessary power.~~ A DIDSON system will be used to monitor for fish impingement. A special apparatus to secure and locate the DIDSON system at various fish screen panels and subsections will be fabricated. The mounting apparatus, including a support frame, will likely be fastened to either the screen cleaner assembly or the screen cleaner rail. This support frame will be able to move laterally across the intake structure so that all 16 screens can be evaluated. The mounting apparatus will provide a stable platform for the DIDSON system, yet be configured to allow for full pan and tilt capabilities to allow the transducer to be positioned so that optimal viewing of the fish screen panel is possible. Field trials with acoustic targets with similar dimensions as the target fish species will be used to determine the optimum distance, orientation, and operating settings of the DIDSON system for detecting target species at the face of the fish screen.

Divers will use standard SCUBA equipment and will be outfitted with a diver's slate for taking notes and underwater and fine-mesh bags for collecting fish found impinged on the fish screen. Divers will access the downstream end of the water intake facility by boat or from shore. Three safety flags displaying the universal sign for diving will be deployed during times when the divers are in the water. The flags will be deployed at the middle, upstream end, and downstream end of the water intake facility, on the river side of the log boom where they will be visible to boaters. Underwater flashlights will be used during nighttime dives to facilitate observations in the dark. ~~If a boat is used to conduct diver inspections, the boat operator will ensure that the boat is properly outfitted with standard safety equipment and navigation lighting, as described above.~~ If a boat is used to conduct diver inspections, the boat operator will ensure that all standard safety precautions are followed, including ensuring that U.S. Coast Guard–approved life jackets are on board for every occupant of the boat. Because DIDSON monitoring will occur during dusk and at night, the boat will need proper navigation lighting.

Sampling Procedures

Impingement monitoring will occur over two days in April or May during each of the first three years that entrainment monitoring is initiated. This period coincides with the time of year when delta smelt are most likely to be present in the vicinity of the intake facility and at risk of impingement as a result of changing environmental conditions (e.g., reverse flow). If practical, impingement monitoring will be conducted concurrent with entrainment monitoring to detect any relationships between impingement and entrainment observations. If weather or environmental conditions (e.g., high flows or turbid conditions) result in poor viewing or unsafe diving conditions, diver inspections will be postponed until the next suitable entrainment-monitoring day.

If dry-year deliveries to EBMUD are not occurring when monitoring for impingement is initiated in the first two years of monitoring, the third impingement monitoring effort will be postponed until a time when the Freeport intake facility is pumping to meet both EBMUD and SCWA deliveries. By conducting impingement monitoring when both EBMUD and SCWA deliveries are occurring, FRWA will be able to inspect the fish screens for impinged fish at a time when the

Freeport intake facility is operating at a higher capacity than it would be if only SCWA or EBMUD demands were being met.

Diver Inspections

On the days that impingement monitoring is conducted, two divers will systematically inspect each screen panel for impinged fish on ~~two~~ three separate occasions. Up to three divers will be used to perform the dive inspections; however, divers will work in pairs for safety and to maximize efficiency, rotating the divers using the third diver as a substitute as needed to ensure that divers are provided sufficient rest periods. Diver inspections will occur during the two DIDSON monitoring periods. The first inspection will occur shortly ~~after~~ before commencement of the daylight portion of the afternoon DIDSON monitoring, the second inspection will occur between the daylight and nighttime DIDSON monitoring, ~~and the second inspection will commence 2 hours after sunset during the nighttime DIDSON monitoring~~ and the third inspection will commence immediately after the nighttime DIDSON monitoring is complete. Conducting diver inspections outside of the DIDSON monitoring periods will ensure that divers do not affect fish behavior during DIDSON monitoring.

Immediately before a diver inspection, the fish screen brush cleaning system will be turned off for diver safety and to allow the divers to be able to observe and collect any fish that have been impinged.

Immediately before a diver inspection, the fish screen brush cleaning system will be turned off for diver safety and to allow the divers to be able to observe and collect any fish that have been impinged. The fish screen cleaning system will be turned off during diver inspections to allow divers to safely inspect the screen and collect any fish that have been impinged. The brush cleaning system will be disabled just long enough for divers to complete their inspections of the fish screen. However, if debris accumulates on the fish screen panels to the point that it compromises the integrity or normal operation of the fish screen or brush cleaning system, or affects the hydraulics of the fish screen in such a way that it biases the impingement monitoring results (e.g., causes more fish to be impinged than would occur under normal brush cleaning operations), diver inspections will cease temporarily. The brush cleaning system will be reactivated once divers are notified (using a prearranged signal that is audible to the divers) and have returned to shore or the boat. After accumulated debris has been removed by the brush cleaning system, the cleaning system once again will be deactivated and diver inspections will resume. The process will be repeated, as necessary, until all screen panels have been inspected.

After the dive flags are deployed, the divers will enter the water from shore or from a boat at the downstream end of the intake facility and swim upstream to the Number 8 and/or Number 16 fish screen panel depending on operation status of the two intake forebay chambers (Figure 2). Prior to beginning the dive, divers will note on their dive slates the date and time. The two divers will thoroughly and systematically inspect the entire surface of the screen panel for impinged fish. The species (if possible), size, and location of impinged fish will be noted. To note location of impinged fish on individual fish screen panels, divers will visually divide each fish screen panel into nine equal subsections (i.e., subsections A–I). Subsections A–C will make up the top row of the fish screen panel subsections from left to right, followed by the middle row of subsections (D–F) and the bottom row of subsections (G–I). Impinged fish that can be collected from the face of the fish screen will be placed in a marked mesh bag for later identification and measurement. One diver from each dive team will have 16 pre-marked bags numbered in sequence from 1 to 8 or 9 to 16. Divers will place all impinged fish collected from the fish screen panel into the bag that corresponds to the numbered fish screen panel being surveyed. The process will be repeated until all of the fish screen panels are observed. Only the screen panels covering operating chamber forebays will be inspected. During the time that the divers are in the water, the automated brush cleaning system for the fish screen will be turned off for safety and to allow the divers to be able to observe and collect any fish that have been impinged (see above).

Following completion of each dive, the divers will tally the results (grouped by screen panel) on their dive slates and record these results on prepared data sheets. Impinged fish collected from each fish screen panel will be transferred to a labeled sample jar filled with ~~5%~~ 10% formalin for later identification and measurement. Each sample jar will contain the date and time of the inspection and the number of the fish screen panel from which collections were made.

DIDSON Monitoring

On the day DIDSON monitoring is conducted, monitoring will occur over two 4-hour periods. The first 4-hour monitoring period will occur during daylight and will end at dark, approximately 30 minutes after sunset. The second 4-hour monitoring period will occur at night and will begin shortly after the daylight monitoring period has concluded. The DIDSON monitoring crew will randomly select one of the fish screen panels in front of an operating forebay chamber for observation.

Once a fish screen panel is selected for monitoring, the ~~boat~~ DIDSON system will be positioned ~~approximately 15 feet~~ in front of the fish screen and held in place with the mounting apparatus and support frame.~~with several anchors to minimize movement of the boat and the DIDSON system (Figure 3)~~. ~~However, the~~ The precise distance that the DIDSON system will be positioned from the fish screen will depend on the need to achieve sufficient detection capabilities and resolution to detect small fish and their proximity to the screen. At most, it is expected that only one or two fish screen panels will be viewable at a time because of the need to have the DIDSON system close to the fish screen.

The DIDSON system will be ~~suspended from the boat and~~ positioned at an oblique angle (looking upstream) relative to the fish screen to maximize the opportunity of observing fish that are close to the fish screen. Once they are positioned, the ~~boat and~~ DIDSON system will remain in place for the duration of both 4-hour monitoring periods unless environmental conditions or other factors require repositioning of the ~~boat or the~~ DIDSON system. The DIDSON system will be operated continuously during each 4-hour monitoring period. ~~, including when divers are conducting underwater inspections of the fish screen.~~

Water velocity will be measured from ~~the~~ a boat at the beginning of impingement monitoring and every ½ hour thereafter while the DIDSON monitoring is being conducted. A Marsh-McBirney flow meter (or similar device) will be used to measure velocity. Water velocity (in feet per second) will be measured approximately 3 feet below the water surface and away from the influences of the fish screen log boom and DIDSON monitoring equipment. Velocity measurements will be recorded on prepared data sheets.

Appendix B

Personnel Who Conducted Entrainment, Impingement, and Predator Monitoring, and Entrainment Sample and ARIS Image Processing

Appendix B

Personnel Who Conducted Entrainment, Impingement, and Predator Monitoring, and Entrainment Sample and ARIS Image Processing

B.1 Entrainment Monitoring

B.1.1 ICF International

Jeff Kozlowski	Fish Biologist
Patrick Crain	Fish Biologist
Bill Mitchell	Fish Biologist
Jeff Peters	Geomorphologist
Anne Huber	Water Resources Specialist
Mike Wingfield	Water Quality Specialist
Alex Gole	Field Technician
Alex Angier	Field Technician
Jacey Turay	Intern

B.1.2 Fishery Foundation of California

Trevor Kennedy	Fish Biologist
Kari Burr	Fish Biologist
Jim Walker	Fish Biologist
Roxanne Kessler	Fish Biologist

B.2 Sample Processing

B.2.1 ICF International

Patrick Crain	Fish Biologist
Rita Wilson	Research Technician

Seth Taylor	Research Technician
Aundrea Asbell	Research Technician

B.2.2 Fishery Foundation of California

Trevor Kennedy	Fish Biologist
Kari Burr	Fish Biologist
Jim Walker	Fish Biologist

B.2.3 Fish Taxonomist

Dr. Johnson C.S. Wang	Fish Taxonomist

B.3 Impingement Monitoring

B.3.1 ICF International

Jeff Kozlowski	Fish Biologist

B.3.2 Normandeau Associates

Ken Cash	Principal Scientist
Kyle Brown	DIDSON/ARIS Image Processing
Erik Fel’Dotto	Diver
Alan Frizzell	Diver
Chris Baker	Diver

B.3.3 Fishery Foundation of California

Trevor Kennedy	Fish Biologist
Jim Walker	Fish Biologist

B.4 Predator Monitoring

B.4.1 ICF International

Jeff Kozlowski	Fish Biologist

B.4.2 Normandeau Associates

Ken Cash	Principal Scientist
Kyle Brown	DIDSON/ARIS Image Processing

B.4.3 Fishery Foundation of California

Trevor Kennedy	Fish Biologist

Appendix C

Subsampling Test Results

Appendix C
Subsampling Test Results

The abundance of larval fish in the samples in water year (WY) 2014 made it impractical to fully sort each sample; therefore, a subsampling approach (i.e., sorting a quarter of each sample) was initiated. The subsampling approach was consistent with the methods described in the adopted monitoring plan (Appendix A) for instances when the number of organisms makes it impractical to enumerate and identify all fish larvae.

To facilitate subsampling, the approach described by Sebastian et al. (1988) was followed. In general, these methods were developed for subsampling unsorted benthic macroinvertebrates by weight and are especially useful for samples containing large amounts of filamentous algae that preclude the use of conventional subsampling methods (Sebastian et al. 1988). To ensure that larval fish were evenly distributed in the sample before subsampling began, the entire contents of the sample jar were emptied into a 1 Liter container filled approximately two-thirds with water. The contents were thoroughly mixed to separate debris and to evenly distribute larvae fish in the sample. The contents of the container were then quickly poured onto a 125-micron sieve in a uniform fashion and allowed to drain until excess water had drained from the sieve (about 7–10 minutes). The sieve and sample contents were then weighed (to nearest 0.1 gram) on a tared electronic balance to determine the weight of the sample, and a portion of the sample contents were removed from the sieve by taking small amounts of material evenly from all areas of the sieve until a subsample equal to one-quarter of the total sample weight was obtained. The subsample contents were placed into a separate labeled sampled jar filled with 70% ethyl alcohol. The remaining sample material on the sieve was placed back into the original sample jar along with the original preservative (formalin).

To test the appropriateness of applying this subsampling method to the remaining samples, each of three samples was divided into equal quarters as described above and each of the 12 subsequent subsamples were fully sorted. An index of evenness (i.e., Simpson's E) for each of the three quartered samples was then calculated to quantify how evenly distributed the fish larvae were among the subsamples. The evenness index ranges from 0.25 to 1.0, with 1.0 indicating a completely even distribution among subsamples and 0.25 indicating a very high degree of diversity (i.e., unevenness) among subsamples. The results for the three test samples indicate that the evenness of fish larvae across the four subsamples for each of the three quartered samples was relatively high (i.e., 0.951, 0.965, and 0.874) (Table 1). These results indicate that the approach described by Sebastian et al. (1988) was appropriate for subsampling the remaining entrainment samples.

Table 1. Fish Larvae Subsample Totals and Evenness Indices for Three Entrainment Samples

Subsample ID	Number of Fish Larvae	Subsample ID	Number Of Fish Larvae	Subsample ID	Number Of Fish Larvae
20140403_0426_0915_A	15	20140423_0715_1020_A	70	20140423_1345_1820_A	16
20140403_0426_0915_B	21	20140423_0715_1020_B	48	20140423_1345_1820_B	6
20140403_0426_0915_C	21	20140423_0715_1020_C	48	20140423_1345_1820_C	14
20140403_0426_0915_D	12	20140423_0715_1020_D	45	20140423_1345_1820_D	21
Sample Total	69	Sample Total	211	Sample Total	57
Evenness Index	0.951	Evenness Index	0.965	Evenness Index	0.874

C.1 Literature Cited

Sebastien, R. J., D. M. Rosenberg, and A. P. Wiens. 1988. A method for subsampling unsorted benthic macroinvertebrates by weight. *Hydrobiologia*. 157: 69–75.

Appendix D

Entrainment Data Files (Electronic)

Electronic data files to be provided with submittal of final report