A History of the Operational and Structural Changes to the Tracy Fish Collection Facility

by

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Preface

The Tracy Fish Collection Facility (TFCF), a fish salvaging facility, was built over 60 years ago as mitigation for the negative effects of exporting water by the Central Valley Project. The facility's main purpose, to salvage fish from water destined for export and replanting them away from the south Sacramento-San Joaquin Delta (Delta) export pumps' influence, has not changed; however, over time, operational and structural changes have occurred at the facility that may have potentially affected salvage. Salvage data is used by various agencies and many using the data are unaware of these changes, the history associated with it, and its implications to salvage.

The TFCF produces a large amount of salvage data which can be used for monitoring the effects of water exports on fish populations; however, caution should be used when interpreting salvage data. Common pitfalls when analyzing salvage data include:

- Equating salvage with entrainment. Entrained fish are not always salvaged since they can be lost through the screens or eaten within the facility and therefore not counted during sampling of salvage. In other words, salvage only refers to fish that were successfully diverted for counting and extrapolated (expanded) for salvage estimates. Pre-screen loss (i.e., predation) and screen loss are separate from salvage data but are important factors for calculating entrainment and fish loss. In essence, not all entrained fish are salvaged, and entrainment is always greater than salvage.
- Using wrong expansion factors. Salvage data are expanded values that depend on sample duration and salvage duration. But data from predator removal events and from experiments (special studies) are not expanded since they are from a single event rather than an estimate.
- Assuming all Delta Smelt die during salvage. Delta Smelt that are observed during fish estimation sampling counts are often alive and undamaged. A more accurate portrayal of Delta Smelt during entrainment is that Delta Smelt are exposed to high predation in the south Delta, high predation within the TFCF (without the predator removal program), and potentially lost through the louvers at fast water velocities. The survival of Delta Smelt following salvage and return, though, are relatively high (Churchwell et al. 2005; Morinaka 2013a).
- Not accounting for other screens in the system. Fish loss through the various screens downstream of the system also comes into play. Ideally, to retain smaller fish that are 20 mm (the minimum size counted at the salvage facilities), screen opening should be 2.3 mm or less. However, this size screen opening does not exist in any of the screened components of the facility and therefore smaller fish are not properly accounted.
- Using older salvage data. Salvage data throughout the facility's history has not always been consistent. Data before 1993 were marred with inconsistent sampling duration and frequency (or lack of sampling), questionable fish identification, and other non-standardized sampling practices. Consistency and accountability with the salvage data has vastly improved since 1993 through standardized sampling (1993–2009: 10-minute sampling per 2-hour period, 2010–recent: 30-minute sampling per 2-hour period) and transparent daily transmittal and reporting of salvage data.

Because this document incorporates over 60 years of historical information, details can easily be buried within the text. Therefore, it is important to keep in mind the goal of the document: to describe the facility and its operations and to describe changes that may have affected salvage over time. For ease of use, we have divided the report into three sections:

I. Historical perspective of the TFCF
II. Overview of the TFCF
III. Facility changes from 1957–2017.

Section I is an introduction to the history behind the creation of the federal salvage facility. A description and discussion of the Central Valley Project and the Pilot Fish Screen, a precursor to the TFCF, are included in this section along with a discussion on water exports through time. Section II is more technical, covering the various components of the facility and how fish are diverted to collection tanks. This section also includes two topics of importance that are interrelated: “Louver efficiency” and “Interpreting salvage, entrainment, and loss.” Section III covers both operational and structural changes that have occurred since 1957; therefore, this section will have the most information (these changes are also summarized in Appendix 10). Changes that are covered in the third section include both major (e.g., regulatory changes impacting facility operations) and minor (e.g., screen changed to smaller mesh opening) but all could potentially affect salvage data.

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Abstract

The Tracy Fish Collection Facility (TFCF) is one of two fish salvage facilities located in the southern region of California's Sacramento-San Joaquin Delta (Delta), salvaging millions of native and non-native fish annually. The facility is operated by the U.S. Bureau of Reclamation and is an important component of the Central Valley Project (CVP). Completed in 1956, the purpose of the TFCF is to salvage fish entrained by the export of water by the CVP and return them back to the Delta, away from the immediate influence of the CVP's Jones Pumping Plant. During the past 60 years, the TFCF has undergone a variety of operational and structural changes and many of these changes may have impacted the reported number of fish salvaged at the facility. Fisheries data collected at the facility is used by various agencies; however, many using the data are unaware of the history associated with it. The purpose of this document is to provide a background to the TFCF and to describe the changes that have occurred, both operational and structural, at the facility throughout its existence. Changes to the facility and its operations should be considered when analyzing salvage data collected from the TFCF.

Acknowledgements

Various resources were used in researching the history of the Tracy Fish Collection Facility. Information was acquired through internal memorandums, correspondences, archived electronic mails, interviews, technical reports, grey literature, and other manuscripts both published and unpublished. Information on repairs and structural changes was acquired from maintenance logs, archived email communications, and memorandums, Tracy Office Engineering Branch records, and the Tracy Office records archive. Opinions or perceived opinions are solely those of the authors and do not in any way represent the views of the Bureau of Reclamation. The authors are grateful to John Carl Dealy, Herb Ng, Robert Fujimura, and Javier Miranda for reviewing the manuscript. Acknowledgements also go to Dan Odenweller, Liz Partridge, Lloyd Hess, Richard Murillo, Alba Scott, Patricia Stewart II, Joel Imai, Jackie Donato, Paulette Bottoms, Robert Myers, Yvette Alcantar, Warren Feng, Ronald Silva, Brandon Wu, Geir Aasen, Diana Jones, Tim Keopadubsy, Zachary Sutphin, Dr. Johnson Wang, Gary Jordan, Jonathan Speegle, Catherine Karp, Michael Trask, Alex Luna, Delbert Hansen, Winetta Owens, Dan Macon, Betty Harris, Brian Shinmoto, Paul Stearns, and Geoff McDonald.

Introduction

The U.S. Bureau of Reclamation's (Reclamation) Tracy Fish Collection Facility (TFCF), located in the southern region of the Sacramento-San Joaquin Delta (Delta) in California, is a federal facility that collects (salvages) fish from Delta water exported by the C.W. "Bill" Jones Pumping Plant (JPP, formerly the Tracy Pumping Plant). The TFCF is part of the Central Valley Project (CVP), a federal water project initially created to address California's agricultural water shortages and floods. The CVP moves water from the Sacramento River, entering the Delta from the north, across the Delta, and pumped by the JPP to the Delta Mendota Canal (DMC) traversing the western side of the San Joaquin Valley. The DMC provides water primarily for farming but does service cities en route. Fish are entrained by the JPP and are removed from water by the TFCF, counted and identified by a subsampling program, and relocated to the confluence of the Sacramento and San Joaquin rivers. In addition, since the completion of Friant Dam in 1942, the CVP has taken the entire San Joaquin River, which used to enter the Delta from the south, and diverted it to farms and cities on the eastern side of the San Joaquin Valley.

Before the TFCF became operational in 1957, the concept of fish protection was in its infancy, and the magnitude of potential fish loss from moving vast amounts of water was predicted to significantly impact the sport Striped Bass (*Morone saxatilis*) and commercial salmon fisheries (Erkkila et al. 1950). Various methods of fish protection were tested, and the concept of using louvers, a vertically-aligned series of metal slats that influence the swimming behavior of fish, became the basis for a full-scale construction of a fish collection or salvage facility (U.S. Bureau of Reclamation 1957). Aside from louvers, several other components that function together to limit debris entry and allow fish to be diverted for salvage were included in the design of the TFCF. These components had to be refurbished and replaced over time.

During the past 60 years, the TFCF has undergone a variety of operational and structural changes, and many of these changes may have impacted the reported number of fish salvaged at the facility. The purpose of this document is to provide a background to the TFCF and to describe the operational and structural changes that have occurred at the facility throughout its existence. These changes should be considered when analyzing salvage data. This report is a companion to IEP Technical Report 85 (Morinaka 2013) detailing the history of the State Water Project's Skinner Delta Fish Protective Facility.

Because this report incorporates over 60 years of historical information, details can easily be buried within the text. Therefore, for ease of use, we have divided the report into three sections: (I) Historical perspective of the TFCF, (II) Overview of the TFCF, and (III) Facility changes from 1957–2017. Section I provides historical background that lead to the construction of the TFCF. Section II describes the various components of the facility and how fish are diverted for salvage. Section II also includes two topics that are of importance: "Louver efficiency" and "Interpreting salvage, entrainment, and loss." Section III covers both operational and structural changes that have occurred since 1957; therefore, this section will have the most information. If the reader is limited in time, Section III is also summarized in Appendix 10.

I. Historical Perspective of the Tracy Fish Collection Facility

Central Valley Project

The Central Valley is situated between two long mountain ranges on its western (Coast Range) and eastern (Sierra Nevada) boundaries and two shorter ranges on its northern (Cascade Range) and southern (Tehachapi Mountains) boundaries. California receives almost 200 million acre-feet (maf) of precipitation in an average year (Carle 2009), but average rainfall from each mountain range differs immensely, with most of the rainfall occurring at the northern and eastern boundaries. In the Cascade and Sierra Nevada ranges surrounding the Sacramento Valley, average annual rainfall is over 510 millimeters (mm) (20 inches [in]), while in the Tehachapi Mountains at the southern San Joaquin Valley, average rainfall is less than 127 mm (5 in) (California Data Exchange Center 2015). Two major rivers in the valley, the Sacramento River flowing from the north and the San Joaquin River flowing from the south, send freshwater inflow to the Delta, a region covering more than 1,100 square miles (2,900 kilometers [km]^2) with more than 80 percent devoted to agriculture (Ingebritsen et al. 2000).

Water diversion and storage have been major driving forces in the development of the Central Valley. As agriculture in the Central Valley in the late 1800s evolved from ranching to intensive wheat and other crops, thereby overextending the groundwater (Rowley 2006), Californians entertained the possibility of moving water from the water-rich north to the drier south. As demand for water increased, California settlers wanted to store “wasted” runoff from rains and snow for later use (U.S. Bureau of Reclamation 2015), particularly during the drier seasons. In 1902, President Theodore Roosevelt pushed the Reclamation Act through Congress with the goal of developing the West through irrigation for small-scale farmers. The Reclamation Act of 1902 funded irrigation projects on arid lands of twenty states, including California, and established the U.S. Reclamation Service, which was later renamed U.S. Bureau of Reclamation.

In 1915, the California State Legislature considered a “State Water Plan” for irrigation, water storage, flood control, navigation, and other water infrastructure development. The water plan (known as the “the Plan” or the “Marshall Plan” after then governor of California, Robert Bradford Marshall) had an important component, the construction of a large dam on the upper reaches of the Sacramento River near the mining town of Kennett (Rowley 2006). Finally, in 1933, the State Legislature passed the Central Valley Project Act to be funded by the sale of State bonds; however, because of the Great Depression, the bonds could not be sold, and the State could not afford to implement the water plan. The State turned to the federal government for assistance and, in 1935, President Franklin D. Roosevelt made federal relief and recovery money available through the Emergency Relief Appropriation Act, which authorized funds to Reclamation to develop the Central Valley Project (CVP) and other public work jobs.

Soon after the CVP was transferred to Reclamation, the construction of Shasta Dam, a major component of the CVP, began in 1938, even though the method of water conveyance from the Sacramento River/Shasta Dam was yet to be decided (Lund et al. 2007). Reclamation entertained two ideas for water transfer: (1) fresh water could be released from the Shasta Dam to dilute or expel saltwater from the Delta through a closed conduit or a cross-channel or (2) completely bypass the Delta and build peripheral canals around the Delta. Reclamation’s initial concept of a cross-channel would take water just below Hood in the Sacramento River, through the Delta, and to the Delta-Mendota Canal (Appendix 1A) (U.S. Bureau of Reclamation 1945). The concept of the peripheral canal, on the other hand, would take water from the

American River and the Sacramento River to two canals (named Folsom-Newman Canal and Folsom-Ione-Mendota Canal) that would bypass the Delta and fill the San Luis Reservoir and the Mendota Pool (Appendix 1B) (U.S. Bureau of Reclamation 1949). Reclamation chose the cross-channel plan and, in 1945, Reclamation announced the final location for the cross-channel, which is now called the Delta Cross Channel (DCC). In 1951, Reclamation completed construction of the DCC (64 m [210 feet] wide with a capacity of 99.1 m^3/s [3,500 cubic feet per second]), which allowed the diversion of water from the Sacramento River into Snodgrass Slough through a short, excavated channel near Walnut Grove. Water then dilutes the Mokelumne River and the Delta and then flows about 50 miles to the southern Delta where the JPP is located. The diverted water also supplies the Contra Costa Canal. Reclamation opens and closes the DCC control gates depending on salinity and water needs.

Pilot Fish Screen (1952–1956)

As early as 1938, years before the DCC, JPP, and the TFCF were built, fishery concerns related to the transfer of water across the Delta to farmlands in the southern San Joaquin Valley were known and documented (Hatton 1940; Hatton and Clark 1942; Erkkila et al. 1950; Lancaster and Rhone 1955). The water transfer was expected to greatly "decrease the present extent of the brackish water nursery grounds," "increase the area of those waters populated by freshwater species," and significantly "affect the abundance of anadromous fishes" (Hatton 1940; Hatton and Clark 1942). Early researchers also knew that diversion of water at Tracy "will have a pronounced effect on the flow pattern in the canals of the Sacramento-San Joaquin Delta" and that reverse flows would also occur (Barnaby et al. 1953). California Department of Fish and Wildlife (CDFW) (then known as Division of Fish and Game and then Department of Fish and Game) and the U.S. Fish and Wildlife Service (USFWS), with the cooperation of Reclamation, conducted a study of the Delta's fisheries from 1947 to 1950 to determine the composition and occurrence of various Delta fish populations. The study included the effects of changing hydrodynamics and the means for protecting fish populations from damage that might result from the pumping plant operations (Erkilla et al. 1950). Erkilla et al. (1950) stated that the "evidence is conclusive that in order to protect and maintain populations of king (Chinook) salmon *Oncorhynchus tshawytscha*, striped bass *Morone saxatilis*, and shad, positive means for preventing their passage through the pumps must be adopted." Barnaby et al. (1953) recommended that a "fish protective device should be designed to protect the smallest size of fish possible." Furthermore, Erkilla et al. (1950) recommended that "a screen be installed in the approach canal, complete with a fish collecting system and a bypass canal that will carry screened fish to an area beyond the influence of the Tracy Pumping Plant. The screen should be of the traveling water type." But because belt-type traveling water screens have never been used in a situation of the same magnitude as in Tracy (U.S. Bureau of Reclamation 1957) and because of the high cost (estimated in 1950 at $4,500,000) (Lancaster and Rhone 1955; Bates et al. 1960) associated with traveling water screens, Reclamation was reluctant to invest in them. Instead, a pilot fish screen structure (Pilot Fish Screen) was conceived and planned.

The Pilot Fish Screen, built in 1950–1951, tested several types of screens, including perforated plate screens, traveling water screens, and stationary screens (U.S. Bureau of Reclamation 1952, 1956, 1957; Rhone and Bates 1960), and served as a fish screen for the first few years (1952–1956) of the JPP's operation. It was located in a channel that bypassed the main intake canal, which left available a permanent fish salvage facility site on the main canal (U.S. Bureau of Reclamation 1956b). To evaluate the facility's progress and findings, a consortium of agencies including Reclamation, USFWS, CDFW, and California Department of Water Resources (DWR) (then known as Division of Water Resources) formed the Tracy Fish Screen Advisory Council (TFSAC). The Pilot Fish Screen structure was made of timber, measured 77.7 meters (m) (255 feet [ft]) in length, was angled 37° to the direction of the flow, and was divided into 12 bays, each containing a different type of screen (U.S. Bureau of Reclamation 1956). Results from these tests showed that traveling water screens caused high fish mortality and that perforated and stationary screens were difficult to clean and clogged too quickly (U.S. Bureau of Reclamation 1955, 1957).

In a study that was conducted concurrently at the Pilot Fish Screen structure, researchers noticed that fish "seemed to sense the presence of an obstruction as they drifted downstream and that they tended to avoid it while still several feet away" (U.S. Bureau of Reclamation 1957), a behavior that led to the study of louvers. The concept of using louvers for fish diversion had been tested around the same time, but at a smaller scale, by USFWS at the Coleman Fish Hatchery (Bates et al. 1960) and by Pacific Gas & Electric at the Contra Costa power plant (Kerr 1953). With these observations, a prototype-size louver system was tested at the Pilot Fish Screen structure in 1953, which included evaluations of the hydraulic performance of various features such as trash racks, transition sections, louvers, and bypass sections (U.S. Bureau of Reclamation 1955a; Bates and Vinsonhaler 1957; Rhone and Bates 1960). One of the prototype louver systems designed and tested was the "sawtooth" arrangement (U.S. Bureau of Reclamation 1956) which was the design implemented at the State Water Project's (SWP) J.E. Skinner Delta Fish Protective Facility (SDFPF) in 1968. Members of TFSAC agreed in 1954 to employ louvers for the final structure of the TFCF.

Tracy Fish Collection Facility and water exports (1957–present)

Tracy Fish Collection Facility (TFCF). The TFCF was completed in the fall of 1956 and operation began in February of 1957 (Bates et al. 1960) (Figure 1). The TFCF is at the head of the Delta-Mendota Canal (DMC), 4 km (2.5 miles) upstream of the JPP, in Byron, California, at the point where the Contra Costa, San Joaquin, and Alameda County lines converge. The primary purpose of the facility is to salvage fish entrained by the export of water by the JPP and return them back to the Delta away from the influence of the CVP and SWP pumping plants. The TFCF was designed for small fish less than 3 inches (7.6 centimeters [cm]) since "larger ones were capable of avoiding the plant" (Rhone and Bates 1960). The TFCF was also originally designed to salvage outmigrating Chinook Salmon, Striped Bass, and White Catfish (*Ameiurus catus*). The State's equivalent of the TFCF, the SDFPF, is located 4 km (2.5 miles) northwest of the TFCF.

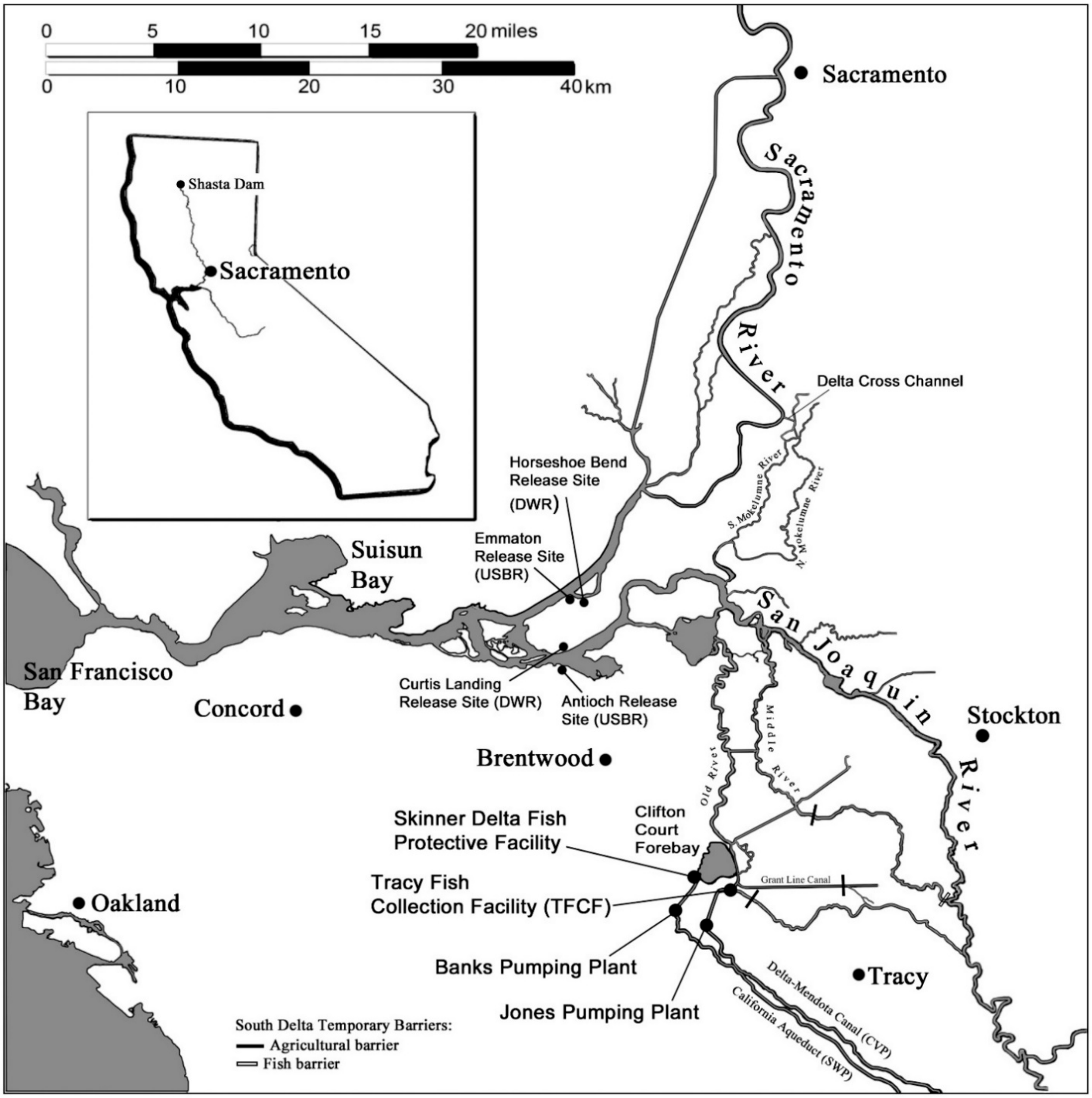


Figure 1 Map of the Sacramento-San Joaquin Delta showing location of the Tracy Fish Collection Facility and other related structures

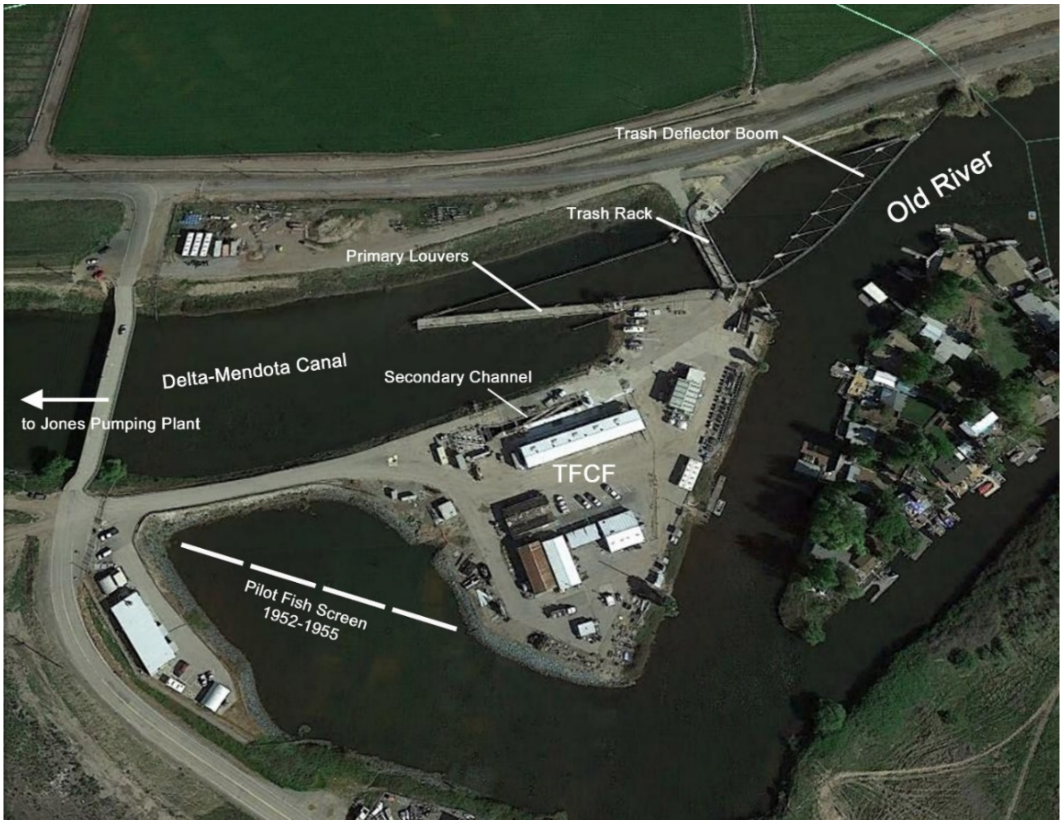
C.W. "Bill" Jones Pumping Plant (JPP). The JPP has six pumps, two rated at 23–24 m^3/s (800–850 cubic feet per second [cfs]), and four at 27–28 m^3/s (950–1,000 cfs). When all six pumps are operating, the discharge can be between 132–144 m^3/s (4,650–5,100 cfs) (U.S. Bureau of Reclamation 1956a) or 2 million gallons per minute (7,800 m^3/min) (U.S. Bureau of Reclamation 1985), and approximately 119 m^3/s (4,200 cfs) during the winter non-irrigation season. Each pump increases the velocity of the DMC by ~0.5 feet per second (fps). Because the design capacity of the DMC is 130 m^3/s (4,600 cfs) at the upper reaches, only five pumps can be run at one time, thereby leaving one pump as a spare (P Stearns pers. comm.). The 125,000 horsepower (hp) pumps, powered by the Shasta and Keswick power plants, move water through three 4.6 m (15 feet [ft]) diameter discharge pipes, lifting the water a vertical distance of 60 m (197 ft) into the DMC. Water then flows by gravity 188 km (117 miles) southward and discharges into the Mendota Pool, a small reservoir located 40 miles downstream of Friant Dam. From the Mendota Pool, water is then redistributed to canals for agricultural use. The DMC carries water along the west side of the San Joaquin Valley for irrigation supply, for use in the San Luis Unit, and to "replace" (i.e., discharge into the natural channel of the) San Joaquin River water that is diverted southward by Friant Dam (U.S. Bureau of Reclamation 1952; Stene 1994). In comparison, the SWP's Harvey O. Banks Pumping Plant (BPP) moves Feather River water through the 444-mile California Aqueduct that supplies agricultural communities in the San Joaquin Valley and urban Southern California. Reclamation transferred the operation of the JPP in 1998 to the San Luis & Delta-Mendota Water Authority (SLDMWA) (JC Dealy pers. comm.) as part of their mission to assume operation and maintenance responsibilities of certain CVP facilities. This transfer agreement is valid until 2023 and does not include the transfer of operation for the TFCF.

Water Exports. Historically, many factors have affected pumping rates at the JPP, including water storage and availability, water demand, and water quality standards. During the first years of water export (1951–1957), pumping seldom exceeded 20 percent of capacity from October to March, and peak pumping during July and August was 50 percent of capacity. For the years between 1958 and 1966, pumping was related to agricultural requirements, and peak pumping during July and August was 90 percent of capacity. Between 1967 and 1972, pumping exceeded 60 percent of capacity for March to September, and through the 1970s, pumping reached 95–100 percent of capacity from May through August. In general, prior to the construction of San Luis Dam/Reservoir, exports were generally lower in wet years and higher in dry years. Since construction of the San Luis Dam/Reservoir in 1967 and other offstream storage reservoirs, CVP exports have tended to be near peak DMC capacity year-round, regardless of water year type (Arthur 1987). With the completion of the SWP's BPP in 1967, the ability to divert water out of the Delta was doubled (Arthur et al. 1996). Both the BPP and JPP can export more than half of the inflow to the Delta (Kimmerer 2004). In summary, water exports have increased significantly from about 1 million acre-feet per year in the 1950s to more than 2.5 million acre-feet per year by the late 1970s, while salvage has decreased (Appendix 2).

Effects of SWP's Clifton Court Forebay. Unlike the SDFPF, the TFCF does not have a forebay (i.e., Clifton Court Forebay), instead, Delta water is obtained directly from the Old River at the DMC intake where the TFCF is located (Figure 2). Before the Clifton Court Forebay was put into operation, the relative densities of fish species between the TFCF and the SDFPF were similar (Heubach 1973). With the operation of Clifton Court Forebay in 1970, Chinook Salmon densities more than doubled at the TFCF while Striped Bass and catfish spp. were much greater at the SDFPF (Heubach 1973). The difference in the densities and species salvaged at the two facilities is a result of how water moves through the facilities and the respective pumping regimes. Water enters the Clifton Court Forebay only when the gates at its intake are opened, and only during high tides. The SWP exports mostly at night for electricity cost savings, which further causes differences in salvage trends. At the TFCF, water is continuously "filtered" through as long as the JPP is pumping.

An ecosystem exists within the Clifton Court Forebay where piscivorous predators (Mecum 1980; Kano 1990) and avian predators (Clark et al. 2009) can occur in large numbers at times; therefore, pre-screen losses are considerably greater at the SDFPF (75 percent) than at the TFCF (temporary placeholder value of 15 percent). Pre-screen loss is a large source of mortality for Chinook Salmon, Striped Bass (Gingras 1997), Delta Smelt (Castillo et al. 2012), and Steelhead (*O. mykiss*) (Clark et al. 2009) at the SDFPF. At the TFCF, evidence of Chinook Salmon mortality has been observed in front of the TFCF trash rack (Vogel 2010) and in the primary channel (Bridges et al. 2019 in press; Wu et al. 2019 in draft).

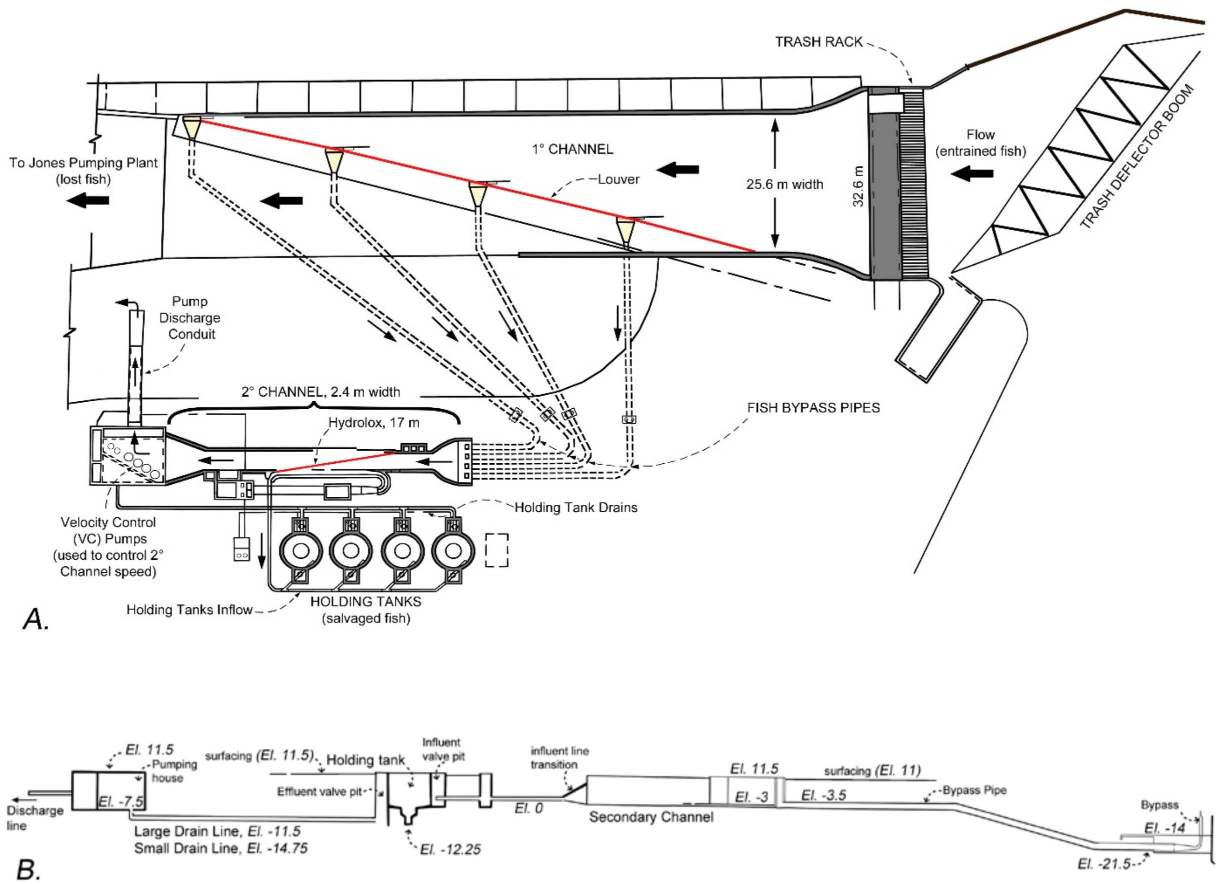
Figure 2 Aerial view of the Tracy Fish Collection Facility in relation to the Delta-Mendota Canal and the Old River



II. Overview of the Tracy Fish Collection Facility

Although the different components of the facility have been replaced and changed over the years (see B. Structural changes section for details and Appendix 10), the general concept of the TFCF has remained the same. The TFCF has several components (Figure 3A) that function together to limit debris entry and allow fish to be diverted for salvage with the help of gravity and a few pumps (Figure 3B). A general overview of the facility and its components are presented below, detailing where fish enter (trash deflector boom and trash rack), are diverted (primary channel, secondary channel), and then collected (holding tanks) at the facility. The facility's measurements and dimensions are presented within the descriptions of the components and are also summarized in Appendix 12. Louver efficiency is also discussed since salvage relies heavily on the performance of louvers. The section concludes with a discussion on salvage and loss data and how to interpret it.

Figure 3 Diagram of the Tracy Fish Collection Facility



Note: Diagram is oriented north and water flow is from right to left: A. Top view of the TFCF showing the various components; B. Side view of the TFCF with elevation (El.).

Trash deflector boom and trash rack. The trash deflector boom and the trash rack prevent debris from entering the facility. For the first three years of operation, the TFCF implemented a 2-ton cableway to remove heavy trash deposited in front of the trash rack (Bates et al. 1960). Since this was deemed unsafe, the cableway was replaced with a floating trash deflector boom in 1960. The trash deflector boom (Figure 4, top inset) deflects large floating debris such as logs and water hyacinth (*Eichhornia crassipes*) toward a conveyor for disposal. The trash deflector boom is a floating structure (pontoon with watertight air chambers) (U.S. Bureau of Reclamation 1959) with a leading edge extending about 1 m (3 ft) below the water surface; therefore, the trash deflector boom is not a major barrier to fish movement toward the TFCF.

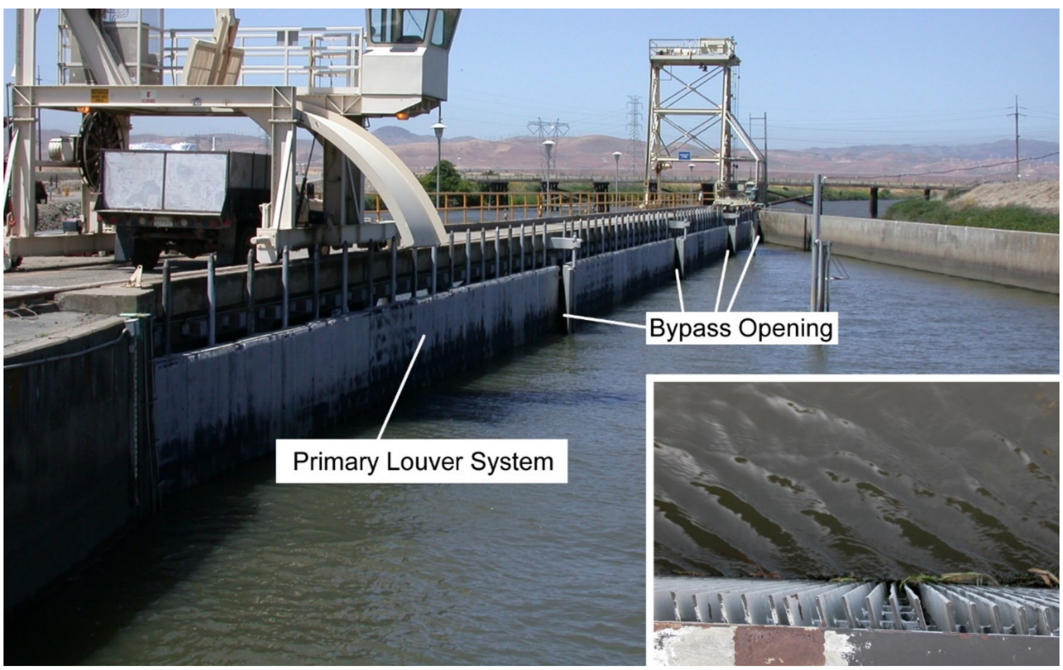
Immediately downstream of the trash deflector boom is the trash rack (Figure 4), the first major barrier that fish encounter. The trash rack is 32.6 m (107 ft) long and is constructed of vertical steel bars that have an average clear opening or gap of 5.7 cm (2.25 in, range: 2–2.5 in; Figure 4, bottom inset), extends 8.9 m (29 ft 3 in) from the deck to its bottom, and has a 2 to 1 slope (U.S. Bureau of Reclamation 1956a). The trash rack was designed to withstand a differential head of 1.5 m (5 ft). The trash rack prevents the entry of trash and large fish (Rhone and Bates 1960; Hyde et al. 1967; Odenweller and Brown 1982) and limits aquatic weeds such as the Brazilian waterweed (*Egeria densa*) from entering the primary channel. Heavy accumulation of debris on the trash rack can lead to a number of problems including head differentials and structural failure. Heavy debris accumulation can also impede fish passage into the facility at the trash rack and create turbulence within the primary channel. The trash rack was cleaned manually using a mechanical rake (1957–2010) but is currently automated with a mechanical claw (2010–recent).

Figure 4 View of the front of the Tracy Fish Collection Facility trash rack located at the head of the Delta Mendota Canal

Inset: trash deflector boom (top) and view from the deck of the trash rack's vertical bars with average opening of 5.7 cm (bottom).

Primary channel. Fish that successfully pass through the trash rack enter the primary channel where the primary louver system is located (Figure 5). The primary channel has a width that tapers from 32.6 m (107 ft) at the head (trash rack area) to 25.6 m (84 ft) at the primary louvers and an elevation of channel bottom of 4.3 m (14 ft) below sea level (see Figure 3B). The length of the primary louver system, starting from the upstream louver panel to the downstream louver panel at the mouth of the last bypass, is 98 m (322 ft) long and has a height of 7 m (23 ft). The primary louvers are installed in a vertical position immediately downstream from the trash rack. There are 36 louver panels in the system and each is supported by 8.9 cm (3.5 in) guide rods, which were designed to safely withstand a differential of 30.5 cm (1 ft) between the upstream and downstream faces of the louvers (U.S. Bureau of Reclamation 1956a). Each louver panel is 2.6 m (8.5 ft) across and consists of 84 vertical louver bars. The 63.5 mm x 4.8 mm (2.5 in x 3/16 in) louver bars, with clear opening space of 2.54 cm (1 in) (Figure 5 inset), are placed at 90° to the flow but are installed on a structure oriented 15° to the flow. The louvers do not physically exclude fish from the intake; therefore, the TFCF is not a fish screen (Hess 2005). The louver system creates hydraulic conditions that guide fish along the louver face: fish sense and try to avoid the turbulence caused by the louver slat array, maintain a distance from the louver face, and are guided ("louvered") to bypass entrances. At faster water velocities, the turbulence wake is closer to the louver slats; at slower water velocities, the turbulence wake extends further into the channel. In essence, the louver system is a behavioral barrier (U.S. Bureau of Reclamation 2006).

Figure 5 Primary louver system of the Tracy Fish Collection Facility viewed from the trash rack deck



Inset: View from the primary louver deck of the louver bars with 2.54 cm opening and turbulence/ripples created by the louvers.

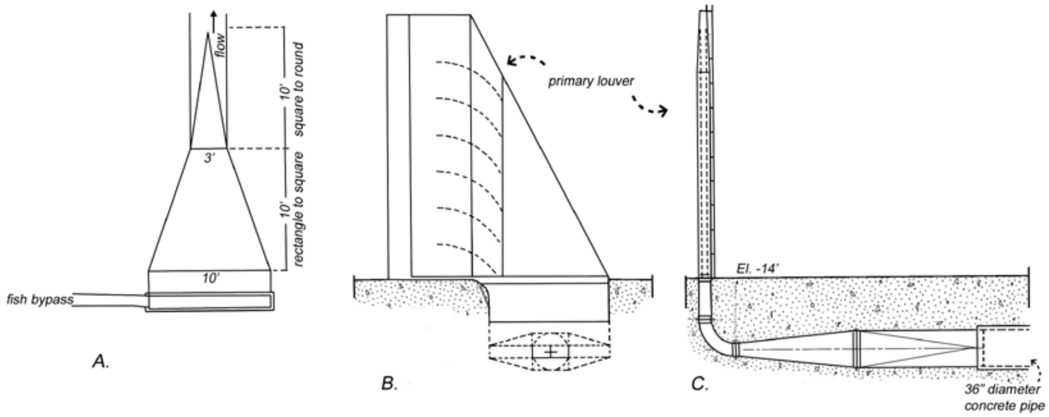
The four bypasses are spaced 22.9 m (75 ft) apart and each bypass has a vertical metal baffle that directs water and fish into the 15.2 cm (6 in) wide bypass opening. The bypass openings extend from top to bottom, diverting about 1/40th (or 2.5 percent) of the total flow that enters the primary channel. During the Pilot Fish Screen tests, smaller bypass openings between 6.4–10.2 cm (2.5–4 in) were tested with success. Other studies showed that larger bypass openings resulted in higher guiding efficiency. For example, Ruggles and Ryan (1964) observed an increase in bypass efficiency for juvenile salmon as the width increased from 15.2 cm (6 in) to 61 cm (24 in). They also observed that fish lost through the louvers occurred in the "vicinity of the bypass" and may be attributed to "the apparent reluctance of salmon to enter a narrow bypass" opening. Meinz (1978) also observed an increase in bypass efficiency for juvenile Chinook Salmon as width increased from 14.5 cm (5.7 in) to 30.5 cm (12 in). Mecum (1980a) found that American Shad (*Alosa sapidissima*) required a greater bypass opening, > 68.6 cm (27 in), than the other tested species. Although these studies showed that a larger bypass opening showed better efficiency, the 15.2 cm (6 in) bypass opening was nevertheless selected for the TFCF with the reasoning that it was less likely to be clogged by debris (Bates and Vinsonhaler 1957; Rhone and Bates 1960).

Water velocity at the channel and at the bypass opening, expressed as bypass ratio (velocity at the bypass opening : velocity at the primary channel), is an important element in operating the facility effectively. For fish to enter the bypass, a bypass ratio of > 1 is best, i.e., the velocity at the bypass opening should be faster than the velocity of the primary channel. Bates et al. (1960) observed an increase in bypass efficiency with increasing channel approach velocity for Striped Bass and Chinook Salmon between 3.8–10.1 cm (1.5–4 in). Ruggles and Ryan (1964) also observed an increase in bypass efficiency as the approach velocity increased from 49 cm/s (1.6 fps) to 76 cm/s (2.5 fps). Other life stages and species, though, do not fare well with increasing water velocities. For example, Bates et al. (1960) recorded a decrease in bypass efficiency for Striped Bass between 8.4–25.4 mm (0.33–1 in). Threadfin Shad (*Dorosoma petenense*) also had reduced efficiency with increasing channel velocity (Skinner 1973). Early studies at the TFCF showed that a "gradual increase in flow velocity toward the bypass and a rapid acceleration after entering the bypass was found most effective in diverting fish" (Rhone and Bates 1960). Meinz (1978) observed reduced Chinook Salmon louver efficiency with increased approach velocity but an increase in efficiency when the bypass ratio was increased from 1 to 2.2.

A bypass slide gate located at the end of each bypass controls the amount of water through a bypass. The water elevation along the face of the primary louvers is not level; therefore, bypass slide gates may need to be adjusted (U.S. Bureau of Reclamation 1956a), one or two primary channel bypasses may need to be closed (Mecum 1977), or the bypasses opened halfway (Direct Loss Mitigation Agreement 1992) in order to meet proper ratios. Currently, a bypass ratio of 1.2 and 1.6 are followed, depending on the time of year. Partial closure of bypasses equalizes the flow through each bypass.

Each bypass opening is transitioned into 91.4 cm (36 in) diameter concrete pipelines at the transition box. This transition occurs within a span of 6.1 m (20 ft) where the bypass transitions from a rectangular opening to a square and then to a round concrete pipe (Figure 6). The four bypass pipes, varying in length (Bypass one = 64 m [211 ft], Bypass two = 69 m [227 ft], Bypass three = 84 m [274 ft], Bypass four = 97 m [318 ft]), run underground and converge at the head of the secondary channel (U.S. Bureau of Reclamation 1956a).

Figure 6 **Bypass pipe and transition box at the Tracy Fish Collection Facility**



Diagrams of the bypass opening transition: A. Top view diagram showing geometric transition at the transition box, B. Cross section diagram, and C. Sagittal view of the transition.

Secondary channel. The four bypasses empty into the secondary channel. The secondary channel bottom is only 0.9 m (3 ft) below sea level; therefore, the secondary channel bottom is 3.4 m (11 ft) higher than the bottom of the primary channel (see Figure 3B). The secondary channel originally had two sets of louvers arranged parallel to each other with general description and design similar to those installed in the primary louver structure. This double line of louvers was replaced in May 2014 with a single line of Hydrolox™ traveling screen, 17 m (56 ft) in length, and angled 7° to the flow (Figure 7). The velocity of the secondary channel is controlled by six velocity control (VC) pumps: four large pumps that can move a total of 4 m^3/s (140 cfs) and two small pumps that can move another 1 m^3/s (40 cfs) (U.S. Bureau of Reclamation 1956a).

When the original double set of louvers were in place, fish were guided to the holding tank bypass that decreased in width from 25.4 cm (10 in) before the first line of louvers, to 20.3 cm (8 in) at the end of the first line of louvers, and finally to a 15.2 cm (6 in) bypass at the end of the second line of louvers (U.S. Bureau of Reclamation 1956a). This decrease in width was cited as problematic and "*undesirable*" in that it would "*create considerable turbulence at the downstream end*" of each of the secondary louvers structure causing fish to "*escape through the vanes*" (California Department of Fish and Game 1955). Furthermore, eddying flows that occur from this design configuration "*will tire, disorient, and sweep fish through the louvers*" and will decrease louver efficiencies (Babb 1966). The design was nevertheless implemented, and turbulence occurred, especially when the louvers were clogged with debris (see 2. Operation & Maintenance\Cleaning).

A clean water loop system (formerly called screened water supply) (U.S. Bureau of Reclamation 1956a) equipped with a traveling screen was installed in the secondary channel to reduce the amount of debris entering the holding tanks. The system was designed to screen post-secondary louver water of peat and other fine debris and pump the debris-free water back upstream of the secondary louver. The water flows along the wall of the secondary louver channel and into the bypass leading to the holding tanks. The screen for this system was replaced with a Hydrolox™ screen in 2014. For more details, see B. Structural changes/Clean water loop system.

Figure 7 **Secondary channel of the Tracy Fish Collection Facility**

Note: Aerial view of the two sets of parallel louvers (arrows) before May 2014 and the six VC pumps located at the end of the channel (circled) that control the water velocity (left); the single line of Hydrolox™ screens installed in May 2014 (right). Inset: closeup of Hydrolox™ screen with 1.5 mm x 50 mm slit opening.

Louver efficiency. The efficiency of louvers in guiding fish into a collection tank has been calculated numerous times throughout the facility's existence using various methods. Initial studies at the Pilot Fish Screen showed high louver efficiency rates for 39 mm (1.5 in) Chinook Salmon (82–94 percent) (U.S. Bureau of Reclamation 1955a) and 25.4 mm (1 in.) Striped Bass (81–92 percent) (U.S. Bureau of Reclamation 1955b). From 1957 up to 1959, using Striped Bass, Chinook Salmon, and White Catfish, Bates et al. (1960) found that the primary louver efficiency results were inconclusive, although speculated that they were similar or even better than the secondary louvers (Shafer 1959). Bates et al. (1960) were not able to determine the numbers of fish "escaping through the primary louver structure," and furthermore, turbid waters contained "vast amounts of minute peat fibers" and "frequent high flow velocity made fishing with nets difficult." Because of the difficulty Bates et al. (1960) had in measuring primary louver efficiency, the TFSAC suggested the results from the secondary louver efficiency tests be applied to the primary louver since "the two louver structures are similar in design, in function and in operation, and that in the secondary all of the water could be sampled" (Bates et al. 1960).

Attempts at measuring primary louver efficiency were conducted in the mid-1960s and summarized in two reports, Hallock (1967) and Hallock et al. (1968). In 1966, Hallock et al. (1968) used Striped Bass, Chinook Salmon, shad spp., and White Catfish to test the primary louver system by fishing two identical fyke nets and plankton nets, one above and one below the louvers, comparing their catches. Hallock (1967) found a primary louver efficiency of 76–99 percent for Striped Bass with efficiency increasing with size. This finding is similar to Skinner's (1973) louver studies at the SDFPF where efficiency was directly related to fish length, i.e., as fish increased in length, length became less of a factor for louver efficiency. Hallock et al. (1968) found that the primary louver efficiency for Striped Bass ranged from 2 percent (6–19 mm fish; using plankton nets) to almost 100 percent (≥ 70 mm fork length [FL]). The near zero efficiency for Striped Bass larvae of Hallock et al. (1968) was expected since larvae drift with the flow and were not expected to swim away from louvers. There was, though, a discrepancy on the reported values for 10–24 mm Striped Bass: Hallock (1967) reported 5.4 percent and Hallock et al. (1968) reported 64.7 percent. Nevertheless, the louver efficiency estimates from Hallock (1967) and Hallock et al. (1968) were likely not reliable since the two locations where the fyke nets were fishing (i.e., upstream and downstream of the primary louvers) do not have the same hydraulic conditions and therefore were not comparable.

In 1993, using juvenile Striped Bass and Chinook Salmon, Karp et al. (1995) reported that the primary louvers had a combined mean efficiency rate of 59.6 percent (0–96 percent for Striped Bass, 13–82 percent for Chinook Salmon). Karp et al. (1995) noted that fish released into the primary channel had greater opportunity to move upstream and away from the facility (non-participation in the study), or downstream either through the louvers or through the gap created by the primary louver cleaning process. These fish also may have been more vulnerable to predation or may have found refuge within the system (Karp et al. 1995).

Recently, the use of acoustic tags for tracking the movement of Chinook Salmon, Steelhead, and Striped Bass within and around the facility has been promising and should resolve issues related to non-participation and, potentially, predation (B Wu pers. comm.). Primary louver efficiency was high (71.4–100 percent) using acoustically tagged Chinook Salmon (mean 136.2 mm FL), with greater efficiency occurring at 4–5 JPP units; however, the relationship is still weak because of the low sample size (Karp et al. 2017). Currently, primary louver efficiency at the TFCF can be described as:

PLE = (# moved to SC) ÷ (# injected in PC – # non-participant in PC – # preyed in PC), where (Eq. 1)
PLE = Primary Louver Efficiency,
 # moved to SC = amount of test fish that were guided by the primary louvers to the secondary channel,
 # injected in PC = amount of test fish inserted in the primary channel,
 # non-participant in PC = amount of test fish that held in the primary channel, and
 # preyed in PC = amount of test fish eaten by predators in the primary channel.

The efficiency of the secondary louver has historically been higher than the primary louver (Table 1) and, similar to the primary louver, its efficiency is dependent on fish size, the fish species, and life stage. Initial studies at the Pilot Fish Screen showed that “double-louvers” using 22.2 mm average (0.8 in.) Striped Bass had 99 percent efficiency (0.8 m/s, 50.5 mm louver spacing) (U.S. Bureau of Reclamation 1955c; Bates and Vinsonhaler 1957). Bates et al. (1960) used a large net at the end of the secondary channel constructed with “four separate funnels or fykes built into the throat, each leading into a common pot” to capture test fish that went through the secondary louver, showing that the secondary louver system was at least 90 percent efficient. In 1993, using juvenile Striped Bass and Chinook Salmon and a 12.7 mm mesh sieve net at the end of the secondary channel, Karp et al. (1995) found that the secondary louvers were generally more effective (mean = 80 percent, range: 72–100 percent for Chinook Salmon and 30–90 percent for Striped Bass) than the primary louvers (mean = 59.6 percent, range: 13–82 percent for Chinook Salmon and 40–96 percent for Striped Bass) at diverting fish. Bowen et al. (1998), hypothesizing that louver efficiencies have deteriorated at the TFCF, reported a mean secondary louver efficiency of 83 percent for Chinook Salmon and 86 percent for Striped Bass by collecting paired samples from the sieve net (similar to Karp et al. 1995 study) and the holding tank. These secondary louver efficiency values were still within, or close to, the first estimates reported by Bates et al. (1960). The secondary louver system was not effective at guiding Pacific Lamprey (*Entosphenus tridentatus*) macrophthalmia (Goodman et al. 2017; Reyes et al. 2017). Goodman et al. (2017) estimated that between 1957 and 2014, 94–96 percent of the lampreys that were entrained in the export flows were lost and not returned to the Delta. Also, the secondary louver system is not as effective in guiding small fish. For example, secondary louver efficiency as low as 22 percent for juvenile Delta Smelt (32–40 mm FL) was observed in a bulk fish release study in 2010 (Bridges unpub.). Furthermore, in a comparison of larval efficiency at varying secondary channel velocities (1 vs 3 fps) in 2012, more larvae were salvaged at slower velocities (Reyes unpub.).

Finally, the velocities at the primary channel and the secondary channel, which affect the efficiencies, are controlled differently. At the primary channel, the velocity depends on how many pumping units are running at the JPP, i.e., the TFCF does not have the ability to regulate velocity at the primary channel. Since it is a large body of water, placing nets behind the primary louvers to recover louver-lost fish is extremely difficult. At the secondary channel, the six VC pumps located at the end of the secondary channel enable control of the secondary channel velocity. Since it is a smaller channel, sieve nets can be placed behind the screen to recover lost fish. Thus, secondary louver efficiency can be described as:

SLE = (# moved to HT) ÷ (# moved to HT + # lost through SL + # preyed in SC), where (Eq. 2)

SLE = Secondary Louver Efficiency,

 # moved to HT = amount of test fish that were guided to the holding tank by the secondary louvers,

 # lost through SL = amount of test fish that went through the secondary louvers and recovered by sieve net, and

 # preyed in SC = amount of test fish eaten by predators in the secondary channel.

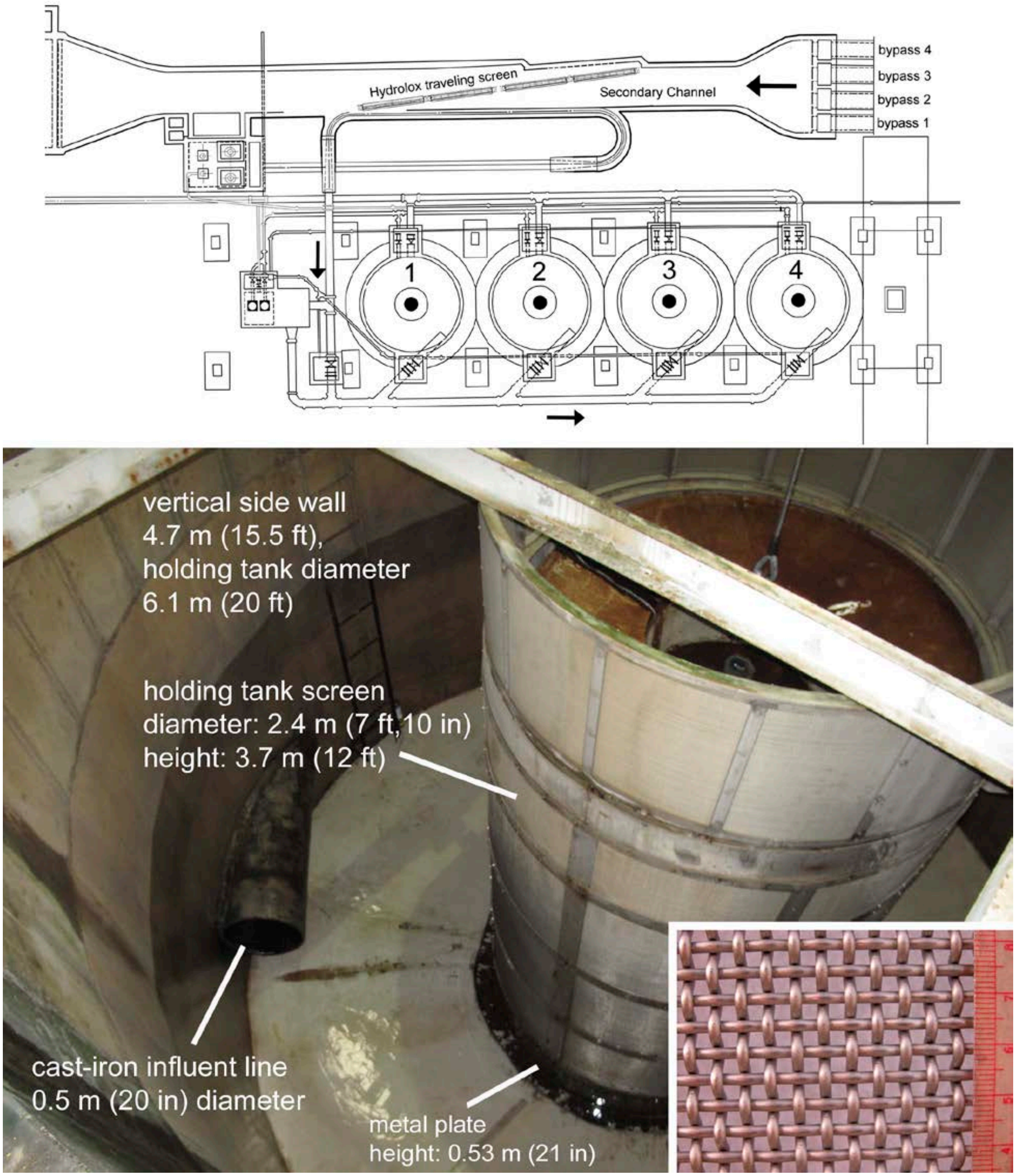
Table 1 Louver efficiency results of the different studies conducted on the Tracy Fish Collection Facility primary louver and secondary louver systems since 1957

Author	year	Primary Eff	Secondary Eff	Species used	Lengths (mm)
Bates et al. (1960)	1957–1959	—	92–100	Chinook Salmon	38.1–101.6
		—	86–95	Striped Bass	8.3–101.6
		—	65–92	White Catfish	8.3–101.6
Hallock (1967)	1966–1967	5.4	—	Striped Bass	10–24
		76–99.4	—	Striped Bass	25–39
Hallock et al. (1968)	1966–1967	90	—	Chinook Salmon	70–100
		2–100	—	Striped Bass*	6–19
		64.7–99.7	—	Striped Bass	10–24
		89	—	Shad spp.	—
Karp et al. (1995)	1993	13–82	72–100	Chinook Salmon	58–127
		0–96	30–90	Striped Bass	73–288
Bowen et al. (1998)	1993–1995	—	83.2	Chinook Salmon	70–130
		—	85.7	Striped Bass	116 (avg.)
Bowen et al. (2004)	1996–1997	—	85.1	Chinook Salmon	—
		—	61.6	Striped Bass	—
		—	13–82.5**	Delta Smelt	—
		—	60–75	Splittail	—
Bridges, unpublished	2010	—	22–63 `	Delta Smelt	32–40
Karp and Bridges (2015)	2009	32.2	93.3	White Sturgeon	105–265
Karp et al. (2017)	2013	71.4–100	> 75	Chinook Salmon***	103–176
		50–100	> 75	Steelhead***	165–228
Reyes et al. (2017)	2012	—	3.9–23.6 (day)	Pacific Lamprey	132–140
		—	16–28 (night)	Pacific Lamprey	132–140

Notes:
**using plankton net.*
***13% when > 3.1 fps (0.94 m/s), 82.5% when ≤ 1.09 fps (0.33 m/s).*
****acoustic telemetry.*

Holding tanks. Fish that enter the secondary channel are directed into one of four circular, recessed, in-ground, concrete holding tanks. Holding tanks are numbered from 1 to 4 (upstream to downstream). Each holding tank is 6.1 m (20 ft) in diameter and 5.0 m (16.5 ft) deep with 2.4 m diameter (~8 ft) cylindrical wire-mesh screens (2.7 mm mesh opening, 3.8 diagonal opening) in the center that retain fish between the screen and the outside wall of the holding tank away from the drain (Figure 8). Water and fish enter the holding tanks from an influent pipe located at the bottom outside edge of the tank and their entry is controlled by a 20-inch knife-gate valve (influent valve: four total, one for each influent pipe).

Figure 8 **Holding tank at the Tracy Fish Collection Facility**



Inset: closeup of the current stainless-steel wire-meshed holding tank screen with 2.7 mm square opening/3.8 mm diagonal opening.

The center of the holding tanks is designed to receive a 1,893 liter (L) (500 gallon [gal]) bucket (haul bucket) or a 341 L (90 gal) fish sampling bucket (sampling bucket; Figure 9). When a holding tank is to be drained, the inflow from the secondary channel is turned off and the flow routed to another tank. The holding tank is then drained (by two dewatering sump pumps) through the cylindrical screen except for 5,299 L (1,413 gal) containing the fish, which are held back by a 53.3 cm (21 in) tall metal plate around the bottom of the cylindrical screen (see Figure 8). The combined capacity of both sump pumps can lower the water level in one holding tank at a rate approximately 30–45 cm/min (1–1.5 ft/min), which is about 4–7 minutes depending on the tidal water level and pump combination (U.S. Bureau of Reclamation 1956a). The bucket is then lowered into a sump in the bottom of the tank and the center cylindrical screen raised 23 cm (9 in) to release water and fish into it. If the fish are to be hauled to a release site, the larger haul bucket is used to lift the fish out of the bottom of the holding tank and is emptied into a fish tank truck. For a fish count, the process is the same except that the smaller sampling bucket is used, and the contents are emptied into a fish count station.

Figure 9 Fish bucket: the sampling bucket (left) and the haul bucket (right) used at the Tracy Fish Collection Facility

Note: The sampling bucket is the original bucket from the 1950s; the haul bucket pictured is a new bucket put into operation in 2008. Inset: closeup of the sampling bucket's 3 mm opening woven mesh screen (left) and haul bucket's 2.5 mm opening perforated screen (right).

A subsample (fish count) is collected to estimate the amount of fish that are salvaged. These fish counts are conducted to estimate how many fish are collected during a two-hour interval and also allows the operator to estimate how many fish have been salvaged since the last fish transport. The length of time fish are held in the holding tanks varies according to species of fish (e.g., time limits when salmon and smelt are detected in counts), number of fish, and size of fish. Bates et al. (1960) developed tables (known as Bates Tables) for the loading of transport trucks using size classes, species, and water temperature which are still used today for informing operators when a fish haul has to be conducted (see B. Structural changes/Fish transport trucks). Fish are trucked and returned to the Delta at release sites located on the San Joaquin River immediately upstream of the Antioch Bridge and on the Sacramento River near Horseshoe Bend (Emmaton and Sherman Island; see Figures 1 and 23 for location of the release sites). Particle tracking modeling (Kimmerer and Nobriga 2008) suggested that these locations were far enough from the influence of the pumps. Barnaby et al. (1953) recommended that fish be released during high tide and that releases further down the river would mean better survival; however, releasing freshwater-oriented fish into more saline water may be a concern.

Summary of fish screens at the TFCF. The TFCF uses several screening components for different purposes, and all work in series to prevent large fish from entering the facility (trash rack), guide fish either behaviorally (louvers) or as a positive barrier (Hydrolox™ traveling screen), and retain fish (holding tank screen, fish sampling bucket, fish count station, fish haul bucket). Louver efficiency varies widely (see Table 1) depending on size and species of fish, water velocity, and life stage. The two sets of parallel louvers in the secondary channel, in general, were more efficient than the longer, single line of louvers at the primary channel. Its replacement, the Hydrolox™ traveling screen, was expected to be more efficient than louvers, especially for larger fish. For smaller fish, though, larval and juvenile fish are still lost through the traveling screens, especially at higher water velocities (Reyes 2019 et al. in draft).

Once fish enter the holding tanks, screen-size openings play a major part in fish retention. For woven wire screens which are used for the holding tank screen and fish sampling bucket, the openings are square; the diagonal opening determines the effectiveness of the screen. The fish count station and the fish haul bucket currently use plates perforated with circular holes. Because it has been demonstrated that ≥ 20 mm fish are lost through openings greater than 2.3 mm (Sutphin et al. 2007; Wu and Bridges 2014b), the TFCF likely underreports fish ≥ 20 mm, the size the TFCF is required to report. The holding tank screen has the largest screen opening (3.8 mm diagonal opening) of the entire set of screened components used for fish retention and loses large amounts of larval fish < 10 mm (Reyes et al. 2012) and juvenile fish as large as 28 mm FL (Wu and Bridges 2014b). The various screened components at the TFCF are summarized below.

Table 2 Screened components at the Tracy Fish Collection Facility

Screened Component	Historical		Current		Year Replaced
	Opening (mm)	**Screen Type**	**Opening (mm)**	**Screen Type**	
Trash rack	50.8	vertical bars	50.8	vertical bars	1994, 2010
Primary channel	25.4	louvers	25.4	louver	1990
Secondary channel	25.4	louvers	1.5 x 50 (slit opening)	traveling screen	2014
Holding tank screens	3.5 (diag. opening)	galvanized wire	3.8* (diag. opening)	woven wire	2000
Fish sampling bucket	3 (diag. opening)	woven wire	3*	woven-wire	original
Fish count station	6.35, 4.8	wire, perforated plate	2.4*	perforated plate	2014
Fish haul bucket	3.4 (diag. opening)	woven wire	2.5*	perforated plate	2008

**Ideal screen opening is between 2.1 and 2.3 mm (Sutphin et al. 2007; Wu and Bridges 2014b).*

Interpreting salvage, entrainment, and loss. There are several terms related to the operation of the fish salvage facility. "Entrainment" is the influence of a project (e.g., SWP, CVP) on fish drawn in by the flow of water. "Salvage" refers to the process of collecting and holding fish entrained by the operation of the JPP. "Loss" occurs when the fish are eaten by a predator, go through the facility's louver or screens, or die during handling and transport. Summarizing the fate of a fish, a fish that enters the facility because of JPP operations can be preyed upon before the facility (i.e., in front of the trash rack), be eaten between the trash rack and the primary louvers (pre-screen loss), swim through the louvers (louver loss), swim through other screened components (screen loss), swim through the louvers during cleaning (cleaning loss), maintain position within the facility (non-participation), swim out of the facility (non-participation), or can be collected in the holding tank (salvaged).

Salvage. Salvage refers to fish that were successfully diverted to a holding tank. To obtain a salvage estimate, a fish count has to be collected for a certain length of time (in minutes) within a time interval (usually two hours). Fish collected from that fish count are then multiplied by an expansion factor. The expansion factor is the value calculated by dividing the time interval by the fish count duration. For example, if a 30-minute sample is collected for a 2-hour interval, the expansion factor would be 4 (i.e., 120 min ÷ 30 min). The number of each species collected from the sample will then be multiplied by the expansion factor to obtain an estimate of total species-specific salvage for the 2-hour interval. For example, if 53 Splittail and five Striped Bass were in the 30-minute sample collected from 8–10 a.m., the expanded numbers would then be 212 Splittail (i.e., 53 x 4) and 20 Striped Bass (i.e., 5 x 4) for the 10 a.m. fish count. Samples are collected toward the end of the 2-hour interval; therefore, for this 10 a.m. fish count, the sample was collected from 9:30 a.m. to 10 a.m. Salvage estimation can be described as:

Salvaged = Number of fish counted x (Time Interval in minutes ÷ Count Length in minutes) *or* (Eq. 3)
= Number of fish counted x expansion factor.

The salvage process has changed over the years and therefore caution should be used when interpreting data collected from the fish counts. Salvage data before 1993 contained sampling times and durations that varied widely, and the accuracy of fish species identification was questionable. Data from 1993 to 2009 was more standardized and reliable because of the regular use of 10-minute fish counts to estimate salvage and because of the presence of resident biologists to oversee the accuracy of collected data. Unfortunately, shorter 10-minute fish counts had higher chances of missing schools of fish. Despite this, the large expansion factor of 12 (or 120 min ÷ 10 min) used for 10-minute fish counts may overestimate salvage. The current 30-minute fish count, which has been the standard practice since late-2009, is less biased since sampling time increased from 8.3 percent to 25.0 percent of entrainment, increasing the likelihood of counting entrained fish. The expansion factor of 4 (or 120 min ÷ 30 min) is also less likely to overestimate salvage. Fish less than 20 mm are also not included in the salvage reporting, resulting in the underestimation of salvage. Because of all these factors, salvage numbers produced from the salvage estimation process (i.e., fish counts) can give presence and absence of fish species but cannot produce an accurate estimate of fish population. For more details on how the salvage process has changed over the years, see 2. Operation & Maintenance\Fish salvage monitoring.

Entrainment. Entrained fish refer to fish that enter the facility because of the pumping influence at JPP. Entrainment varies by time of year, fish life stage, and the facility's operational parameters. The current method for estimating entrainment at the TFCF is mainly calculated for salmonids (California Department of Fish and Game 2013). In order to estimate entrainment, it is necessary to know how many fish encounter the primary louvers and how many fish enter the facility. The number of fish that encounter the primary louvers is calculated by dividing the salvage by the primary louver efficiency. Some fish will be lost through the louvers, generally higher for fish < 100 mm than for fish > 100 mm. Although studies on primary louver efficiency have been completed at the TFCF (see Table 1), screen efficiency values currently used at the TFCF are based on studies conducted at the Skinner Delta Fish Protective Facility from 1970–71 (Delta Fish Agreement 1986). For the following equation, it is assumed that the louver efficiencies at the two facilities are similar. The number of fish encountered by the louvers at the TFCF can be described as:

Encountered = Salvage ÷ Louver Efficiency, where (Eq. 4)

Louver Efficiency = 0.630 + (0.0494 x Velocity*), if salmon is < 100 mm *or*

Louver Efficiency = 0.568 + (0.0579 x Velocity*), if salmon is > 101 mm.

**Velocity at the TFCF is calculated as primary channel flow ÷ (primary channel depth x primary channel width). Primary channel width at the TFCF is 84 ft.*

To estimate how many fish enter the TFCF, i.e., are entrained, the number of fish that encounter the louvers is divided by the proportion of fish assumed to survive the journey to the louvers, 1 – P where P is the predation or pre-screen loss rate. Entrainment at the TFCF can be described as:

Entrained = Encountered ÷ (1 – P), where P = 0.15. (Eq. 5)

Pre-Screen Loss. Loss calculation at the TFCF, similar to entrainment, is mainly calculated for salmonids (note: Jahn [2011] proposed an alternative method for calculating loss; however, only the current method is presented below). Currently, a 15 percent pre-screen loss rate because of predation (P, mentioned above) is a temporary placeholder value (D Odenweller pers. comm.) and is yet to be fully verified. For this placeholder, "pre-screen loss rate" is defined as "the rate of loss to entrained salmon during movement from the trash racks to the primary louvers" (California Department of Fish and Game 2013). In essence, the "pre-screen loss rate" is the predation rate within the primary channel. Predation in front and upstream of the trash rack, although important and can be considered pre-screen loss, are not included in the loss calculation. Predation rates at the bypasses, secondary channel, and the holding tanks are also not included in the loss calculation; however, predation rates at these locations are probably low because of the current monthly-scheduled predator removal program. Predation rate within the primary channel is currently being verified with the use of Predation Detection Acoustic Tags (PDAT) and preliminary results indicate that the predation rate may be close to the 15 percent placeholder value (B Wu pers. comm.).

Predator removals were not part of the facility protocol before 1993; therefore, the predation rate before 1993 was likely higher at all locations in the TFCF. Predation in general will reduce salvage and salvage efficiency since entrained fish are eaten before they reach the holding tanks. With the recent regular (monthly) and effective predator removal process at the bypasses and secondary channel using carbon dioxide, entrained fish are more likely to be salvaged and predation rates at these locations are expected to be low.

Other Loss. Other "loss" to consider include louver loss, screen loss, cleaning loss, and handling and transport loss. Louver loss is already addressed by the louver efficiency mentioned above; however, loss from other screened components at the TFCF is not included in the TFCF loss calculation since this mainly impacts fish in the 20 mm range. Loss through other screened components is not an issue for salmon, since salmon at the 20 mm size range are not observed at the facility. In general, louver loss and screen loss increase with increased velocity, although facility efficiency also increases with velocity since predation and non-participation (swim-out or fish that maintain position within the facility) tend to decrease with increased velocity. Loss because of louver cleaning (see Figure 10) is also not quantified in the current loss calculation method. Finally, salmon loss because of handling and transport are generally low and are based on CDFW trucking and handling studies, < 2 percent for salmon < 100 mm and zero percent for salmon > 100 mm (Raquel 1989; California Department of Fish and Game 2013). The number of fish that survive the process of trucking and handling and are released at the release site can be described as:

Released = Salvage x (1–0.02), if salmon is < 101 mm *or* **(Eq. 6)**
Released = Salvage, if salmon is > 100 mm.

Finally, to estimate the TFCF system loss, subtract the estimated number of fish released from the estimated number of fish entrained. This can be described as:

Loss = Entrained – Released **(Eq. 7)**

III. Facility Changes (1957–2017)

A. Operational changes

Since the 1950s, many changes have occurred in the Delta that required changes to the operations at the TFCF. The growing concern for the health and decline of Delta fish has resulted in regulation of TFCF activities through several agreements, decisions, and biological opinions. Some of the operational changes that have occurred at the TFCF have been because of the changing nature of the Delta brought on by anthropogenic activities. Since the 1950s, there has been a proliferation of invasive aquatic vegetation, resulting in higher debris loading, and more invasive fish, resulting in predator accumulation at the facility. Invasive plant introduction was mostly from the aquarium trade, and many of the fish introductions were from ship ballast releases and legal and illegal introductions (Dill and Cordone 1997). Furthermore, with the large State facilities (Banks Pumping Plant and Clifton Court Forebay) coming online in the late 1960s (Morinaka 2013), additional debris and fish were pulled toward the South Delta and the TFCF. A summary of the operational changes is listed in Appendix 10A.

1. Regulatory commitments

Major regulatory mandates directly affecting the TFCF have included rules that established hydrologic requirements and agreements that enabled consistent monitoring of salvaged fish. Some of the more important regulations, agreements, and congressional acts are listed and summarized below and the specific documents and wording are included in the Appendix:

a. 1957 Memorandum of Agreement. Before the TFCF came online, Reclamation entered a two-year agreement (Appendix 3) with USFWS starting in January 1957 (U.S. Bureau of Reclamation 1957). The most relevant terms that Reclamation and U.S. Fish & Wildlife Service mutually agreed upon were:

1. Establish a joint program of testing, appraisal, and evaluation as a necessary part of completion and proper operation of the TFCF.
2. USFWS to provide competent personnel to supervise and perform the biological phases of the program as jointly adopted, the total program to be appurtenant to the operation and maintenance of the TFCF by Reclamation through the Tracy Operations Field Branch Chief.
3. Reclamation and USFWS were to prepare a joint monthly progress report covering both the mechanical and biological phases of the program, and copies of this report were to be supplied to CDFW (formerly California Department of Fish and Game). A final joint report covering the procedures, analyses, and findings of the entire testing, appraisal, and evaluation program would also be prepared.

b. 1978 State Water Resources Control Board Decision 1485. In the 1960s, water exports were mostly for agriculture and most occurred during summer, but in the 1970s, soon after the completion of San Luis Reservoir, water exports occurred year-round and more than doubled by the late 1970s. With this backdrop, in August 1978, the State Water Resources Control Board issued their Water Rights Decision 1485 (D 1485) (Appendix 4), the first major mandate affecting the operation of the TFCF to protect fish and wildlife. This decision (1) amended the water rights permits for the CVP and SWP facilities, (2) exercised its jurisdiction to set terms for protections of fish and wildlife, and (3) coordinated the terms for both facilities. This decision requires standards to be maintained for the protection of fish and wildlife as a condition of CVP and SWP permits (State Water Resources Control Board 1978).

Table II Appendix A of the decision established standards for the operation of the TFCF. The most relevant standards are listed below:

1. Maintain appropriate records of the numbers, size, kind of fish salvaged, and of the water export rates and facility operations.
2. The secondary system is to be operated to meet the following standard, to the extent that they are compatible with water export rates:
   A. The secondary velocity should be maintained at 3.0 to 3.5 fps, whenever possible, from February through May while salmon are present.
   B. To the extent possible, the secondary velocity should not exceed 2.5 fps and preferably not exceed 1.5 fps between June 1 and August 31 to increase the efficiency for Striped Bass, catfish, shad, and other fish. Secondary velocities should be reduced even at the expense of bypass ratios in the primary, but the ratio should not be reduced below 1:1.
   C. The screened water discharge should be kept at the lowest possible level consistent with its purpose of minimizing debris in the holding tanks.
   D. The bypass ratio in the secondary should be operated to prevent excessive velocities in the holding tanks, but in no case should the bypass velocity be less than the secondary approach velocity.

Water Rights Decision 1485 requires the secondary velocity be "maintained at 3.0 to 3.5 fps whenever possible from February through May while salmon are present." This requirement negatively affects larval and juvenile Delta fish. Delta larvae and juveniles are collected in the larval samples from March to June and are best salvaged at slower velocities of 1.0–2.0 fps (Reyes unpub.). At faster velocities, they are lost through the louvers and other screens. Furthermore, Delta Smelt larvae and juveniles are at peak salvage around April and May. Flexibility in the implementation of Water Rights Decision1485 may be necessary to balance the needs of outmigrating Chinook Salmon, young-of-the-year Delta Smelt, and fish larvae.

c. 1983, 1995, 2012 U.S. Bureau of Reclamation/CDFG Agreement Regarding Fish Salvage Operations at the TFCF. The 1983 Agreement Regarding Fish Salvage Operations at the TFCF (Appendix 5), which was revised in 1995 (Appendix 6), allowed CDFW to monitor the fish salvage operations at the TFCF. The agreement was updated in 2012 to include points 7, 8, and 9. Under the agreement, CDFW's responsibilities included:

1. Monitor the fish salvaged by a routine sampling program conducted by Reclamation when the facilities are operating.
2. Monitor the random sub-samples from routine samples for species composition, size, and other life history information conducted by Reclamation.
3. Collect the data sheets from Reclamation and analyze data and provide monthly and annual reports.
4. Assemble, analyze, and maintain records of salvage operations of facilities.
5. Provide biological expertise to facility operations.
6. Conduct other evaluations related to the facilities and their operation as required and mutually agreed upon by Reclamation and CDFW.

7. Provide daily salvage summary table for adult, juvenile, and larval Delta Smelt and Longfin Smelt (*Spirinchus thaleichthys*).
8. Provide daily (as needed) salvage summary table for Green and White Sturgeon.
9. Provide daily reports on salvage, loss, and loss density of Chinook Salmon and Steelhead in table format.

d. 1992 U.S. Bureau of Reclamation/CDFG Direct Loss Mitigation Agreement. On July 17, 1992, CDFW and Reclamation executed a cooperative agreement (Appendix 7) to reduce and offset Striped Bass and Chinook Salmon losses associated with the operation of the JPP and the TFCF. The TFCF has not attained the salvage efficiencies originally expected, and CDFW estimated millions of fish were being lost annually (Liston et al. 1994; Stackhouse 1999). Before this agreement, power outages that occurred at the TFCF were not reported to CDFW. For example, two power outages (totaling 3.5 days) at the TFCF occurred in November 1988 and approximately 36,200 acre-feet (44,652,043 m^3) of unscreened water was pumped (McEwan 1988). Because of events like these, stipulation that Reclamation must notify CDFW of power outages was included in the agreement. The agreement was updated in 2000 (to include fish from "the entire Central Valley," not just Chinook Salmon and Striped Bass) and again in 2005. Under the agreement, Reclamation's responsibilities included:

1. Operate the TFCF whenever the JPP is in operation, except during required maintenance, and shall notify CDFW prior to any scheduled outages.
2. Operate the TFCF in accordance with operational criteria provided in Table II of D 1485.
3. Maintain and adjust holding tank velocities so that the flow in any one tank shall not exceed 10 cfs.
4. Replacement of existing fish hauling trucks with two new trucks (each having a capacity of 2,000 gallons). Fish hauling shall be scheduled in accordance with the most recent set of fish hauling tables and fish shall not be held in the holding tanks for more than 24 hours without prior approval from CDFW.
5. Existing fish release sites shall be maintained in good condition and other sites shall be obtained for use in case both existing sites are not available.
6. During operation of the TFCF, conduct fish counts every two hours, conduct length counts four times a day, and provide monthly and annual reports of the number, size, and kinds of fish, and of facility operations and exports.
7. Improve salvage efficiencies at the TFCF when primary approach velocities are excessive or when the TFCF is removed from operation for other than normal maintenance purposes.
8. Reclamation will provide funding for CDFW's oversight of the fish salvage and enumeration aspects of TFCF operations.
9. Reclamation, with input from CDFW, shall develop and implement a predator control program at the TFCF to regularly remove and/or control predators in the vicinity of the primary louvers, the primary bypasses, and the secondary bypasses and channels.

e. 1992 Central Valley Project Improvement Act. In 1992, the 102nd Congress passed the Central Valley Project Improvement Act (CVPIA) which mandated changes in the management of the CVP, particularly for the protection, restoration, and enhancement of fish and wildlife. Section (b)(4) of CVPIA (Appendix 8) mandates the mitigation of fishery impacts associated with the operations of the JPP. These include physical improvements by replacement of the existing fish screen with improved technology for fish recovery and protection, as well as improved management practices.

f. Endangered Species Act. The TFCF encounters several species that are listed under the Endangered Species Act (ESA) of 1973 and California Endangered Species Act (CESA) of 1984. Sacramento winter-run Chinook Salmon was the first to be listed as State endangered in 1990 and federally endangered in 1994 because of the extremely low number of returning spawners in the early 1990s (as low as 200). The proposal to list Delta Smelt under the ESA was met with opposition from Reclamation (Fults 1990; Underwood 1991; Glaser 1991) and DWR (Kennedy 1991) and from groups such as state water contractors (Baumli 1990), the Central Valley Project Water Association (Simmons 1990), and the California Central Valley Flood Control Association (Martin 1990). Delta Smelt were eventually federally listed as threatened in 1993. Three more fish were added soon after: Steelhead (Central Valley Distinct Population Segment [DPS]) were listed as threatened in 1998, Central Valley spring-run Chinook Salmon were listed as threatened in 1999, and Green Sturgeon (*Acipenser medirostris*) (southern DPS) were listed as threatened in 2006. A proposal to list Splittail (*Pogonichthys macrolepidotus*) as a threatened species was published in 1994 (Federal Register 1994) and the species was listed as threatened in 1999; however, it was removed in 2003 through a federal ruling in support of the San Luis & Delta-Mendota Water Authority. The Longfin Smelt was listed as threatened under the CESA in 2009. While all fish species are reported daily to regulatory agencies when encountered in the salvage, additional information such as DNA tissue samples, coded wire tag (CWT), Passive Integrated Transponder (PIT) tag, radio tag, and hydroacoustic tag are collected from threatened and endangered species.

g. Biological Opinions. The U.S. Fish and Wildlife Service (USFWS) issued their Biological Opinion in 1995, 2004, and 2008 for the operation of the TFCF to minimize take of Delta Smelt. The requirements are similar to NMFS Biological Opinions with additional relevant requirements listed below:

1. Between December 1 and March 30, trucks must go to the "new" release site when catch is 0.5 Delta Smelt per count minute.
2. Delta Smelt are to be held in holding tanks for no more than eight hours.
3. Reclamation are to monitor for the presence of spent female Delta Smelt.

Unlike the 1995 USFWS Biological Opinion which stated that the CVP and SWP operations were "not likely to jeopardize the continued existence of the Delta Smelt," the USFWS determined in the 2008 USFWS Biological Opinion (which includes the Long-Term Operational Criteria and Plan (OCAP) for coordination of the CVP and SWP) that the coordinated operation of the two water projects was "likely to jeopardize the continued existence of Delta Smelt" and adversely modify its critical habitat. The inclusion of reasonable and prudent alternatives (RPA) to the 2008 Biological Opinion allowed the CVP and the SWP to continue their operations without "jeopardizing the continued existence" of Delta Smelt and "resulting in the destruction or adverse modification" of their critical habitat. The most relevant components or requirements of the RPA relating to the operation of the salvage facilities were:

1. The protection of the adult Delta Smelt that are migrating during December and March by controlling the Old and Middle River (OMR) flows. OMR flow is measured, and also indexed or estimated; however, a criticism of the indexed method is that it does not track

actual OMR values (National Resources Defense Council & The Bay Institute 2014). The CVP uses the indexed method, which was developed by Metropolitan Water District of Southern California (Hutton 2008).

2. The improvement of flow conditions in the Central and South Delta so that larval and juvenile Delta Smelt can rear in the Central Delta and move downstream when appropriate.

The 2008 USFWS Biological Opinion does not require the salvage facilities to successfully salvage Delta Smelt; however, it does require the facilities to monitor the species, particularly the presence of spent female Delta Smelt and ≤ 20 mm larval Delta Smelt and Longfin Smelt. Because of the higher costs of implementing a quantitative monitoring program, a qualitative larval sampling program was instead established at the TFCF in 2008 to monitor the presence and absence of Delta Smelt and Longfin Smelt larvae in the vicinity of the TFCF (see 2. Operation & Maintenance\Fish salvage monitoring).

National Marine Fisheries Service (NMFS) issued their Biological Opinion for the Operation of the CVP and the SWP in 1993, 2002, 2004, and 2009 to minimize the take of winter-run Chinook Salmon, Steelhead, and Green Sturgeon. The most relevant requirements to the TFCF were:

1. The secondary channel velocity be approximately 1 fps between May 15–Oct. 31 for Striped Bass criteria and approximately 3 fps between Nov. 1–May 14 for Chinook Salmon criteria.
2. Fish counts are conducted no less than 30 minutes every two hours year-round. Exceptions may occur with NMFS concurrence under unusual situations.
3. Salt to be added to water in hauling trucks to attain 8 parts per thousand (ppt) salinity.
4. Fish transportation runs for salmonids — at least every 12 hours, more frequently if required by the "Bates Tables."
5. Reclamation to remove predators in the secondary channel at least once per week.
6. Reclamation to install equipment to monitor for the presence of predators in the secondary channel.
7. Reclamation to operate the TFCF to achieve whole facility salvage efficiency of 75 percent.
8. Reclamation to maintain head differential at the trash rack of less than 1.5 ft at all times.
9. Reclamation to install/maintain flow meters in primary and secondary channels to continuously monitor/record flow rates.
10. Websites shall be created/improved to make salvage count data publicly available within two days. Information on the website shall include:
    A. Duration of count minutes.
    B. Species of fish salvaged.
    C. Number of fish salvaged including raw counts and expanded counts.
    D. Volume of water in acre-feet and average daily flow in cfs.
    E. Daily average channel velocity and bypass ratio in primary and secondary channel.
    F. Average daily water temperature and electrical conductivity data.
    G. Periods of non-operation because of cleaning, power outages, or repairs.
11. All personnel conducting fish counts must be trained in juvenile fish identification.
12. DNA tissue samples/coded wire tag samples from Chinook Salmon and Steelhead shall be collected for genetic analysis or tag removal/reading.

Under Terms and Condition 2a of the 2009 NMFS Biological Opinion, Reclamation was required to select and fund an independent contractor to determine the best technique to quantify the incidental take of listed anadromous salmonid species and the Southern DPS of Green Sturgeon at the federal and State export facilities. Dr. Andy Jahn, who was selected by NMFS, produced a final report in July 2011 that included a new alternative loss calculation. Both Reclamation and DWR were not ready to adopt the alternative loss calculation proposed by Dr. Jahn and proceeded to consult with NMFS. The consultation with NMFS resulted in a two-year study to come up with alternative loss equations.

DWR contracted with Cramer Fish Sciences in 2012 to conduct a sensitivity and uncertainty analysis on the alternative loss equation from Jahn (2011). At about the same time, a "Terms and Condition 2a Technical Team" was created to provide input. Cramer Fish Sciences released their final sensitivity and uncertainty analysis report in April 2013. The report was followed by a review of proposed modifications to the NMFS Biological Opinion Terms and Condition 2a by an independent review panel (IRP).

In May 2014, The Terms and Condition 2a Technical Team submitted a second opinion scope of work to DWR and NMFS. DWR created a task order that included the following areas of focus: (1) continue and refine Green Sturgeon lab studies, (2) review conceptual models for estimating entrainment loss at the facilities, (3) re-draft the narrative for the alternative loss equations, (4) incorporate IRP input for the alternative loss equations, and (5) get a second opinion from statisticians for the IRP recommendations. All of the tasks under the task order were completed by 2016. The review process of the new loss method and tool has been delayed, because of a shift in project management. At this point, DWR is awaiting direction from Reclamation on how to proceed on the project.

h. 2000 State Water Resources Control Board Decision 1641. In 2000, the Vernalis Adaptive Management Plan (VAMP) was initiated as part of the SWRCB Decision 1641. VAMP was designed to protect juvenile Chinook Salmon migrating from the San Joaquin River through the Sacramento-San Joaquin Delta. The long-term plan utilized a 31-day pulse flow period during April and May in the San Joaquin River near Vernalis and included decreased export pumping at the SWP and CVP for salmon protection. During the annual VAMP period, the TFCF did not salvage many fish because of limited pumping.

2. Operation & Maintenance

a. Hydrological monitoring. Monitoring of flows, velocities, and bypass ratios were always done at the TFCF since 1957; however, there were no guidelines on velocities and bypass ratios until 1978 with Water Rights Decision 1485. Biological Opinions added extra guidance for the facility. Below is the current operational guidance (Table 3) for the TFCF.

Table 3 Operational guideline for the Tracy Fish Collection Facility based on D 1485 and the various Biological Opinions

Effective Dates	Criteria	Bypass Ratio

Chinook Salmon	November 1–May 31	Secondary velocity of 3.0 fps. Individual primary bypass ratios equal to or greater than 1.0 (bypass #4 should have a bypass ratio equal to or greater than 1.0). Secondary bypass ratio equal to or greater than 1.0.	1.6
Striped Bass	June 1–October 31	Secondary velocity equal to or less than 2.5 fps. Individual primary bypass ratios equal to or greater than 1.0 (bypass #4 should have a bypass ratio equal to or greater than 1.0). Secondary bypass ratio equal to or greater than 1.0.	1.2
Larval Sampling	Starts on triggers (Approximately March 15) Ends on triggers or June 30, whichever occurs earlier.	(1) Average water temperature at Rio Vista, Antioch, or Mossdale reach 12 ℃ *or* (2) "spent" adult female in Spring Kodiak Trawl survey or CVP and SWP salvage facilities or (3) larval smelt found in CDFW's 20 mm survey. 3-day mean water temperature at Clifton Court Forebay reaches 25 ℃.	

b. Fish salvage monitoring. The TFCF has always monitored fish salvage since operation began. Yet, important aspects of salvage monitoring have changed and improved through time:

i. Salvage estimation process. Currently, routine fish counts are conducted every two hours ending on the even hour (e.g., 0200, 0400, 0600, etc.). Fish counts are a subsample (usually 30 minutes) of each two-hour interval. At the beginning of a fish count, the main holding tank being used to collect fish (collection tank) is closed and all salvaged fish are diverted into an empty tank dedicated for sampling (sampling tank). The sampling tank is opened only for a specific length of time, after which it is closed, and the fish being salvaged are diverted into the main collection tank.

Fish count sample can be biased because of the design of the pipes leading to the holding tanks (see Figure 8) and because of operating procedures. The influent valves which open and close the individual holding tank influent pipes are set back about 2.7 m (9 ft) from the junction of the main influent pipe. This area of dead water behind the closed valve and the junction can accumulate fish. When a valve is opened for sampling, fish resting in the slack water will enter the sampling tank and will bias the count high. Historically, the first holding tank (holding tank #1) on the bypass line was used to count fish in order to reduce sampling error from a buildup of fish in the holding tank influent pipe because the amount of slack is minimized (California Department of Water Resources 1967). But because of recent maintenance issues, holding tank #4 is often used for the fish estimation process. The use of holding tank #4 is not ideal since this tank is the most downstream of the holding tank system, with three other influent pipes upstream where fish can build up. Furthermore, when the sampling tank is drained, TFCF operators often open the influent valve (1–2 times) for a few seconds to allow water to wash stranded fish into the sampling bucket. This may allow more fish into the sample after the sampling duration has ended and may also bias the count high. The potential error would be greatest for markedly short count times.

ii. Fish count duration. Bates et al. (1960) recommended the concept of "10-minute counts" to estimate the number of fish diverted to the holding tanks; however, historically, fish count duration has varied significantly from one minute during huge fish abundance to two hours during facility studies when few fish are present. Only salvage summaries for the years 1957 to 1967 could be located for this report, i.e., neither count duration records nor detailed salvage records were located; however, it was noted in a 1963 study that fish counts were five minutes long (California Department of Water Resources 1967). Salvage records since 1968 indicate that fish count duration and frequency varied from year to year. For example, in 1969, fish count durations were 10 minutes between January and June, switched randomly between one and five minutes between June and September, and back to 10 minutes between September and October. Often, count durations changed within the day with no explanation noted. One- to five-minute counts were common practice throughout the 1970s until gradually replaced by longer fish counts in the mid-1980s (5–60 minutes).

Fish count duration varied less since 1993. Fish count duration of 10 minutes, which is only 8 percent of daily entrainment and, according to Karp et al. (1997), effectively estimates fish salvage for all fish combined and individual species, was accomplished 96 percent of the time from 1993 through 2007. The USFWS Biological Opinion on the Long-Term OCAP and the NMFS Biological Opinion required sampling a minimum 25 percent of the time from December through June. Reclamation has met this requirement except during periods of heavy debris loads when Reclamation has consulted with the regulatory agencies to reduce the fish count duration. Since late-2009, 30-minute fish count duration has been standard practice at the TFCF.

iii. Fish species counts and identification. Currently, all fish collected during routine fish counts are identified to species and given a specific code (Appendix 9). This has not always been the case. Between 1957 and 1966, salvaged fish were counted according to these groups: Striped Bass, salmon, catfish, spiny ray, shad, smelt, and miscellaneous. Total catch was reported on a monthly basis per the 1957 Memorandum of Agreement, but only for two years (1957–1959). Thereafter, through the 1960s, fish were reported to CDFW via correspondence, sometimes by monthly or quarterly salvage totals for the seven fish groups. Totals were usually only tallied for the months of May to October, which corresponded with agricultural demands. From 1968 to 1977, some fish were identified to species while other fish were combined and recorded in groups. For example, fish such as Chinook Salmon, Steelhead, and Striped Bass were identified to species, Delta Smelt and Longfin Smelt were recorded as “smelt,” White Sturgeon (*Acipenser transmontanus*) and Green Sturgeon as “sturgeon,” and all sunfish were recorded as “spiny ray.” In 1974, the species name “Delta Smelt” was used for the first time but reverted back to “smelt” in 1975.

TFCF historically conducted routine fish counts on the odd hour (e.g., 0100, 0300, 0500, etc.). Sampling fish on the even hour started in 1992. Whether odd or even hours, a total of 12 fish counts were collected per day. Between 1968 and 1974, fish counts were taken every two hours and species identified (or grouped) and enumerated. Nevertheless, between 1975 and 1979, only two fish counts were collected per day and no fish data was collected in 1978.

Data recording improved drastically in May 1979, gaining more specificity in fish identification. New species codes (i.e., unique database number used by CDFW for each species) (see Appendix 9) for Delta Smelt (code 26), Splittail (code 9), Black Crappie (*Pomoxis nigromaculatus*) (code 18), and other species were first implemented. Accountability was also implemented for the first time with operator initials added for each fish count completed. Fish length measurement data were also first collected in 1979. Improved data recording at the TFCF beginning in 1979 may have been influenced by the Water Rights Decision 1485 which permitted the CVP and SWP to operate but placed standards on their operation for the protection of fish and wildlife.

Although there were improvements in data recording and accountability at the TFCF starting in 1979, fish identification and fish data recording were still questionable through the 1980s, which was made evident through a weekly quality control regime conducted by CDFW. For example, there were 101,340 Delta Smelt salvaged between July and September 1981 and 9,700 Longfin Smelt salvaged in August of 1990. Temperatures in the South Delta easily reach 23.9 °C (75 °F) during summer, which is above the temperature tolerance level of osmerids; therefore, it is likely that these fish were juvenile clupeids that are more prevalent during the warmer part of the year. Some of the problems pointed out by the CDFW quality control included “inaccurate data collection, misidentification of species, and inaccurate/incomplete data recording” (Chadwick 1989). Compounded with these issues was Reclamation’s intention of saving money by eliminating the graveyard shift (2300–0700) thereby eliminating evening fish monitoring. This was opposed by CDFW (Bolster 1986; Collins 1986; McEwan 1988) because it violated both Decision 1485 (see Appendix 4), which required Reclamation to maintain records of fish salvage and water export rates, and the 1983 Reclamation/CDFG Agreement Regarding Fish Salvage Operations at the TFCF (see Appendix 5), which required Reclamation to collect species composition and length counts between 0600 and 1800 (Bolster 1986; Collins 1986). CDFW had proposed to “relieve present (fish diversion) operators of fish counting responsibilities” (Chadwick 1977; Collins 1985) with CDFW personnel; however, this never came to fruition. In 1992, coinciding with the 1992 CVPIA, Reclamation installed its first resident TFCF biologist, paving the way for a credible fish identification program.

From 1980 to April 1992, fish were identified to species twice a day (sometimes three times a day) usually at 0500- and 1700-hours. CDFW selected 0500- and 1700-hour counts in an effort to enable TFCF operators to remain available for operation and maintenance activities between 0800 and 1600 hours. Fish counts were still conducted outside of these times, but only the “total number of fish” (code 98) were recorded. Therefore, if a particular species of fish was collected outside of the 0500- and 1700-hour fish count, that species was not recorded as being salvaged on that day.

Weight Estimation Process. In 2006, in response to extremely high numbers of Splittail and Common Carp (*Cyprinus carpio*) salvaged, biologists at the TFCF developed a method for estimating fish collected in a fish count sample by using fish weight. The process involved obtaining total fish weight of the count sample and a weight of a subsample taken from the count sample in order to obtain a multiplier, i.e., multiplier = total fish weight ÷ subsample weight. In developing the method, biologists noticed that large fish, particularly Chinook Salmon and Steelhead, swim to the top. These species and other large fish were removed first to be processed later and were counted separately from the subsample. The subsample species composition is counted and the multiplier is used to estimate fish species total for the fish count. This fish count estimation by weight improves fish survival by significantly reducing the amount of time fish are processed. The weight estimation process is used about one to five times each year since it was first implemented in 2006 and is only used when the maximum volume of the fish count station is reached. Below is an example of the weight estimation procedure:

Weight of all fish from count sample = 42 kg

Subsample of fish from count sample = 1.3 kg
Multiplier = total fish weight/subsample weight = 42 kg/1.3 kg = 32.3

Each species from the subsample is multiplied with the multiplier to obtain an estimate:

Species	Number in subsample		Multiplier		Estimated total
Splittail	559	x	32.3	=	18,056
Common Carp	38	x	32.3	=	1,227

DNA Sampling. Since 1997, collection of tissue samples from non-adipose clipped Chinook Salmon for DNA analysis has been part of the fish count routine. The TFCF though, continues to use the Delta Model size criteria (length-at-date tables), a modified version of the Fisher Model (Fisher 1992, 1993) for reporting and tracking winter-run and spring-run Chinook Salmon. Since salmon runs can now be accurately identified using genetic analysis (Hedgecock et al. 2001), the Delta Model size criteria tables only provide an approximate guide for operations and management. Since 2016, the TFCF has implemented the use of the length-at-date tables to identify the race of older juvenile salmon and a "rapid genetic" testing of salmon that fall within the winter-run length-at-date.

Coded Wire Tags. Coded wire tags from Chinook Salmon and Steelhead salvaged at the TFCF were historically extracted and read by the USFWS since 1986 (J Speegle pers. comm.). Since 2011, coded wire tags are processed at the TFCF and are reported the day after the fish is captured.

Delta Smelt Gonadal Development. All adult osmerids collected from the fish counts are currently euthanized, species verified, and sexual maturation determined as part of the monitoring of spent Delta Smelt females in the vicinity of the TFCF (2008 USFWS Biological Opinion). Determining the oocyte stage helps determine when sampling for larval smelt should commence at the TFCF.

Larval Smelt Sampling Program. In 2008, Reclamation initiated a larval smelt sampling program, required by the 2008 USFWS Biological Opinion, to identify the presence and absence of larval Delta Smelt and Longfin Smelt at the TFCF. Larval fish samples are taken at each fish length count (four times per day), from approximately February through June, initiated and terminated by biological "triggers" (see Table 3 under 2. Operation & Maintenance\Hydrological monitoring). Since its inception in 2008, the larval fish sampling program has collected and identified 377 Delta Smelt, 407 Longfin Smelt, and 50 Wakasagi. Smelt larvae (5–20 mm) are visually identified using published morphological characteristics (Wang et al. 2005; Wang 2007) and are reported on a near real-time basis. The Smelt Working Group uses the Delta Smelt and Longfin Smelt larval identification from the TFCF to estimate when smelt protection is warranted. Their recommendations go to the Water Operations Management Team (WOMT), a management level team. WOMT actions can include water flow requirements at the Old River and Middle River by restricting water diversion by the JPP (U.S. Fish and Wildlife Service Biological Opinion 2008).

eDNA. The feasibility of using environmental DNA (eDNA) at the TFCF to detect Delta Smelt is currently being tested. This technique may be used to complement salvage and may help the facility implement an early detection system for smelt.

iv. Fish length measurements and frequency. Since May 1992, fish measurements are taken four times a day at 0200, 0600, 1400, and 1800 hours. Up to 24 of all fish species collected in the length count are also measured (mm FL). The only exceptions are for the State and federally listed fish species. Every Chinook Salmon and Steelhead is measured and checked for origin (potential wild or hatchery) by the presence or absence of the adipose fin during all fish length measurement counts as well as all fish species counts. All Delta Smelt and Longfin Smelt were only measured during the fish length measurement counts, but since 2008 they have been measured during all fish species counts as well. Green Sturgeon were only measured (mm FL and mm total length) during the fish length measurement counts, but since being federally listed in 2006, they are also measured during all fish species counts. During all fish count times, only fish that are ≥ 20 mm are counted and/or measured.

v. Data reporting and accounting. The first two years of operation, Reclamation worked with USFWS under the 1957 Memorandum of Agreement to supply USFWS with mechanical and biological reports (see Appendix 3). For two decades after the agreement, data recording was inconsistent and data reporting was done by monthly or annual summary reports. Water Rights Decision 1485 of 1978 (see Appendix 4) finally established standards of operation for the TFCF, which stated that Reclamation must "maintain appropriate records of numbers, size, (and) kind of fish salvaged" at the TFCF; however, there was no wording of accountability in the document. The 1983 Agreement Regarding Fish Salvage Operations at the TFCF (see Appendix 5) finally allowed CDFW monitoring of salvage at the TFCF. Currently, the TFCF Biological Resources Branch is responsible for the quality assurance/quality control (QAQC) and the daily distribution of salvage data to regulators.

Although fish data reporting has improved considerably by standardizing fish salvage through Decision 1485 and the 1983 salvage agreement, the quality of the reported operational and salvage data still needs improvement. For example, the operational data (e.g., temperature, water depths, flow volumes) from meters located throughout the TFCF are not always correct since calibration schedules have yet to be finalized. Also, the flow values that are reported are estimated flows based on the original standard operating procedures for the TFCF (U.S. Bureau of Reclamation ca. 1985) and are not real-time values. Instead, these flow values are obtained from tables using bypass ratio criteria and the number of pumps operating at JPP. Often, flow values from the meters differ greatly from the estimated flows. Bypass ratios, as required by the Biological Opinions, and water velocities, as required by Decision 1485, are recorded and are followed by the facility operations but do not have to be reported to regulatory agencies.

c. Cleaning. Cleaning involves the removal of debris, mainly aquatic vegetation, from the various components of the facility and is a crucial part of TFCF maintenance. Entrained aquatic vegetation consists primarily of two species, water hyacinth (*Eichhornia crassipes,* 82 percent), a floating aquatic vegetation (FAV), and Brazilian waterweed (*Egeria densa*, 18 percent), a submerged aquatic vegetation (SAV). Although water hyacinth has caused cleaning problems at the TFCF as early as 1958 (United States Bureau of Reclamation 1958; Bates et al. 1960), water hyacinth has recently become the primary debris removed at the TFCF. Accumulation of aquatic vegetation occurs at two locations, the trash deflector boom and the trash rack. Between 2002 and 2015, 245,800 m^3 of FAV was diverted by the trash deflector boom and 38,800 m^3 of SAV was prevented from entering the facility by the trash rack. The facility, on average, removes about 26,500 m^3 of aquatic vegetation, equivalent to about 2,900 truckloads annually (a truckload is roughly 9 m^3). The volume of aquatic vegetation entrained at the facility is correlated to water exports, with increased entrainment of aquatic vegetation occurring with increased water exports. Aquatic vegetation that is not removed from these two debris removal locations enters the facility and affects the downstream screening components within the facility.

Eighty-seven percent of FAV volume occurs from October to February, coinciding with the removal of barriers for the South Delta Temporary Agriculture Barriers Project. The project began in 1991 and consists of three rock barriers (see Figure 1): Old River at Tracy, Middle River, and Grant Line Canal. A fourth barrier, the Head of Old River barrier, is a fish barrier meant to benefit outmigrating Chinook Salmon from the San Joaquin River. The other three barriers are agricultural barriers meant to benefit South Delta agricultural water users. The agricultural barriers create a lake-like environment behind them which promotes the growth of water hyacinth. They hold back large volumes of the vegetation between April (installation of the barriers) and November (removal of barriers). When these barriers are removed, vegetation is entrained at the TFCF. Water hyacinth is effectively removed by the trash deflector boom and conveyor system; however, manually pushing the mats of hyacinth by hand and/or by boat is often necessary to move the vegetation to the conveyor. Hyacinth biomass is greatest in winter (Spencer and Ksander 2005) and once the plants die from freezing, they sink and clog the trash rack, louvers, and screens downstream of the trash boom. Recently, mechanical removal of hyacinth using weed harvesting vessels and shredding boats were used with some success.

The operation of the Clifton Court Forebay radial gates also affects the debris load at the TFCF. When the radial gates are open, debris accumulates and is prevented from entering the Clifton Court Forebay by a debris boom at the inlet to the forebay. As the radial gates are closed, there is an observed sudden rise of water at the TFCF and an influx of debris. As the radial gates open, the opposite occurs where there is a sudden decrease of water depth and less debris at the TFCF.

Debris not removed by the trash boom and trash rack accumulate at the primary louver system and must be cleaned routinely. The primary louvers were cleaned daily when the TFCF started operation in 1957 without a trash deflector boom. Once the trash deflector boom was installed in 1960, replacing the dragline that was used for water hyacinth from 1958–1959, the primary louvers only needed to be cleaned weekly (Bates et al. 1960). In recent years, though, the facility has faced high debris loads, and often the primary louvers are cleaned up to six times a day. Debris-clogged primary louvers affect the water velocity of the primary channel (Bates et al. 1960) and can act like a wall preventing fish from going through the louvers. Debris-clogged louvers also cause water level differential which may cause structural failure. If the differential is larger than 30 cm (~1 ft), lifting each panel for cleaning becomes difficult, if not impossible.

Cleaning the primary louvers can cause fish loss and affect salvage operations. Since the TFCF's inception, cleaning of the primary louvers has been done by lifting the individual panel with a

4-ton gantry lifting beam, washing off the debris from the lifted section (Figure 10) to drift downstream. When a panel is lifted, fish can potentially be lost through the opening. Karp et. al. (2017) estimated that approximately 6.7 percent of juvenile Chinook Salmon that encounter the louvers are lost through the louvers when the panels are lifted for cleaning, and approximately 33.3 percent of louver loss occurred during louver cleaning activity. Pumping at the JPP is not stopped and salvage of fish continues during the cleaning process. Hallock et al. (1968) speculated that whenever a panel is lifted, it "seems probable that any fish in the area would use that opening instead of the much smaller bypass opening." Liston et al. (1994) released floy-tagged Striped Bass at the DMC (downstream of the TFCF) and recaptured three (by anglers) at the Old River and the Clifton Court Forebay, which meant that these large fish must have entered the primary channel during primary louver cleaning. More recently, acoustically-tagged Striped Bass have been detected moving from the primary channel and into the DMC during cleaning (B Wu pers. comm.); therefore, it is possible that fish can also re-enter the primary channel from the DMC. Primary louver cleaning also disrupts the efficiencies of the components downstream, specifically the secondary channel and the holding tank screens. Debris that is sprayed off the primary louver usually enters the closest bypass and is deposited at the secondary channel and holding tanks. This "washing of trash into the secondary system" has been observed to lower fish counts (California Department of Water Resources 1967).

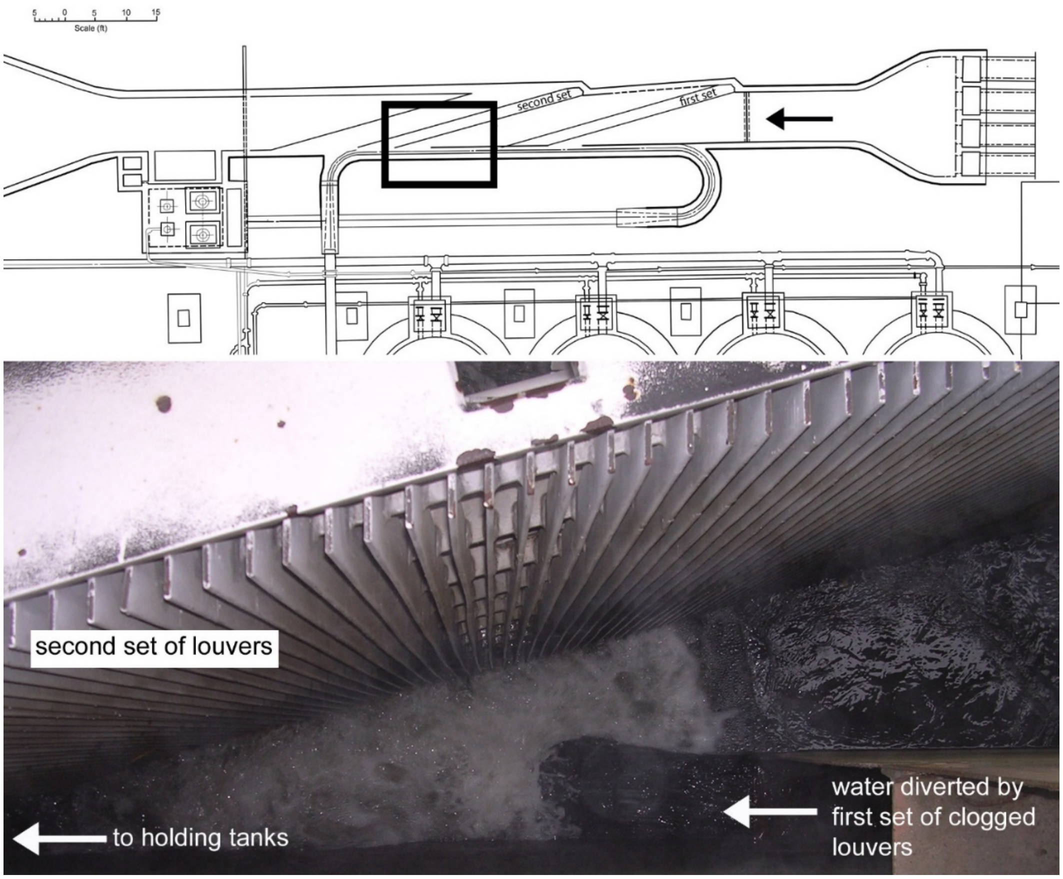
Duration of primary louver cleaning has increased over time thereby increasing the potential for fish loss. Hallock et al. (1968) stated that as a result of cleaning, there is "an opening in the primary louver system equivalent to the area screened by one louver section for a period of 74 minutes each cleaning day" and, since cleaning was only done three times a week in the 1960s, the unscreened time "is one-half of one percent of the time" and "does not seem serious." Recently, each louver panel takes between three to four minutes to clean (J Imai pers. comm.), which means that there is a duration of 108 to 144 minutes of unscreened water per day to clean all 36 primary louver panels. In other words, for 7.5 to 10 percent of each day water is unscreened because of cleaning. Furthermore, during 5-unit JPP operation, cleaning frequency can be as high as three to six times per day, thus up to 60 percent of the day may be unscreened because of cleaning.

Figure 10 Primary louver panel, one of 36, lifted for cleaning at the Tracy Fish Collection Facility

Methods for cleaning the primary louvers without lifting have been attempted without much success. In 1992, a hydraulic louver trash rake (see Figure 5) was installed but decommissioned soon after. In 1999, a brush louver cleaner was used to brush debris off the louvers; however, this cleaning apparatus was not maintained and broke down often (Hess 1999). In 2002, a cleaner-pump was implemented to pump debris off the louver, but it too was subsequently discontinued because it was ineffective. Reclamation also considered placing “solid blank” panels to close off the openings during cleaning operations (Patterson 1992), unfortunately, designs were never finalized because engineers were unable to design a solid blank panel that can withstand the force of the flow. Recently, instead of a solid blank panel, designs for a screened panel are being considered (W Dutton pers. comm.).

At the secondary channel, debris is also an issue. The original double array of louvers was never anticipated to encounter debris problems, and no measures were made for cleaning these louvers during the design of the TFCF (United States Bureau of Reclamation 1956). Within the first month of operation in 1957, the secondary channel louvers encountered debris “of a magnitude to require removal and cleaning of the louvers about every other day” (United States Bureau of Reclamation 1957a). Before the secondary louvers were replaced in May 2014, debris often clogged the secondary louver system and changed the hydraulics of the secondary channel and bypass. Debris clogged the first bank of louvers, which made it a positive barrier rather than behavioral, may have diverted fish well but only up to the bypass opening. The first set of clogged louvers created a waterfall effect or turbulence on the second set of louvers, causing fish to be lost through the second set of louvers (Figure 11). The bypass ratio used to monitor how well the bypass was working did not indicate there was a problem.

Figure 11 Debris-clogged secondary louvers at the Tracy Fish Collection Facility



Note: Location of turbulence (bold black box) caused by debris-clogged secondary louvers (top) and image showing waterfall effect at the second set of louvers (bottom). Turbulence from the waterfall can cause fish loss.

To clean the secondary louvers, the secondary channel had to be dewatered so that facility workers could enter the confined space of the secondary channel with pitchforks and nets to manually remove all debris. Cleaning activity usually lasted less than one hour but sometimes reached two to three hours with heavy debris loads. During this time, fish cannot be salvaged because the bypasses are closed and JPP continues to export water even though salvage operation has ceased for cleaning. The confined space entry process was eliminated in 2014 when the secondary louvers were replaced by a single line of the self-cleaning Hydrolox™ traveling screen system (1.5 mm x 50 mm slit opening) (see Figures 8 and 15).

The Hydrolox™ traveling screen, made of engineered polymer screen material rotating within a steel frame (Intralox 2014), was designed to remove aquatic vegetation from the water column. In a controlled setting, removal efficiency of the new system was ~90 percent (Heiner and Mefford 2011). But because of the acute angle (7° to the flow) of this new system, water velocity is faster and debris is still diverted to the holding tank system. Furthermore, pegs on the traveling screens are partially effective at removing *Egeria densa* but ineffective at removing woody branches, sand, and clam shells.

d. Predator removals. Piscivorous predators at the TFCF, the majority of which are Striped Bass, are found in front of the trash rack and in the primary channel, the four bypasses, secondary channel, and holding tanks. There is also evidence of Striped Bass using the trash deflector boom for cover (B Wu pers. comm.). The large structures at the TFCF provide cover for predators and disorient prey fish as they pass through unfamiliar structures (Tucker et al. 1998; Sutphin et al. 2014). Striped Bass are size segregated with the resident Striped Bass (often > 400 mm) inhabiting the primary channel and smaller Striped Bass downstream (Bridges et al. 2019 in press). These smaller Striped Bass prey on larval and juvenile Delta Smelt in the bypasses and secondary channel (Reyes et al. 2019 in press). Bates et al. (1960), in their evaluation of the facility, did not study predation but only "assumed that it exists." A pre-screen loss (predation) rate of 15 percent was chosen for the TFCF primary channel based on studies conducted at other fish screen facilities and is meant as a placeholder until more studies can be conducted (D Odenweller pers. comm.; Jahn 2011). A recent study by Karp et al. (2017) and Wu et al. (2019 in draft) showed evidence that a 15 percent pre-screen predation loss for smolt-size Chinook Salmon is reasonable. Nevertheless, if predator abundance is not monitored or controlled for long periods then total abundance is not known, which hinders the ability to estimate entrainment from salvage data (Bridges et al. 2019 in press).

The movement and impact of Striped Bass in front of the trash rack, inside the facility, and downstream of the facility at the DMC are currently being quantified using acoustic telemetry technology. Residence time for Striped Bass within the facility was 75.4 ± 30.6 days although likely biased low due to expiration of acoustic transmitters (Wu et al. 2015). Striped Bass enter the facility when they are small and grow large within the DMC and the facility. These resident Striped Bass, which are not part of the Delta's breeding population and are too large to exit through the 5.7 cm (2.25 in) trash rack (Bridges et al. 2019 in press), are often located in the upper primary channel (Wu et al. 2015) and therefore benefit from the first prey that enter the facility. Striped Bass in front of the trash rack also benefit and have more options in terms of locating prey. For example, acoustically tagged and released Striped Bass at the TFCF have been observed moving in and out of the Clifton Court Forebay (Vogel 2010) and have also been recaptured as far north as Red Bluff (C Karp pers. comm.). Movement in and out of the primary channel and the DMC during cleaning has always been speculated (see 2. Operation & Maintenance\Cleaning) but is now being verified with acoustic telemetry technology.

Over the years, TFCF biologists have reviewed various means of moving predators through the TFCF system, such as sound, light, electricity, chemical, and mechanical methods. Many of these methods were largely ineffective for moving or removing large predatory fish, expensive to install and operate, and are logistically difficult to implement at the primary channel. Because of the large volume of water at the primary channel, which cannot be dewatered (Fausch 2000), removing predators through gillnets (Bridges et al. 2019 in press) and hook-and-line is effective but labor-intensive (Sutphin et al. 2014; Wu and Bridges 2014a). Gillnetting and removal of large Striped Bass > 400 mm (> 15 in) from the primary channel has resulted in increased salvage of about 35 percent and decreased fish loss (Bridges et al. 2019 in press); however, by removing the large Striped Bass, there is a possibility that numerous smaller Striped Bass will take their place and have a greater impact as predators. In fact, smaller predators, particularly Striped Bass and catfish spp. that are > 100 mm FL (> 4 in), have the largest impact on salvageable fish (Liston et al. 1994; Fausch 2000; Sutphin et al. 2014). Over time, Striped Bass are able to repopulate the primary channel. Since the trash rack opening only allows entry to juvenile Striped Bass because of the trash rack spacing (5.7 cm; 2.25 in), large Striped Bass in the primary channel (for example, the > 400 mm Striped Bass removed by gillnetting) likely grew in the DMC or within the facility (Bridges et al. 2019 in press). Recently, with the use of acoustically tagged Striped Bass, tests showed that large amounts of CO_2 can influence the behavior of Striped Bass and showed promise as a possible method of removing predators from the primary channel (B. Wu per. comm.).

Removing predators from the four bypasses and the secondary channel is less labor-intensive when compared with removing them from the primary channel but still requires numerous personnel. During the 1993–1994 water year, a predator removal program was initiated in the secondary channel after the first collection of a winter-run Chinook Salmon (Liston et al. 1994). This secondary channel predator removal program involved shutting off the flow in the secondary channel while lowering a trap screen (to prevent fish from escaping up the bypasses), placing a second screen in front of the louvers (to prevent fish from heading to the holding tank), and dipnetting and seining the trapped fish (Liston et al. 1994). Another method, developed in the late-1990s, involved flushing the bypass tubes of water and fish, one bypass tube at a time, into a modified fyke net held by two operators (Sutphin et al. 2014). Using this fyke net method, a predator removal study conducted between 2004–2006 concluded that a single predator removal effort removed the majority of predator biomass from the bypasses and the secondary channel, but a second and third effort was required to assure that nearly all of the predators were captured (Sutphin et al. 2014). Bates et al. (1960) noted that most Striped Bass use the most downstream bypass tube (bypass 4); however, Sutphin et al. (2014) found that the mean total weight of Striped Bass and White Catfish was greatest at the most upstream bypass (bypass 1). Furthermore, following removal, predators have the potential to re-colonize the secondary channel within a week (Sutphin et al. 2014).

The most effective method of removing predators at the four bypasses and the secondary channel has been the use of CO_2, specifically for its anesthetic properties. Wu and Bridges (2014a) showed that the swimming performance of predatory fish could be manipulated using CO_2, inducing them to move into collection tanks. With the proper concentration of CO_2, it has been shown that almost 100 percent of predators inhabiting the bypasses and the secondary channel can be removed through this method (B Wu pers. comm.), making it the most effective, safe, and least labor-intensive predator removal method available to the TFCF and is currently the method in use at the TFCF. Since the use of CO_2 has been shown to be the most effective and safe method of predator removal, Reclamation has completed a preliminary design for a gaseous CO_2 injector system, with the hope of remedying personnel safety concerns.

Predator management was included as one of the long-term solutions for improving the performance of the TFCF under the 1992 Reclamation/CDFG Direct Loss Mitigation Agreement (see Appendix 7) and the Biological Opinions (several Biological Opinions have stated that predator removal should be done weekly). The TFCF has the potential of curbing the number of predators within the facility, and probably within the Delta as a whole, by modifying some of its operations. Before 2018, after predator removal events, predators were counted and released back to the Delta with other salvaged non-predatory fish. In order to eliminate the potential for re-salvaging these predators and prevent augmenting the predators in the Delta, predators from predator removals are now released at the DMC downstream of the JPP since January 2018, thereby limiting their reintroduction into the Delta. Even though it is not specifically mentioned in the 2016 Delta Smelt Resiliency Strategy, which states that Reclamation will "adjust summer salvage operations so that non-native salvaged fish will not be returned to the Delta," Reclamation can limit the non-native predator population in the Delta by not returning these Striped Bass to the Delta.

e. Personnel changes. Reclamation has been responsible for the operation and maintenance of the TFCF since its inception. Reclamation has provided both the operations and maintenance personnel necessary to run the facility for most years, except for the period between 1992 and 2004. During these years, a contract (Cooperative Agreement) between Reclamation and the SLDMWA was signed so that the SLDMWA provided the maintenance support and Reclamation personnel continued to operate the facility. CDFW and USFWS personnel provided part-time assistance with fish species identification and fish counts from 1983 until 1992. With the enactment of the 1992 CVPIA, Reclamation biology staff was added to the facility to assist with facility operations, including salvage and operational QAQC, fish counts, operator fish identification training, and facility research support.

B. Structural changes

The TFCF was built using the best available technology in the 1950s; however, the facility is aging and the technology available for fish protection has improved. Because fully replacing the facility is unlikely, Reclamation instead implemented the Tracy Fish Facility Improvement Program (TFFIP) in 1989 with an overall goal of improving fish protection and fish salvage. The TFFIP research was conducted with the help of research and engineering groups from Reclamation's Technical Service Center (TSC) based in Denver. Under the program, the facility replaced aging structures and also funded studies for improving fish salvage efficiency and operation safety. Furthermore, the 1992 CVPIA (see Appendix 8) established the Tracy (Jones) Pumping Plant Mitigation Program which required Reclamation to "improve or replace the fish screens and fish recovery facility and practices associated with the JPP." Most of the improvements at the TFCF for fish protection were the result of the TFFIP and the CVPIA. A summary of structural changes is listed in Appendix 10B.

Trash deflector boom, trash rack, and trash rack cleaner. When the TFCF started operations in 1957, the facility used a 2-ton cableway to remove heavy trash deposited in front of the trash rack and transport it, either in or out of the water, to the trash removal ramp located on the south side of the trash rack (Bates et al. 1960). Because of safety concerns and the manpower needed to operate the cableway, it was replaced with a trash deflector boom and trash conveyor in 1960. The trash deflector boom was later replaced in 1999 using the same 1960 design. In 1991–1992, floy-tagged large fish were released at the primary louver channel downstream of the trash rack and were recaptured outside of the TFCF in the Old River and Clifton Court Forebay (Liston et al. 1994). Liston et al. (1994) reasoned that there were holes in the trash rack where larger sized fish may pass regularly. The trash racks were replaced in 1994 and were temporarily removed in 2010 during the installation of the automated claw system discussed below.

The trash rack bar spacing of 5.7 cm (2.25 in) has not changed since the facility's inception. While this trash rack design and slow through-rack velocity (< 0.6 m/s; Bridges et al. 2019 in press) operational concept was rejected as the optimal technique to salvage fish by the early 1980s (Odenweller and Brown 1982), this structure and facility operation were not corrected at the TFCF (Bridges et al. 2019 in press).

The original mechanical rake (1957–2010) used to clean the trash rack was a two-drum hoist attached to a traveling gantry and was used for raking submerged and floating debris from the trash rack (Figure 12, left image). A TFCF operator manually cleaned the trash rack using a cleaner that moved along a track across the bridge over the trash rack deck to remove the water height differential across the trash rack. During heavy debris loads, it took several hours to clean the entire trash rack. Furthermore, when the radial gates at the SWP's Clifton Court Forebay were closed, the trash rack clogged with debris quicker. The original rake was replaced in 2010 with a programmable automated claw system (EIMCO Water Technologies, Salt Lake City, UT) that runs every two to four hours depending on the debris load (Figure 12 right image). The claw system works well during low flow; however, the claw fails during periods of combined high debris and high flow because the claw design prevents it from descending to the bottom of the trash rack (J Imai pers. comm.). The claw system was originally designed for racks that are perpendicular and not angled (the trash rack has a 2 to 1 slope) (U.S. Bureau of Reclamation 1956a); therefore, extra weight was added to the claw to provide enough downward force to overcome the impingement force. A second claw was added in 2014 to provide redundancy in the cleaning system.

Figure 12 Trash rack cleaning at the Tracy Fish Collection Facility

Note: Manually operated mechanical rake used from 1957 to 2010 (left) and automated EIMCO claw system installed in 2010 (right).

Primary channel, bypass transition boxes, and bypass pipes. A handful of changes have occurred at the primary channel system since 1957. The primary louvers were replaced in 1990 and the louver guide rods in 1997. The four bypass slide gate valves which control the flow through the bypass pipes and to the secondary channel were replaced in 1996. The underground bypass pipes were made of concrete and have never been replaced.

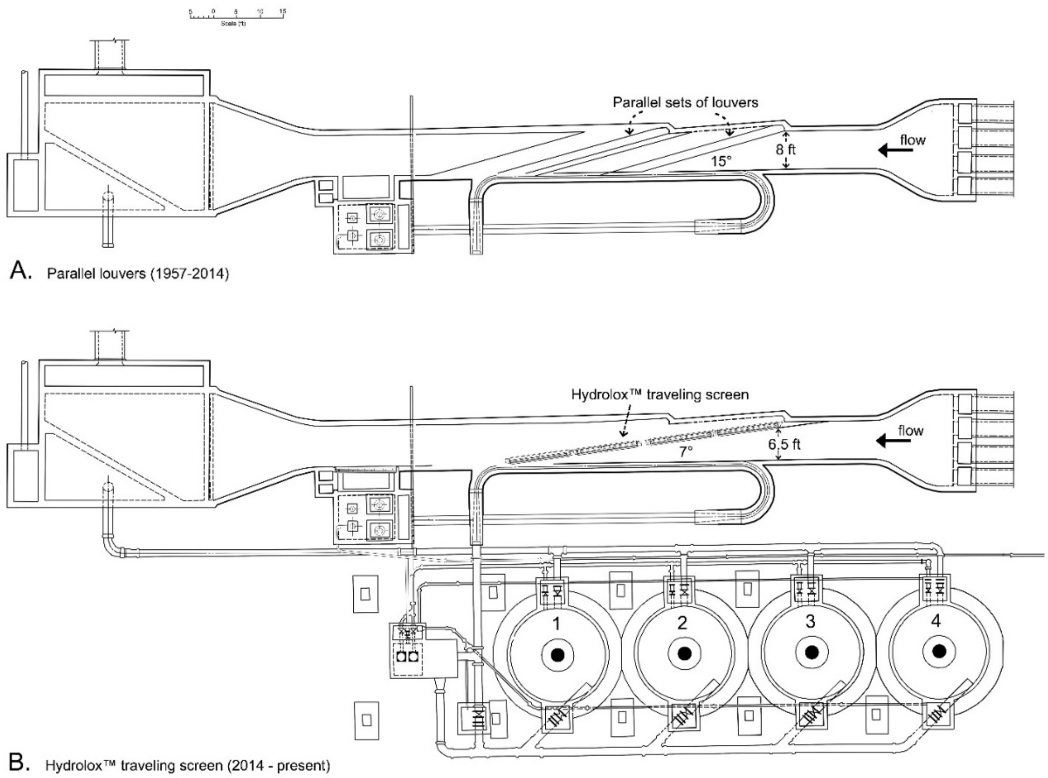
In 1993, during a predator removal event, a hole was observed in one of the primary bypass transition boxes. A dive team hired in 1994 found holes as large as 30 cm x 90 cm (1 ft x 3 ft) in the transition boxes. These holes were patched with steel plates in 1994 (Partridge 1994) and again in 1996. In 2002, holes in the transition boxes were patched again. The transition boxes were temporarily rehabilitated during the fall and winter of 2002 and were fully replaced (Odenweller 2004) (Figure 13) during the San Joaquin pulse flow period of April and May 2004. The new transition boxes deviated from the original 1956 Designers Criteria in that the internal vanes that “turned the flow” from horizontal to vertical were not included in the new boxes because debris accumulated on the vanes in the old boxes and reduced flow through the bypass (L Partridge pers. comm.). The improved boxes were installed after the TSC conducted a model study; however, in the latest underwater inspection of the TFCF in May 2008, divers again found a hole at each transition box, but it was not conclusive if each hole penetrated the box walls (Hawkins 2008).

Figure 13 Transition boxes replacement at the Tracy Fish Collection Facility

Note: One of four corroded transition boxes being removed (left) and a new transition box being assembled (right) in 2004. Photos courtesy of Don McCabe.

Secondary channel. The secondary channel was revamped in 2014, reinforcing the concrete channel walls and replacing the two parallel sets of louvers with four Hydrolox™ (Intralox LLC, Harahan, LA) screen panels aligned approximately 17 m (56 ft) in length and angled 7° to the flow (Figure 14). Because of the dimension of the slit openings and the hydraulics produced by the system, the Hydrolox™ system acts as a positive barrier and not as a behavioral barrier. The screen has 1.5 mm x 50 mm vertical slit openings (see Figure 7) that should allow for higher efficiencies of fish diverted to the holding tanks. With this more acute angle, the velocity increases as water moves from the top of the channel (8 ft wide), to the front of the screen (6.5 ft wide), and to the holding tank bypass (6 in wide). Water velocity at the downstream holding tank bypass is on average 1.8 times faster than the velocity at the entrance to the secondary channel at the top of the channel (Vermeyen and Heiner 2015). To remedy this non-uniformity in velocities, Vermeyen and Heiner (2015) recommended that baffles be installed to restrict higher velocity flows through the screens; however, baffles have yet to be installed.

Figure 14 **Secondary channel with (A) parallel louvers used between 1957 and 2014 and with (B) Hydrolox™ traveling screen in use between 2014 to present**



Pegs (1.9 cm; 3/4 in long) on the Hydrolox™ traveling screen remove aquatic vegetation from the water column. To allow adequate clearance, the screen was raised 2.54 cm (1 in) off the bottom of the channel. This gap is large enough for benthic fish species such as Prickly Sculpin (*Cottus asper*) and juvenile Green Sturgeon to pass through. To remedy this issue, a plate with a brush was installed. The pegs are able to remove some of the aquatic vegetation but fail in removing woody debris, sand, clams, and other benthic debris. As predicted, since woody debris no longer filter through secondary louvers, screens downstream (i.e., holding tank and count station screens) experience higher levels of woody debris.

In the late-1990s, the TFCF was inundated with Chinese mitten crabs (*Eriocheir sinensis*) (Figure 15). The first mitten crab was encountered at the TFCF on September 1996 and, in 1998, over 750,000 mitten crabs were entrained (Siegfried 1999). In 1999, Reclamation and SLDMWA installed a crab removal traveling screen just upstream of the secondary louvers to remove mitten crabs before they could enter the holding tanks. A high-pressure spray wash system was used to remove the mitten crabs from the screen and deposit them into a hopper on the downstream side of the screen. A grain auger in the bottom of the hopper moved crabs and debris into a disposal container (White et al. 2000). By fall 2003, mitten crab numbers dropped dramatically. Although effective for debris removal during heavy debris loads (White et al. 2000; Boutwell and Sisneros 2006), the traveling screen was never used for mitten crab removal again; it was used sparingly since 2003 and was dismantled in 2014 as part of the secondary channel revamp.

Figure 15 Mitten crabs (*Eriocheir sinensis*) inundated a holding tank in 1998 at the Tracy Fish Collection Facility

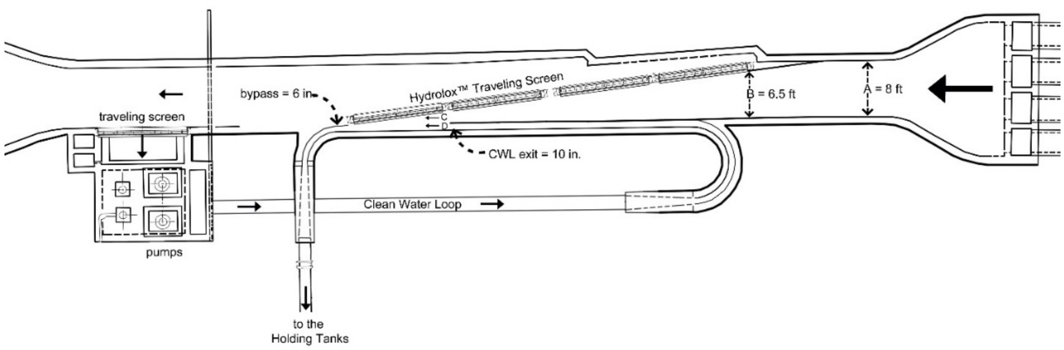
Inset: Traveling screen installed upstream of the secondary louvers (top) and high-pressure spray to wash mitten crabs off the traveling screen (bottom).

Clean water loop system. Debris, particularly fine peat moss, was a major problem at the Pilot Fish Screen facility where screens clogged within minutes (U.S. Bureau of Reclamation 1955a). To remedy the issue, a moss-screen wheel was developed to collect particles from the flow. The concept of "de-mossing" or cleaning the water of debris and introducing it upstream of the bypass was applied at the Pilot Fish Screen facility during the louver experiments. The concept was later incorporated into the design of the clean water loop system (historically known as screened water system).

The clean water loop system was intended to "remove moss and trash from the water" (U.S. Bureau of Reclamation 1956a) being diverted to the holding tank. Although the system worked as intended, i.e., prevented debris from entering the holding tanks, it also reduced the number of fish salvaged by reducing sweeping velocities that carried fish into the bypass. Under the 1992 Direct Loss Mitigation Agreement (see Appendix 7), Reclamation was to minimize the operation of the clean water loop system, consistent with the amount of debris in the secondary channel and the need to keep debris loads in the holding tanks at acceptable levels so that fish will be attracted to the bypass. By 1995, the TFCF only used the screened water approximately 50 percent of the time. The traveling screen at the intake of the clean water loop system was discontinued and was replaced by a wedge wire screen in 1999. The system was used sparingly until the wedge wire screen was damaged (J Imai pers. comm.). In May 2014, the screen of the clean water loop system was replaced with a Hydrolox™ traveling screen of the same mesh size as the screen installed at the secondary channel.

Currently, the clean water loop system operates simultaneously with the secondary channel Hydrolox™ traveling screen (Figure 16). The velocity of the clean water loop system should be the same or slightly faster than the velocity of the secondary channel to ensure debris is removed by the traveling screen. If the velocity of the clean water loop system is too fast, debris and fish get impinged against the traveling screen.

Figure 16 Clean water loop system working simultaneously with the Hydrolox™ traveling screen of the Tracy Fish Collection Facility



The operation of the clean water loop system is dependent on the presence of fish larvae/juveniles and aquatic weed/debris. It is not in operation when Delta Smelt and Longfin Smelt larvae and juveniles are present in the system since these fish are not strong swimmers and will likely be impinged to the traveling screen by the clean water loop system. It is only used when debris is present in the system and listed larvae/juveniles are not present.

Dewatering pumps. The holding tank dewatering pumps and the secondary channel velocity control pumps (VC pumps) are periodically replaced and refurbished. The VC pumps were replaced between 2001 and 2007 and its automation is planned but is not a priority. The two holding tank dewatering pumps supply the required flow through the active holding tank by returning drain water to the main canal. These pumps were replaced in 2003 and 2006. Two additional smaller dewatering sump pumps are used to drain a holding tank after a fish count or haul out. These additional pumps were replaced the past decade.

Holding tank system. The holding tank system has improved since 1957 with changes in aeration, wall/floor coating, and holding tank screen. If considerable time is to pass before the fish are removed from the holding tank and flow through the tank is cut off, the oxygen content of the water in the tank will be depleted by the fish and must be replaced (U.S. Bureau of Reclamation 1956a). The original aeration system installed in each of the holding tanks consisted of several air diffuser stones spaced at regular intervals on the bottom of each tank (Figure 17 left image). The system consisted of a 2.54 cm (1 in) air supply line to a 1.9 cm (¾ in) aeration header and then to 16 lateral pipes (0.95 cm, 3/8 in) along the bottom of the tank that were further connected to two-to-three air stone diffusers (15.2 cm x 15.2 cm, 6 in x 6 in) (U.S. Bureau of Reclamation 1956a). Each tank had between 32 to 48 air stone diffusers. These air stones became clogged with silt and debris within a few years of operation (California Department of Water Resources 1967), cracked from air pressurization, and the whole system was eventually removed in the early 1990s (Hess 2005). In 1999, an air diffuser hose was installed in the perimeter of holding tank #3 and used when fish density required aeration. In 2014, the diffuser line was removed and an oxygen system for the holding tanks was designed. Installation of the oxygen system, however, has not been completed as it is not deemed a priority.

From years of operation, the bottom floor of the holding tanks has become rough. In 1997, the floors were coated with epoxy to provide a smooth transition for fish from holding tank to bucket. The light color of the epoxy coating (grey) (Figure 17 center image) also allowed workers to see stranded fish on the bottom of the tank when dewatered.

The holding tank screens were replaced in 2001 with a more durable stainless-steel material but with slightly larger square opening mesh size. The original 5x5 mesh (meaning 5 square openings per one linear inch) holding tank screen was made of galvanized wire cloth with a wire diameter of 2.3 mm (0.092 in), square openings of 2.5 mm (0.1 in), and diagonal openings of 3.5 mm (0.137 in). This screen was painted and therefore the actual hole size was smaller. It was replaced with a stainless-steel mesh with a wire average diameter of 2.1 mm, an average square opening of 2.7 mm and an average diagonal opening of 3.8 mm (see Figure 8). This new screen's mesh opening, though, is large enough that a percentage of juvenile, streamlined, and fusiform fish are not retained. Wu and Bridges (2014b) estimated that 1,914 Delta Smelt were lost through the holding tank screens from 1993–2013 and recommended that screen openings should be reduced to a diagonal opening of 2.1 mm (not 3.8 mm which is currently in use) in order to consistently retain ≥ 20 mm Delta Smelt. For larval fish < 20 mm, the current holding tank screen has a retention efficiency of 60 percent (± 9.9) for 10–20 mm larvae and as low as 9 percent for larvae < 10 mm (Reyes et al. 2012).

Each holding tank was originally equipped with three protruding wall baffles to limit the rotation of the entire mass of water swirling (Figure 17 right image). The baffles were designed to provide calm water in the holding tank during swirling which allows fish to rest (U.S. Bureau of Reclamation 1956a); however, the baffles generated non-laminar flow in the holding tank, and during the initial filling of the tank, water forcefully impacted the baffles and injured fish. In 1963, the baffles immediately downstream from the holding tank inlet were removed in order to decrease the number of injured fish (California Department of Water Resources 1967). All remaining holding tank baffles were removed within the past decade.

Figure 17 Holding tank at the Tracy Fish Collection Facility

Note: Left, photo from Bates et al. 1960; center, epoxy coated flooring; right, baffle on a holding tank wall.

Fish count station and fish sampling bucket. The current fish sampling bucket has not been replaced since the TFCF's inception (see Figure 9). The steel bucket is 91.4 cm in diameter, approximately 127 cm deep, with 340 L (90 gal) of volume, and a 15.2 cm (6 in) diameter discharge opening. The bucket uses a steel beam for lifting, has a flanged lip on the open end, a 5 x 5 mesh galvanized wire cloth (0.092 in diameter wire) screen, and a solid rubber ball check valve to retain fish and water in the bucket. The average screen opening of the fish sampling bucket is 3.0 mm which means there is also fish loss occurring when a sample is drained from the holding tank into the fish sampling bucket.

The fish count station was revamped in 2013–2015 to improve holding conditions for fish during times of abundant debris. The historical fish count station, used between 1957 and 2013, was cylindrical and condensed the subsample from the 90-gallon sampling bucket into a 23 L (6 gal) sample pan (Figure 18). Often, the pan's volume was insufficient during times of excessive amounts of debris and fish, which caused damage to fish. To lessen the amount of debris in the count station, fish count sampling time has to be shortened, usually from 30 minutes to 10 minutes. Because this shorter sample duration violated the 2009 NMFS Biological Opinion stating that fish count duration should be no less than 30 minutes every two hours year-round, Reclamation had to notify NMFS to justify the shorter counts. With the current larger fish count station, cutting the duration of the fish count sample can be limited. The new count station has a 125 L (33 gal) rectangular sample pan that keeps fish underwater and is large enough to handle most debris loads without damaging fish. The new count station also includes a 322 L (86 gal) plumbed trough for fish recovery and a watered chute for releasing fish back to the holding tank.

Figure 18 Fish count station at the Tracy Fish Collection Facility

Note: Cylindrical count station with 23 L sample pan used from 1957–2013 (left) and new count station with a 125 L sample pan and a fish recovery trough attached to a release chute (right).

The 45 cm x 61 cm (18 in x 24 in) cylindrical fish count screen (Figure 19) is used to retain the sample released from the 90-gallon sampling bucket. From 1957 to 1999, the TFCF used an overlapping double layer of 6.35 mm (0.25 in) square mesh hardware cloth for the count screen, creating a small gap opening. This count screen was replaced in 1999 with a 4.8 mm (0.38-inch) diameter opening perforated plate. Both count screens were not effective in retaining Delta Smelt > 20 mm FL (Sutphin et al. 2007). In fact, Wu and Bridges (2014b) estimated that 4,734 salvageable (fish that are ≥ 20 mm) Delta Smelt passed undocumented through the fish count station screen during the past two decades. In 2014, the TFCF replaced the count screen with a 2.4 mm (0.09-in) diameter opening perforated plate, only 0.1 mm larger than the 2.3 mm diameter opening that Wu and Bridges (2014b) recommended. This smaller diameter count screen is expected to retain ≥ 20 mm larvae/juveniles more effectively than previous screens. Recently, an outside solid sleeve (see Figure 18 right image) placed around the count screen enables the operator to use both the larger fish haul bucket and the sampling bucket interchangeably for fish counts and also increase the retention of larval and small fish during fish counts. The sleeve also reduces the rate at which the bucket empties and helps prevent the station from overflowing.

Figure 19 Count screens used at the Tracy Fish Collection Facility

Note: On the left is the 6.35 mm double layer hardware cloth used between 1957–1999, the center shows the 4.8 mm perforated plate used between 1999–2014, and on the right is the 2.4 mm perforated plate currently in use.

Fish haul bucket. The original fish haul bucket was used for 50 years before it was replaced in 2008 with a considerably improved design. The original steel 1,892 L (500-gal) fish haul bucket used to transfer fish into the fish trucks was 1.8 m (5.9 ft) in diameter and approximately 1.37 m (4.5 ft) deep with a dished bottom. The dished bottom caused excess rolling and tipping, so the bucket was modified with new angled bottom. The original bucket used a 5x5 mesh galvanized wire cloth (0.092-in diameter wire) screen with a 3.4 mm mesh opening, a flanged lip on the open end, a solid rubber ball-check valve to retain fish and water in the bucket, and a discharge opening of 15.2 cm (6 in). In 2008, a bucket with a new design was used (see Figure 9). The new 1,544-L (408-gal) bucket was made of stainless steel and has a discharge opening of 30.4 cm (12 in). The wider discharge opening limits clogging during the release of fish from the fish haul bucket to the transport truck. The wire cloth screen was also replaced with a 2.5 mm diameter opening perforated plate screen.

Lifting fish using buckets has been implicated as one of the greatest sources of fish stress in the salvage process (Portz 2007); therefore, alternatives to the use of fish haul buckets were tested, with promising results. Between 1998 and 2000, holding tank #1 was used for a hidrostal pump experiment to assess its feasibility as an alternative to the lift buckets (Helfrich et al. 2000). The experiment showed that the hidrostal pump could be used as a fish-friendly pump; however, the pump has not been implemented as an alternative to lift buckets. In 2010, a fish vacuum pump (Transvac 2445) was also tested with promising results (Portz et al. unpub.) but also has not been implemented.

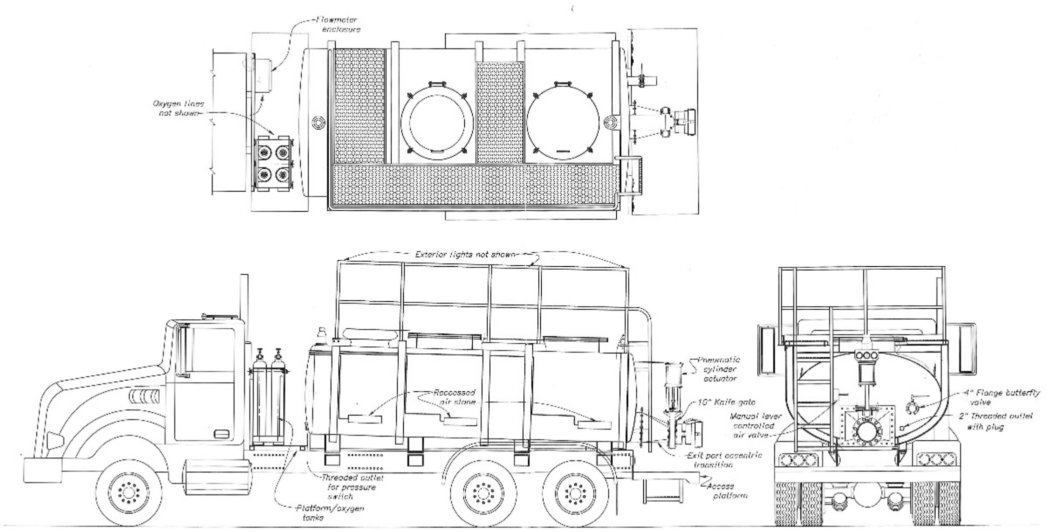
Fish transport trucks. Before transport tank trucks were used, the feasibility of holding fish in aerated tanks was conducted at the Pilot Fish Screen using 416-L (110-gal) drums (U.S. Bureau of Reclamation 1955d). After determining the "amount of air required by a certain number and size of fish within specific limits of water surface area, water temperatures, and volume of water" (U.S. Bureau of Reclamation 1955d), fish transport using 1,892-L (500-gal) tank trucks was also tested (U.S. Bureau of Reclamation 1955a). When the TFCF started operation in 1957, two 3,785-L (1,000-gal) capacity fish trucks were to be used to transport salvaged fish; however, because of a delay in delivery, 1,892-L (500-gal) fish trucks borrowed from Coleman Fish Hatchery were used the first few months of operation (U.S. Bureau of Reclamation 1957b). The first fish trucks used at the TFCF were equipped with diffuser stones for aeration and oxygen tanks (recommended by CDFW but not by USFWS) but were not insulated (U.S. Bureau of Reclamation 1956c). Through time, the tank truck volume increased: the 3,785-L (1,000-gal) trucks were used late in 1957, 5,678-L (1,500-gal) capacity in the early 1960s, 7,570-L (2,000-gal) capacity fish truck in 1990, and finally 9,913-L (2,619-gal) capacity fish truck in 2008 (Figure 20). The current trucks are equipped with an aeration system using oxygen and compressed air.

Bates et al. (1960) developed the "Bates Tables" for proper fish loading of trucks using size classes, species, and water temperature which are still used to this day for informing operators when a fish haul is required. Sutphin and Hueth (2015) quantified the effects of loading and transporting fish at recommended and twice the recommended Bates Table level. They found that density at both levels did not have a significant effect on fish survival or physiological stress. The original Bates Tables were designed for a 3,785-L (1,000-gal) fish truck that hauled fish for approximately one hour (Bates et al. 1960). Newer versions of the tables applicable to the current, larger fish trucks were introduced in 2010. Bates et al. (1960) recommended that fish be hauled at least once a day; however, current Biological Opinions require the facility to transport fish within 12 hours when Chinook Salmon are detected and within eight hours for Delta Smelt.

Fish transport process begins from the time fish are released from the fish haul bucket up to the point when they are released at the fish release site. This process is very stressful to fish. One remedy recommended was the addition of salt for fish transport (Bates et al. 1960) and/or mild anesthetic to the transport truck water (Raquel 1989). The addition of salt was originally the standard procedure at the TFCF but was discontinued at an unknown time. After the 1995 USFWS Biological Opinion requiring 8 ppt salinity for fish transport, this process was reinitiated.

The shape and form of the truck tank was also modified to minimize damage to fish. The historical trucks had baffles to limit sloshing of water during transport. One issue that has not been fixed though, is the transfer of fish from the fish haul bucket to the fish truck. When the contents of the fish haul bucket are discharged to the fish truck, the force of the fall that the fish experience is huge. Currently, even though the fish truck tank is filled half full of water before fish transfer, there is still a 60 cm (2 ft) drop and the fish can still hit the tank floor. Ideally, the opening of the fish haul bucket should be touching the water to ensure water-to-water transfer.

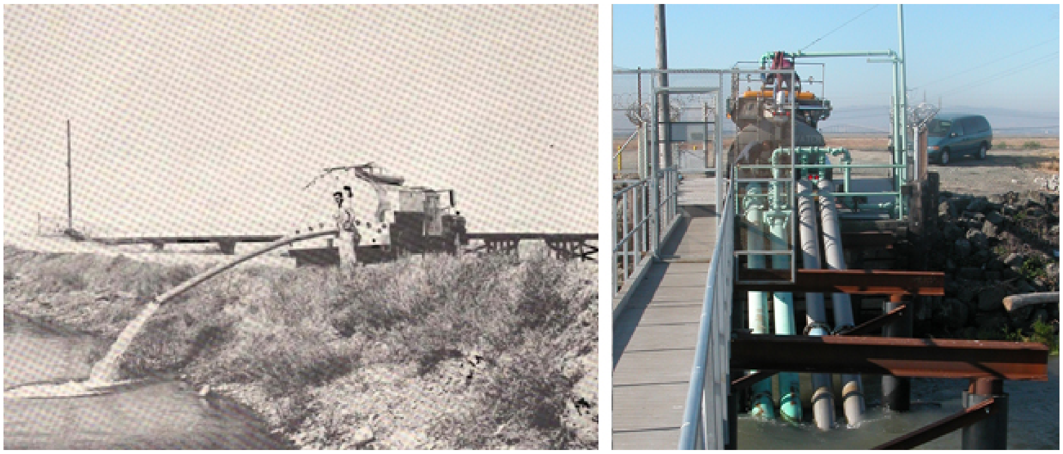
Figure 20 Current 9,913-L (2,619-gallon) fish transport truck used at the Tracy Fish Collection Facility



Note: Diagram illustrates location of aeration system, shape of the tank, and location of the release exit port.

Fish release sites. Although release sites have improved since the 1950s with improved transition from truck to water (Figure 21), securing permanent release site locations took several years. Between 1952 and 1956 when the Pilot Fish Screen acted as a temporary salvage facility, fish were transported an hour or more to different non-permanent locations in the Rio Vista area. Often, the fish truck driver had "to search for an hour or more" and had to "usually trespass" in order to locate a good place to "dump" fish and frequently, fish were released at locations "not entirely beyond the influence of the Tracy pumps" (U.S. Bureau of Reclamation 1956d, 1956e). In the 1960s, Reclamation was using locations on Sherman Island and in Brannon Island State Park, both equipped with "dumping chutes" or half-open pipe for fish release (California Department of Water Resources 1967) (Figure 22). Reclamation was aware of the urgency of securing permanent fish release sites (U.S. Bureau of Reclamation 1956e; U.S. Bureau of Reclamation 1960) and several possible locations were proposed (California Department of Fish and Game 1960; U.S. Bureau of Reclamation 1960); however, permanent locations were not identified until 1969 (Lyons 1969). The two permanent locations selected, one on Sherman Island on the Sacramento River (i.e., Emmaton site) and the other near the Antioch Bridge Pier at the Antioch/Oakley Regional Shoreline on the San Joaquin River (i.e., Antioch site), were primarily selected because of ease of land acquisition (Lyons 1969). The Emmaton site was completed in 1970 and the Antioch site in 1975 (Staley 1975). The release site at Brannon Island was abandoned when the Emmaton and Antioch sites were put into operation; however, there are plans to renovate this site in the future. To this day, Emmaton and Antioch are the only Reclamation-owned release sites in use.

Figure 21 **Fish release**



Note: Left, truck discharging test fish in the 1950s; right, truck attached to a release pipe at Emmaton near Rio Vista, CA, a permanent fish release site. Before permanent release sites were built, fish were released in a manner similar to the photo on the left.

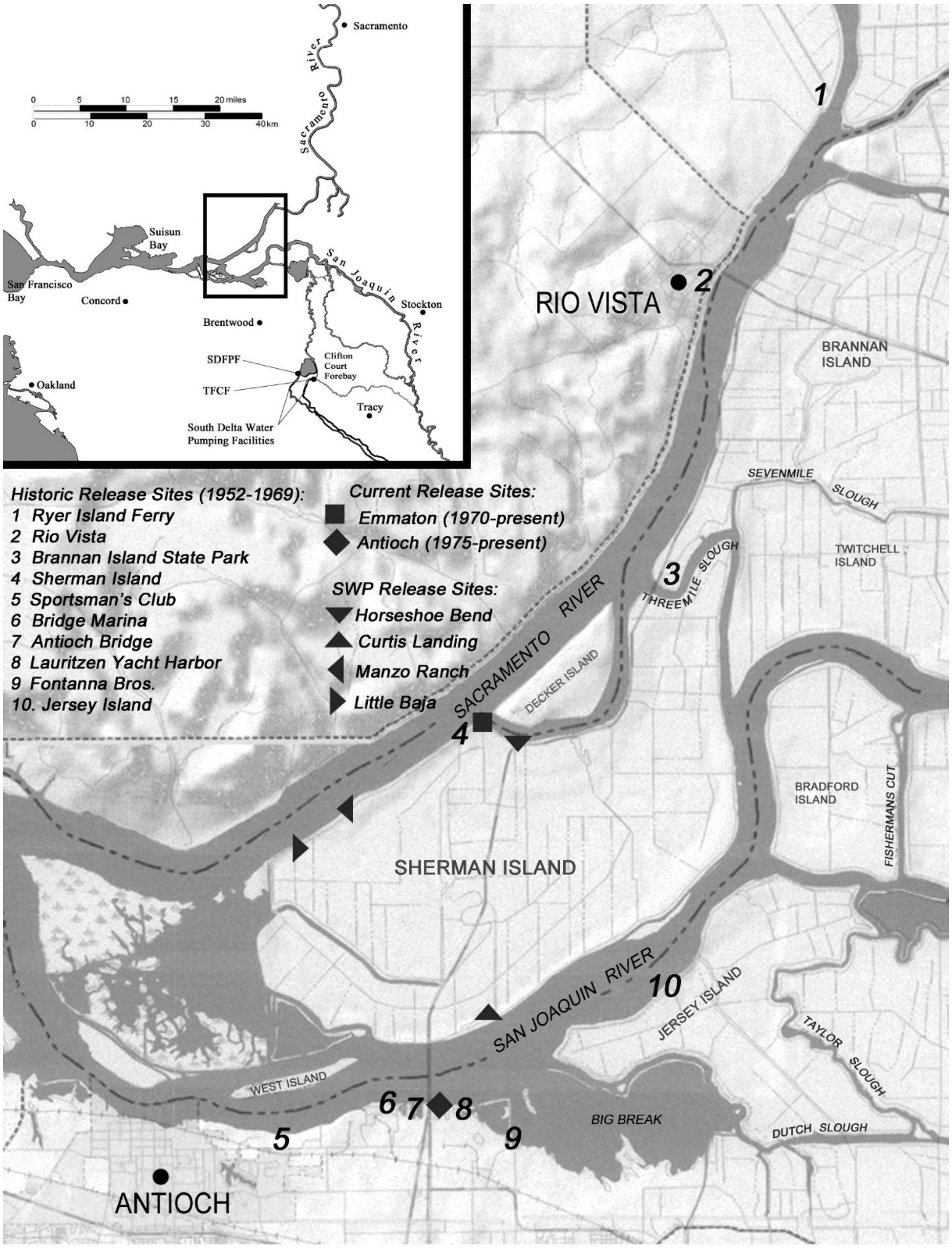
The two permanent release sites are very different from each other: the release site at Emmaton is on the Sacramento River and its pipes have a steep slope. The release site at Antioch is on the San Joaquin River with a much longer pipe and a gradual slope (7-ft elevation) since Joaquin River at this location is much wider and shallower than the Emmaton site. When the Antioch site was remodeled in 1982, Reclamation installed 24.4 m (80 ft) of 30.5 cm (12 in) diameter steel pipe, 18.3 m (60 ft) of 15.2 cm (6 in) diameter steel pipe, and 30.5 m (100 ft) of PVC underwater (U.S. Bureau of Reclamation 1982). In 2013, the PVC section was removed because it was clogged with debris and the remaining steel pipe holes were patched. Because of the release pipe’s gentle slope, the water speed within the release pipe was not fast enough to push the debris out of the pipe thus causing it to clog.

Figure 22 Reclamation release sites at the confluence of the Sacramento-San Joaquin rivers (past and present)

Note: From left to right: Brannon Island site showing "dumping chutes" ca. 1963, Brannon Island site in 2006, Antioch site ca. 1980 with a single release pipe, Antioch site in 2015 with the additional flushing assembly (note the gradual slope of the pipes), incomplete Rio Vista site in 2006, and the Emmaton site in 2015 (note steep slope of the pipes).

An additional release site was required of Reclamation per the incidental take section of the 1993 NMFS Biological Opinion, and in 1993, Reclamation was in the process of identifying alternative sites (Patterson 1993). There was a structure at a site near the Rio Vista Bridge which was removed by Caltrans and replaced by new construction in the early 1990s. This structure was subsequently damaged during high flows in 1997 (Dealy 1998). It was repaired in 2000, but the site was never used for fish release as it does not have a flushing mechanism and is too shallow (Figure 22) (B Shinmoto pers. comm.). Currently, Reclamation can use a site (Curtis Landing) owned by SWP as an optional third release site. In 2018, SWP completed two more release sites (named Little Baja and Manzo Ranch) at Sherman Island, which Reclamation can use in the future (J Miranda pers. comm.). Reclamation intends to build a third release site as one of the "actions" identified for improving fish protection under the CVPIA's Jones Pumping Plant Mitigation Program. In the meantime, a memorandum of understanding is being drafted allowing the site to be shared between the CVP and SWP. A summary of locations of the historical and current fish release sites are shown in Figure 23.

Figure 23 Locations of historic and current fish release sites used by the Tracy Fish Collection Facility



Salvaged fish released back to the Delta are not guaranteed survival. In the release pipes, pressure surges caused by poor air venting and debris movement (Mefford 2007) can disorient fish. Hydraulic jumps, the turbulent and abrupt rise in the water surface when high velocity water is discharged into lower velocity water, can also further disorient fish (Churchwell et al. 2005; Mefford 2007). Debris can also build up inside the release pipe, which blocks the release of fish. Furthermore, water quality inside the fish truck may be different from that of the release site; when fish are released, they may experience shock, stress, and mortality.

The largest impediment to survival at the release site, though, is predation. Fish released at the release sites create an unusual abundance of disoriented fish that are easy prey for larger Striped Bass (California Department of Fish and Game 1989) and Sacramento Pikeminnow (*Ptychocheilus grandis*) that congregate at the release sites. Sacramento Pikeminnow in particular, appear to respond to artificial abundance of food at the release sites, and although fewer in numbers, they consume twice as much volume as Striped Bass (Pickard et al. 1982). Striped Bass do not exhibit strong site fidelity, remaining near a release site for only a few days; however, Sacramento Pikeminnow will remain near a release site for as long as four months (Miranda et al. 2010). Predation rates at the release sites are unknown, although Orsi's (1967) study of a release site at Jersey Island estimated a maximum of 1/3 of fish released per day may be eaten. There is a positive correlation with the number of fish salvaged and the number of predators holding within the immediate vicinity of the release pipe (Miranda et al. 2010). Sonar images have proven that piscivorous predators concentrate seasonally in the immediate vicinity of the release pipe exit (Churchwell et al. 2005), and the release of fish is more of an attractant more than the release site structure itself (Miranda et al. 2010).

References

Arthur J. 1987. *River flows, water project exports, and water quality trends in the San Francisco Bay-Delta Estuary*. U.S. Bureau of Reclamation, Mid-Pacific Region. Sacramento, CA. USBR Exhibit No. 111 of the State Water Board Hearings.

Arthur JF, MD Ball, and SY Baughman. 1996. *Summary of federal and state water project environmental impacts in the San Francisco Bay-Delta Estuary, California*. Pages 445–495 in J.T. Hollibaugh, Editor, San Francisco Bay: The Ecosystem, Further Investigations into the Natural History of San Francisco Bay and Delta with Reference to the Influence of Man.

Babb AF. 1966. *Effects of structural geometry on the velocity distribution patterns in the Delta Fish Protection Facilities*. Volume 1. Water Science and Engineering Papers, Department of Water Resources.

Barnaby JT, SH Bair, and GB Collins. 1953. *Review and appraisal of the fish protection problem associated with the diversion of water at the Tracy Pumping Plant, Central Valley, California*. Fish and Wildlife Service, June 1953.

Bates DW, and R Vinsonhaler. 1957. *Use of louvers for guiding fish*. Transactions of the American Fisheries Society, 86:38–57.

Bates DW, O Logan, and E Pesonen. 1960. *Efficiency evaluation Tracy Fish Collecting Facility*. Central Valley Project, California. Department of the Interior, Bureau of Reclamation, Region 2; Sacramento, CA, Bureau of Commercial Fisheries, Pacific Region, Seattle, Washington.

Baumli GR. 1990. *Response of the State Water Contractors to the petition to list Delta Smelt as an endangered species.* State Water Contractor General Manager Memorandum with attachment. January 17, 1990.

Bolster B. 1986. *Problems with eliminating one or two shifts at the Federal Fish Facility*. Memorandum to Pete Chadwick. July 16, 1986.

Boutwell JE, and D Sisneros. 2006. *Water born debris removal evaluations using a traveling screen at the Tracy Fish Collection Facility, Tracy, California*. Tracy Fish Collection Facility Studies, Volume 33. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Bowen M, S Siegfried, C Liston, L Hess, and C Karp. 1998. *Fish collections and secondary louver efficiency at the Tracy Fish Collection Facility: October 1993 to September 1995*. Tracy Fish Collection Facility Studies, Volume 7. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Bowen MD, BB Baskerville-Bridges, KW Frizell, L Hess, CA Karp, SM Siegfried, and SL Wynn. 2004. *Empirical and experimental analyses of secondary louver efficiency at the Tracy Fish Collection Facility, March 1996 to November 1997*. Tracy Fish Facility Studies, Volume 11. U. S. Bureau of Reclamation, Mid-Pacific Region, Denver Technical Service Center.

Bridges BB. 2010. *Bypass ratio study at the Tracy Fish Collection Facility*. Unpublished data.

Bridges BB, BJ Wu, RC Reyes, RC Bark, and MD Bowen. 2019 in press. *Adult Striped Bass impact on adult Delta Smelt and juvenile Chinook Salmon entrained at the Tracy Fish Collection Facility*. Unpublished manuscript. Tracy Fish Facility Studies, Volume 45. U. S. Bureau of Reclamation, Mid-Pacific Region, Denver Technical Service Center.

California Data Exchange Center (CDEC)/Department of Water Resources. Precipitation data accessed August 25, 2015.

California Department of Fish and Game. 1955. Correspondence from Seth Gordon, Director of CDFG, to C.H. Spencer, Reclamation Regional Director. July 14, 1955.

———. 1960. Letter to Mr. H.P. Dugan, Reclamation Regional Director, regarding suggestions for additional release sites. June 22 and August 9, 1960.

———. 1989. *Striped bass restoration and management plan for the Sacramento-San Joaquin Estuary Phase 1*. State of California, The Resources Agency, Department of Fish and Game.

———. 2013. Chinook Salmon loss estimation for Skinner Delta Fish Protective Facility and Tracy Fish Collection Facility. Protocol. ftp://ftp.dfg.ca.gov/salvage/

Carle D. 2009. *Introduction to Water in California*. California Natural History Guides, University of California Press.

Castillo G, J Morinaka, J Lindberg, R Fujimura, B Baskerville-Bridges, J Hobbs, G Tigan, and L Ellison. 2012. *Pre-screen loss and fish facility efficiency for Delta Smelt at the South Delta's State Water Project, California.* San Francisco Estuary and Watershed Science, Vol. 10, Issue 4.

Chadwick HK. 1977. *State and Federal Fish Protective Facilities Monitoring Program*. Memorandum to Tarbox, Rosten, and Whitesel. May 13, 1977.

———. 1989. CDFG letter addressed to Reclamation's Andrew Farrar regarding TFCF sampling procedures. July 28, 1989.

Churchwell PE, R Padilla, K Enstrom, K Clark, D Dorratcague, CH Hanson, T Finnegan, and J Taplin. 2005. *Summary of the collection, handling, transport, and release (CHTR) process and data available on State Water Project (SWP) and Central Valley Project (CVP) fish salvage*. State of California, The Resources Agency, Department of Water Resources.

Clark KW, MD Bowen, RB Mayfield, KP Zehfuss, JD Taplin, and CH Hanson. 2009. *Quantification of pre-screen loss of juvenile Steelhead in Clifton Court Forebay*. Technical Report, California Department of Water Resources.

Collins BW. 1985. *DFG bid on USBR contract to operate the Tracy Fish Protective Facility*. Memorandum to D.B. Odenweller. February 6, 1985.

———. 1986. *Tracy Fish Facility—Elimination of one or two work shifts.* Memorandum to D.B. Odenweller. June 16, 1986.

Dealy JC. 1998. *Rio Vista Fish Release Site (RVFRS), repair by replacement, protection of the federally listed Delta Smelt, Sacramento River, Solano County*. Reclamation Memorandum to Mat Vandenberg, U.S. Fish and Wildlife Service, May 7, 1998.

Dealy John C. 2015. Personal communication.

Delta Fish Agreement (Four Pumps Agreement). 1986. *Agreement between the Department of Water Resources and the Department of Fish and Game to offset direct fish losses in relation to the Harvey O. Banks Delta Pumping Plant.*

Delta Smelt Resiliency Strategy. 2016. California Natural Resources Agency. July 2016.

Department of Water Resources. 1967. *Fish collection facilities bypass intake passage spacing tests at Tracy Fish Collecting Facility, 1963*. Office Report, second printing of April 1964.

Dill WA, and AJ Cordone. 1997. *History and status of introduced fishes in California, 1871–1996*. Fish and Game Bulletin 178.

Direct Loss Mitigation Agreement between Reclamation and CDFW. 1992. *Agreement between U.S. Bureau of Reclamation and the California Department of Fish and Game to reduce and offset direct fish losses associated with the operation of the Tracy Pumping Plant and the Tracy Fish Collection Facility*.

Dutton William. 2017. Personal communication.

Erkkila LF, JW Moffet, OB Cope, BR Smith, and RS Nielson. 1950. *Sacramento-San Joaquin Delta fishery resources: Effects of Tracy Pumping Plant and the Delta Cross Channel*. U.S. Fish and Wildlife Service Special Scientific Report 56.

Fausch KD. 2000. *Reducing predation mortality at the Tracy Fish Test Facility: Review and analysis of potential solutions.* Tracy Fish Collection Facility Studies, Volume 12. Bureau of Reclamation, Mid-Pacific Region, Denver Technical Service Center and Colorado State University.

Federal Register. 1994. *Endangered and threatened wildlife and plants; Animal candidate review for listing as endangered or threatened species.* Proposed Rules Vol. 59, No. 219.

Fisher FW. 1992. *Chinook Salmon, Oncorhynchus tshawytscha, growth and occurrence in the Sacramento-San Joaquin River System*. DFG Inland Fisheries Division, IFD Office Report, June 1992.

———. 1993. *River and Delta length frequency distributions and lengths of hatchery releases.* CDFW Memorandum to Deborah McKee, February 3, 1993.

Fults DM. 1990. *Review of State of California's proposal to list the Delta Smelt as a threatened species (Endangered Species)*. Reclamation Assistant Regional Director Memorandum, July 23, 1990.

Gingras M. 1997. *Mark/recapture experiments at Clifton Court Forebay to estimate pre-screening loss to juvenile fishes: 1976–1993*. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 55.

Glaser DR. 1991. *Comments on the Notice of Petition Findings on the Delta Smelt.* Assistant Commissioner Memorandum, May 8, 1991.

Goodman DH, SB Reid, RC Reyes, WJ Wu, and BB Bridges. 2017. *Screen efficiency and implications for losses of lamprey macrophthalmia at California's largest water diversions.* North American Journal of Fisheries Management 37:30–40.

Hallock RJ. 1967. *Efficiency tests of the primary louver system, Tracy Fish Screen, 1966–67*. California Department of Fish and Game, Marine Resources Administrative Report, Number 67. Sacramento, CA.

Hallock RJ, RA Iselin, DH Fry, Jr. 1968. *Efficiency tests of the primary louver system, Tracy Fish Screen 1966–1967.* Marine Resources Branch, California Department of Fish and Game.

Hatton SR. 1940. *Progress report of Central Valley fishery investigations, 1939*. California Fish and Game, Volume 26(4):334–373.

Hatton SR, and GH Clark. 1942. *A second progress report on the Central Valley fisheries investigation*. California Fish and Game, Volume 28(2):116–123.

Hawkins DL. 2008. *Underwater examination of inaccessible features, Tracy Pumping Plant and Fish Collection Facility, May 1, 2008, Central Valley Project, Delta Division, California.* Memorandum, December 9, 2008.

Hedgecock D, MA Banks, VK Rashbrook, CA Dean, and SM Blankenship. 2001. *Applications of population genetics to conservation of Chinook Salmon diversity in the Central Valley*. Pages 45–70 in R.L. Brown, editor. Contributions to the Biology of Central Valley Salmonids. California Department of Fish and Game Fishery Bulletin 179(1).

Heiner BJ and BW Mefford. 2011. *Physical hydraulic modeling of secondary louver replacement at the Tracy Fish Collection Facility*. Hydraulic Laboratory Report HL-2011-10. U.S. Bureau of Reclamation, Technical Service Center, Hydraulic Investigations and Laboratory Services Group, Denver, Colorado.

Helfrich L, C Liston, B Mefford, and R Bark. 2000. *Assessment of survival and condition of fish passed through a hidrostal pump at the Tracy Fish Collection Facility, California*. Tracy Fish Collection Facility Studies. Volume 16. U. S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center, and Virginia Polytechnic Institute and State University.

Hess L. 1999. *Biological O&M Manual*. Memorandum, March 8, 1999.

———. 2005. *The final report: an analysis of the factors impacting fish salvage at the TFCF*. Unpublished manuscript.

Heubach W. 1973. *Effects of Clifton Court Forebay on the densities and entrainment of various fishes at the Delta Fish Protective Facility*. California Department of Fish and Game.

Hutton P. 2008. *A model to estimate combined Old and Middle River flows.* Metropolitan Water District. Final Report.

Hyde H, D Davis, R Smith, N Geddes, and P Kotrlik. 1967. *Fish collection facilities louver slat spacing tests at Tracy Fish Collecting Facility*. Department of Water Resources, Delta Fish Protective Facility Office Report.

Imai Joel. 2014. Personal communication.

Ingebritsen SE, ME Ikehara, DL Galloway, and DR Jones. 2000. *Delta subsidence in California; the sinking heart of the State*. U.S. Geological Survey Fact Sheet 005-00.

Intralox. 2014. *Instruction handbook for S1800 vertical or angled water screens*. Project 3081, USBR-Tracy/Valentine Corp. Secondary Channel Screens.

Jahn A. 2011. *An alternative technique to quantify the incidental take of listed anadromous fishes at the Federal and State water export facilities in the San Francisco Bay-Delta Estuary*. Kier Associates, Ukiah, California. Prepared for National Marin Fisheries Service, Central Valley Office.

Kano RM. 1990. *Occurrence and abundance of predator fish in Clifton Court Forebay, California.* Department of Fish and Game Technical Report 24. May 1990.

Karp Catherine. 2015. Personal communication.

Karp C, and B Bridges. 2015. *White Sturgeon salvage efficiency at the Tracy Fish Collection Facility*. Tracy Fish Collection Facility Studies. Tracy Technical Bulletin 2015-3. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Karp C, BJ Wu, and K Kumagai. 2017. *Juvenile Chinook Salmon, Steelhead, and adult Striped Bass movements and facility efficiency*. Tracy Fish Facility Studies, Volume 54. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Karp C, L Hess, and C Liston. 1995. *Re-evaluation of louver efficiencies for juvenile Chinook Salmon and Striped Bass, 1993*. Tracy Fish Facility Studies, Volume 3. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Services Center.

Karp C, L Hess, J Lyons, and C Liston. 1997. *Evaluation of the sub-sampling procedure to estimate fish salvage at the Tracy Fish Collection Facility, Tracy, CA, 1993–1996*. Tracy Fish Collection Facility Studies, Volume 8. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Kennedy DN. 1991. *Delta Smelt*. Department of Water Resources Director Memorandum, March 4, 1991.

Kerr JE 1953. *Studies on fish preservation at the Contra Costa Steam Plant of the Pacific Gas and Electric Company*. California Department of Fish Game, Fish Bulletin 92:1–66.

Kimmerer WJ. 2004. *Open water processes of the San Francisco Estuary: From physical forcing to biological responses*. San Francisco Estuary and Watershed Science. Vol. 2, Issue 1 (February) Article 1.

Kimmerer WJ, and ML Nobriga. 2008. *Investigating Particle Transport and Fate in the Sacramento–San Joaquin Delta Using a Particle-Tracking Model*. San Francisco Estuary and Watershed Science, 6(1).

Lancaster DM, and TJ Rhone. 1955. *Field and laboratory tests to develop the design of a fish screen structure, Delta Mendota Canal headworks, Central Valley Project, California*. Department of the Interior, Bureau of Reclamation, Division of Engineering Laboratories. Hydraulic Laboratory Report No. Hyd-401.

Liston C, R Brockman, G Sackett, C Karp, L Hess, P Johnson, S Hiebert, and G Mueller. 1994. *Improvements in fish collection facilities at the Federal Tracy Pumping Plant in the South San Francisco Bay Delta, California.* Pages 155–160 *in* K. Bates, editor. Fish Passage Policy and Technology: Proceedings of the American Fisheries Society Fish Passage Symposium, Portland, Oregon. September 1993.

Liston CR, C Karp, L Hess, and S Hiebert. 1994. *Summary of the fish predator removal program and intake channel studies, 1991–1992*. Tracy Fish Collection Facility Studies, Volume 1. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Lund J, E Hanak, W Fleenor, R Howitt, J Mount, and P Moyle. 2007. *Envisioning futures for the Sacramento-San Joaquin Delta*. Public Policy Institute of California. Issue 114.

Lyons AD. 1969. *Inspection of potential fish unloading sites.* Memorandum, November 4, 1969.

Martin BE. 1990. *Listing of Delta Smelt (Hypomesus transpacificus) as a threatened species.* California Central Valley Flood Control Association Manager. Memorandum, August 30, 1990.

McEwan D. 1988. *Problems at the USBR Fish Facility*. Memorandum to Fish Salvage Operation. December 14, 1988.

Mecum WL. 1977. *Recommended operations for the Federal Fish Collection Facility at Tracy, from June 1 to September 30*. Anadromous Fisheries Branch Administrative Report. No. 77–4.

———. 1980. *The Clifton Court Forebay sport fishery*. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report 78–21.

———. 1980a. *The efficiency of various bypass configurations for juvenile Striped Bass, Morone saxatilis, and American Shad, Alosa sapidissima*. California Department of Fish and Game, Anadromous Fisheries Branch, Administrative Report 80–12.

Mefford B. 2007. *Fish release pipe model study, hydraulic analysis, CHTR release study*. U.S. Bureau of Reclamation, Denver Technical Service Center. Denver, CO.

Meinz M. 1978. *Use of louvers for guiding juvenile king salmon (Oncorhynchus tshawytscha)*. California Department of Fish and Game, Anadromous Fisheries Branch Administrative Report 78–22.

Miranda Javier. 2015. Personal communication.

Miranda J, R Padilla, J Morinaka, J DuBois, and M Horn. 2010. *Release site predation study*. Department of Water Resources in collaboration with Central Valley Fish Facilities Review Team.

Morinaka J. 2013. *A History of the operational and structural changes to the John E. Skinner Delta Fish Protective Facility from 1968 to 2010*. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 85.

National Marine Fisheries Service. 1993. Biological Opinion. *Biological opinion for the long-term operations of the Central Valley Project.* National Marine Fisheries Service. Southwest Region, Long Beach, California. February.

———. 2002. Biological Opinion. *Endangered Species Act Section 7 consultation Biological Opinion on Central Valley Project (CVP) and State Water Project (SWP) operations from April 1, 2002 through March 31, 2004*.

———. 2004. Biological Opinion. *Endangered Species Act Section 7 consultation Biological Opinion on the long-term Central Valley Project and State Water Project Operations Criteria and Plan*. October 2004.

———. 2009. Biological Opinion. *Endangered Species Act section 7 consultation Biological Opinion and Conference Opinion on the long-term operations of the Central Valley Project and State Water Project*. June 4, 2009.

National Resources Defense Council (NRDC) and The Bay Institute. 2014. *Proposal to revise the Delta Smelt CSI and adult ITL calculation*. Electronic mail response to Jason Hassrick, PhD. October 24, 2014.

Odenweller Dan. 2014. Personal communication.

Odenweller D. 2004. *Tracy Fish Collecting Facility–Primary bypass transition box repair (2002) and replacement (2004) review*. Memorandum, May 4, 2004.

Odenweller D, and RL Brown. 1982. *Delta fish facilities program report through June 30, 1982*. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 6.

Orsi JJ. 1967. Predation Study Report, 1966–1967. California Department of Fish and Game.

Partridge E. 1994. *Repair of bypass–Tracy Fish Collection Facility*. Memorandum, May 2, 1994.

Partridge Elizabeth. 2014. Personal communication.

Patterson RK. 1992. *Program to minimize losses of winter-run Chinook Salmon – Tracy Fish Collection Facility*. Memorandum, June 9, 1992.

———. 1993. *Biological opinion requirement for development of additional dump site for Tracy Fish Salvage Operations (Biological Opinion of May 26, 1993).* Memorandum, June 25, 1993.

Pickard A, A Grover, and FA Hall, Jr. 1982. *An evaluation of predator composition at three locations on the Sacramento River*. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary. Technical Report 2.

Portz DE. 2007. *Fish-holding-associated stress in Sacramento River Chinook Salmon (Oncorhynchus tshawytscha) at south Delta fish salvage operations: effects on plasma constituents, swimming performance, and predator avoidance.* PhD dissertation. University of California, Davis.

Portz DE., Z.A. Sutphin, B. Heiner, and C.D. Hueth. *Effects of a vacuum pump system on tissue damage, physiological stress, swimming, and survival of Rainbow Trout (Oncorhynchus mykiss) and Threadfin Shad (Dorosoma petenense)*. Unpublished manuscript.

Raquel PF. 1989. *Effects of handling and trucking on Chinook Salmon, Striped Bass, American Shad, Steelhead Trout, Threadfin Shad, and White Catfish salvaged at the John E. Skinner Delta Fish Protective Facility*. Department of Fish and Game Technical Report 19. August 1989.

Reyes RC. 2012. *Larval fish secondary louver efficiency at various water velocities*. Unpublished data.

Reyes RC, BJ Wu, ZA Sutphin, SA Porter, and MR Trask. 2019 in draft. *Evaluation of Hydrolox™ traveling screen at the secondary channel using larval and juvenile Delta Smelt*. Tracy Fish Collection Facility Studies. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Reyes RC, BJ Wu, and ZA Sutphin. 2019 in press. *Predation of juvenile Delta Smelt in the bypasses and secondary channel of the Tracy Fish Collection Facility.* Tracy Fish Collection Facility Studies, Tracy Technical Bulletin 2019. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Reyes RC, BB Bridges, BJ Wu, ZA Sutphin, DH Goodman, SB Reid, SA Porter, and MR Trask. 2017. *Pacific Lamprey macrophthalmia louver efficiency at the Tracy Fish Collection Facility*. Tracy Fish Collection Facility Studies. Tracy Series Report Volume 55. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Reyes RC, ZA Sutphin, and BB Bridges. 2012. *Effectiveness of fine mesh screening a holding tank in retaining larval and juvenile fish at the Tracy Fish Collection Facility.* Tracy Fish Collection Facility Studies, Tracy Technical Bulletin 2012–1. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Rhone TJ, and DW Bates. 1960. *Fish protective facilities at the Tracy Pumping Plant, Central Valley Project, California*. Presented at the 9th Hydraulics Division Conference, American Society of Engineers, August 17–19, 1960. Seattle, WA.

Rowley WD 2006. *The Bureau of Reclamation: Origins and growth to 1945.* Volume 1. Bureau of Reclamation, U.S. Department of the Interior. Denver, CO.

Ruggles CP, and P. Ryan. 1964. *An investigation of louvers as a method of guiding juvenile Pacific salmon*. The Canadian Fish. Cult. Issue 33:1–68.

Shafer GA. 1959. *Tracy Fish Collecting Facilities monthly report*. Office Memorandum, May 25, 1959.

Shinmoto Brian. 2016. Personal communication.

Siegfried S. 1999. *Notes on the invasion of the Chinese Mitten Crab (Eriocheir sinensis) and their entrainment at the Tracy Fish Collection Facility*. IEP Newsletter 12(2):24–25.

Simmons PS. 1990. *Delta Smelt*. Central Valley Project Water Association Attorney Memorandum, July 18, 1990.

Skinner JE. 1973. *Evaluation testing program report for Delta Fish Protective Facility*. Department of Water Resources and Department of Fish and Game. Memorandum Report.

Speegle Jonathan. 2015. Personal communication.

Spencer DF, and GG Ksander. 2005. *Seasonal growth of water hyacinth in the Sacramento-San Joaquin Delta, California*. Journal of Aquatic Plant Management, 43:91–94.

Stackhouse RF. 1999. *Revised agreement between Reclamation and the California Department of Fish and Game to reduce and offset direct fish losses associated with the operation of the Tracy Pumping Plant and the Tracy Fish Collection Facility*. USBR Regional Director Memorandum, December 28, 1999.

Staley JR. 1975. *U.S. Bureau of Reclamation fish release sites*. Memorandum from Department of Fish and Game to R. Beland. February 28, 1975.

State Water Resources Control Board (SWRCB). 1978. *Water Right Decision 1485 Sacramento-San Joaquin Delta and Suisun Marsh*. August 1978.

Stearns Paul. 2017. Personal communication.

Stene EA. 1994. *Delta Division: Central Valley Project*. Research on Historic Reclamation Projects, Bureau of Reclamation History Program, Denver, CO.

Sutphin ZA, BB Bridges, B Baskerville-Bridges, and RC Reyes. 2007. *Evaluation of current and historical 10-minute count screens at The Tracy Fish Collection Facility, Tracy, California*. Tracy Fish Collection Facility Studies, Volume 31. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Sutphin ZA, and CD Hueth. 2015. *Effects of loading density during transport on physiological stress and survival of Sacramento-San Joaquin Delta fishes*. California Fish and Game 101(2):108–130.

Sutphin ZA, RC Reyes, and BJ Wu. 2014. *Predatory fishes in the Tracy Fish Collection Facility secondary system: An analysis of density, distribution, re-colonization rates, and impact on salvageable fishes*. Tracy Fish Collection Studies, Volume 51. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Tucker ME, CM Williams, and RR Johnson. 1998. *Abundance, food habits and life history aspects of Sacramento squawfish and Striped Bass at the Red Bluff Diversion Complex, including the research pumping plant, Sacramento River, California, 1994–1996*. Red Bluff Research Pumping Plant Report Series, Volume 4, U.S. Fish and Wildlife Service, Red Bluff, California.

Underwood DB. 1991. *Review of federal endangered species office proposal to list the Delta Smelt (Endangered Species)*. Reclamation Commissioner Memorandum, April 2, 1991.

United States Bureau of Reclamation (USBR). 1945. *Central Valley Project: A condensed presentation of the Central Valley Project, its present status and potential development.* Prepared for Lewis Duschler, August 1945.

———. 1949. *Central Valley Basin: A Comprehensive Department Report on the Development of the Water and Related Resources of the Central Valley Basin, and comments from the State of California and Federal Agencies.* Senate Document 113, Eighty-First Congress, First Session. August 1949.

———. 1952. *Studies of the Delta-Mendota Canal Fish Protective Facilities, 1951–1952*. Central Valley Project.

———. 1955. *Activity report for February 1955—Tracy Fish Screen Studies*. Correspondence with USFWS Regional Director from Reclamation Project Construction Engineer, February 25, 1955.

———. 1955a. *Activity report combined for months of March and April 1955—Tracy Fish Screen Studies*. Correspondence with USFWS Regional Director from Reclamation Project Construction Engineer, April 29, 1955.

———. 1955b. *Activity report for month of June 1955—Tracy Fish Screen Studies.* Correspondence with USFWS Regional Director from Reclamation Project Construction Engineer, July 1, 1955.

———. 1955c. *Activity report for month of July 1955—Tracy Fish Screen Studies.* Correspondence with USFWS Regional Director from Reclamation Project Construction Engineer, August 1, 1955.

———. 1955d. *Activity report for month of August 1955—Tracy Fish Screen Studies.* Correspondence with USFWS Regional Director from Reclamation Project Construction Engineer, September 1, 1955.

———. 1956. *Draft TFCF Pilot Screen Evaluation*.

———. 1956a. *Designers' Operating Criteria*. Central Valley Project.

———. 1956b. *Story on Tracy Fish Screen, C.V.P. published in Western Water News.* Correspondence from Reclamation Regional Director to Commissioner. August 30, 1956.

———. 1956c. *Fish hauling trucks—Permanent Fish Protective Facilities Delta-Mendota Intake Canal-Delta Division—Central Valley Project*. Letter from Reclamation Field Engineer at Tracy to Project Construction Engineer, Winters, CA. December 3, 1956.

———. 1956d. Correspondence with J.E. Skinner of CDFW from Region 2, Tracy Operations Field Branch, December 19, 1956.

———. 1956e. *Delta Fish Collecting Facilities—Disposition of collected fish—Central Valley Project.* Letter from Reclamation Chief, Tracy Operations Field Branch to Regional Supervisor of Irrigation and Power, Sacramento, CA. December 4, 1956.

———. 1957. *Fish Protection at the Tracy Pumping Plant Central Valley Project: Development of a Fish Salvage Facility*. February 1957.

———. 1957a. *Fish Collecting Facilities, Delta-Mendota Canal Intake, apparent deficiencies in equipment—Central Valley Project*. Correspondence from Reclamation Project Construction Engineer to Assistant Commissioner and Chief Engineer, March 26, 1957.

———. 1957b. *Tracy Fish Collecting Facilities—Transmittal of monthly report, May, 1957*. Correspondence with Regional Supervisor of Irrigation and Power from Reclamation Chief, Tracy Operations Field Branch, June 7, 1957.

———. 1958. *Tracy Fish Collecting Facilities monthly report, August, 1958*.

———. 1959. *Furnishing and installing trash removal equipment for fish collecting facilities at Delta-Mendota Intake Canal*. Specifications No. DC-5172. Denver, Colorado.

———. 1960. *Tracy Fish Collecting Facilities—Procurement of fish dumping sites*. Letter from Reclamation Acting Chief, Tracy Operations Field Branch to Regional Supervisor Irrigation and Power, Sacramento, CA. December 28, 1960.

———. 1982. *Antioch fish release site, San Joaquin River*. Invitation for bids. August 13, 1982.

———. 1985. *Fact Sheet: Tracy Pumping Plant*. Central Valley Project, California.

———. ca. 1985. *Standing Operating Procedures for Tracy Fish Collecting Facility*. Central Valley Project, California.

———. 2006. *Fish protection at water diversions: a guide for planning and designing fish exclusion facilities*. Water Resources Technical Publication. Bureau of Reclamation. Denver Technical Service Center. http://www.usbr.gov/pmts/hydraulics_lab/pubs/manuals/fishprotection/index.html.

———. 2015. Reclamation History Website. http://www.usbr.gov/history/index.html. Accessed 8/25/2015.

United States Fish and Wildlife Service (USFWS). 1995. Biological Opinion. *Formal consultation and conference on effects of long-term operation of the Central Valley Project and State Water Project on the threatened Delta Smelt, Delta Smelt critical habitat, and proposed threatened Sacramento Splittail*. Memorandum from USFWS Field Supervisor to Reclamation's Regional Director. March 6, 1995.

———. 2004. Biological Opinion. *Formal and early Section 7 endangered species consultation on the coordinated operations of the Central Valley Project and State Water Project and the operations criteria and plan to address potential critical habitat issues.* July 30, 2004.

———. 2008. Biological Opinion. *Formal Endangered Species Act consultation on the proposed coordinated operations of the Central Valley Project (CVP) and the State Water Project (SWP)*. Memorandum from USFWS Regional Director to Reclamation's Operation Manager at the Central Valley Operations Office.

Vermeyen TB, and BJ Heiner. 2015. *Hydraulic evaluation of Hydrolox™ traveling screen in the secondary channel of the Tracy Fish Collection Facility*. Tracy Fish Collection Facility Studies, Tracy Technical Bulletin 2015–5. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Vogel DA. 2010. *Evaluation of acoustic-tagged juvenile Chinook Salmon movements in the Sacramento-San Joaquin Delta during the 2009 Vernalis Adaptive Management Program*. Natural Resources Scientists, Inc. March 2010.

Wang JCS. 2007. *Spawning, early life stages, and early life histories of the Osmerids found in the Sacramento-San Joaquin Delta of California*. Tracy Fish Collection Facility Studies. Volume 38. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Wang JCS, L Lynch, B Bridges, and L Grimaldo. 2005. *Using morphometric characteristics to identify the early life stages of two sympatric Osmerids (Delta Smelt and wakasagi, Hypomesus transpacificus and H. nipponensis) in the San Francisco Estuary, California*. Tracy Fish Collection Facility Studies. Volume 30. U. S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

White R, B Mefford, and C Liston. 2000. *Evaluation of mitten crab exclusion technology during 1999 at the Tracy Fish Collection Facility, California*. Tracy Fish Collection Facility Studies, Volume 14. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center, and USGS Cooperative Fishery Research Unit, Montana State University.

Wu, BJ, and BB Bridges. 2014a. *Evaluating the use of carbon dioxide as an alternative predator removal technique to decrease Tracy Fish Collection Facility predator numbers and improve facility operations*. Tracy Fish Collection Studies, Volume 49. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

———. 2014b. *Retention efficiency of the Tracy Fish Collection Facility holding tank screens for 20–30 mm fork length juvenile Delta Smelt during 30-minute fish counts*. Tracy Fish Collection Studies, Technical Bulletin 2014–3. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Wu BJ, K Kumagai, and J Miranda. 2019. In draft. *Use of predation detection acoustic telemetry to estimate juvenile Chinook Salmon facility efficiency at the Tracy Fish Collection Facility during 4 pump operation at the C.W. "Bill" Jones Pumping Plant*. Tracy Technical Bulletin 2017–1. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Wu BJ, RC Bark, and WK Frizell. 2015. *Use of acoustic telemetry to estimate Striped Bass residence time and identify most utilized holding locations within the Tracy Fish Collection Facility*. Tracy Fish Collection Studies, Volume 46. U.S. Bureau of Reclamation, Mid-Pacific Region and Denver Technical Service Center.

Wu Brandon. 2014, 2016. Personal communication.

Yoshiyama RM, FW Fisher, and PB Moyle. 1998. *Historical abundance and decline of Chinook Salmon in the Central Valley Region of California*. North American Journal of Fisheries Management 18:487–521.

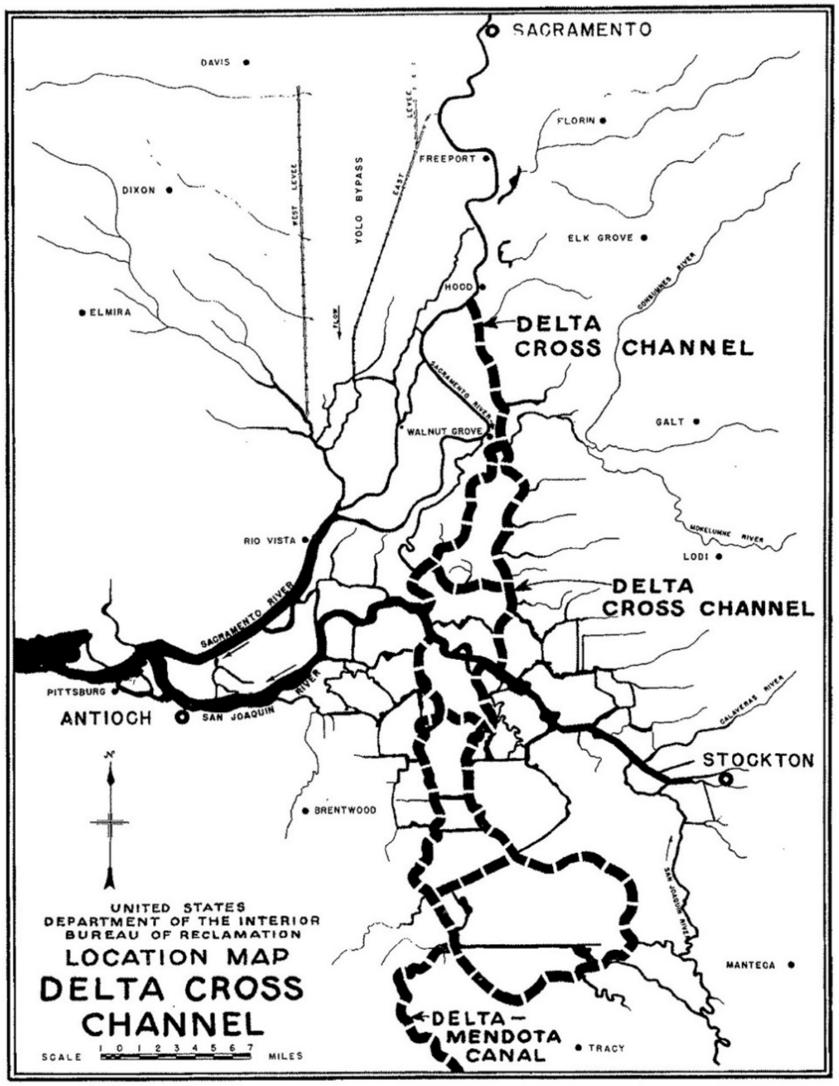
Glossary and Abbreviations

Approach velocity	The mean velocity of water in the primary channel approaching the louvers, and the mean velocity of water in the secondary channel approaching the louvers or perforated plates.
BDCP	Bay Delta Conservation Plan initiated in 2006.
BPP	Harvey O. Banks Pumping Plant
Bypass velocity ratio	The value calculated by dividing the velocity of water at the primary or secondary bypass opening by the appropriate approach velocity.
CA	California Aqueduct
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife, formerly CDFG
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act signed in 1992.
DCC	Delta Cross Channel
Delta	Common name for the Sacramento-San Joaquin River Delta.
DMC	Delta-Mendota Canal
DPS	Distinct Population Segment
DWR	Department of Water Resources, formerly known as Division of Water Resources
Entrainment	A term used to define the influence of a project (e.g., SWP, CVP) to organisms, such as fish, by drawing them in by the flow of water for anthropogenic use. Entrained fish are subject to loss while in the facility, but entrainment does not equate loss.
Fish count	The actual number of fish counted in the systematic counts. Fish counts are a sub-sample of a defined interval of time.
Fish loss	The removal of entrained fish from the facility either through the screens, predation, or mortality related to the salvage process.

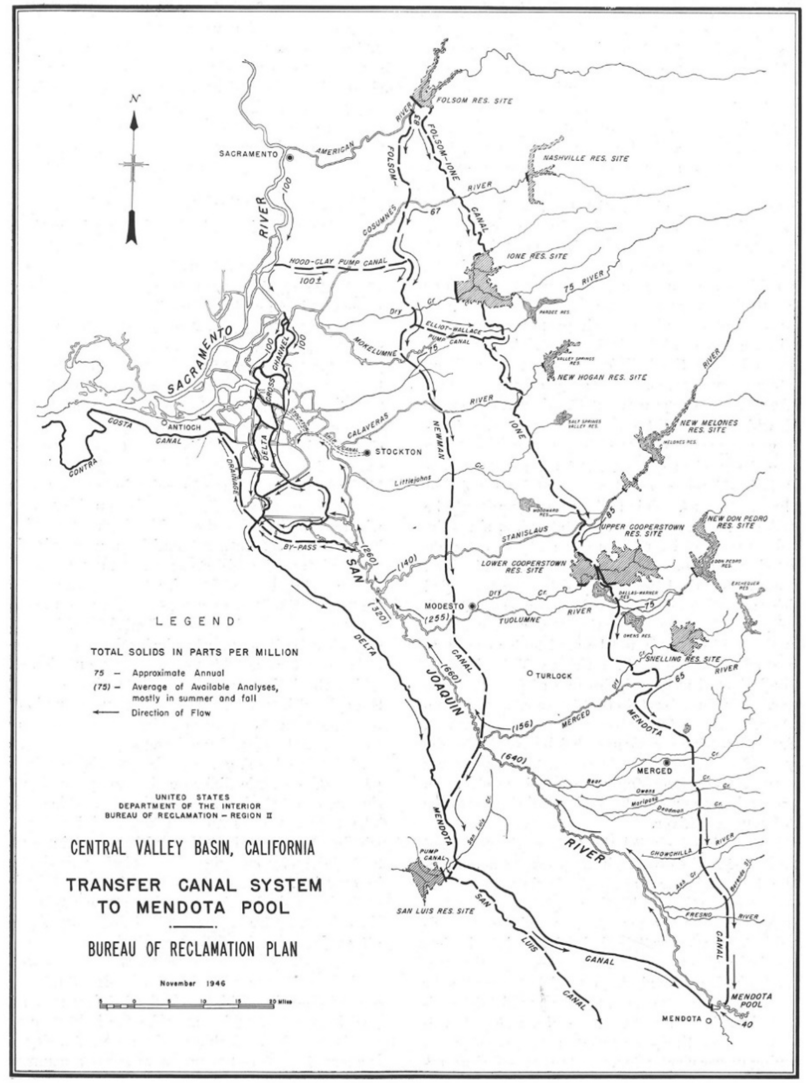
Fish salvage	The act of diverting live and entrained fish into collection holding tanks for future release.
JPP	C.W. “Bill” Jones Pumping Plant, formerly the Tracy Pumping Plant.
NMFS	National Marine Fisheries Service
OCAP	Operational Criteria and Plan
Reclamation	Bureau of Reclamation
RPA	Reasonable and prudent alternatives
Salvage	The process of collecting, holding, transporting, and releasing of entrained fish.
Salvage estimate	The value calculated by multiplying the total number of fish (by species) by an expansion factor. The expansion factor is the value calculated by dividing the total minutes salvaging fish by the length of the fish count.
SLDMWA	San Luis & Delta-Mendota Water Authority
SDFPF	Skinner Delta Fish Protective Facility
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	Tracy Aquaculture Facility
TFCF	Tracy Fish Collection Facility
TFSAC	Tracy Fish Screen Advisory Council (1950–1958)
TSC	Technical Service Center based in Denver, Colorado
USBR	United States Bureau of Reclamation. Synonymous with Reclamation.
USFWS	United States Fish and Wildlife Service
VAMP	Vernalis Adaptive Management Plan
VC	Velocity control pumps

Appendixes

Appendix 1 **Delta Cross Channel route as proposed in 1945 (left) and the Peripheral Canals proposed in 1946 (right)**

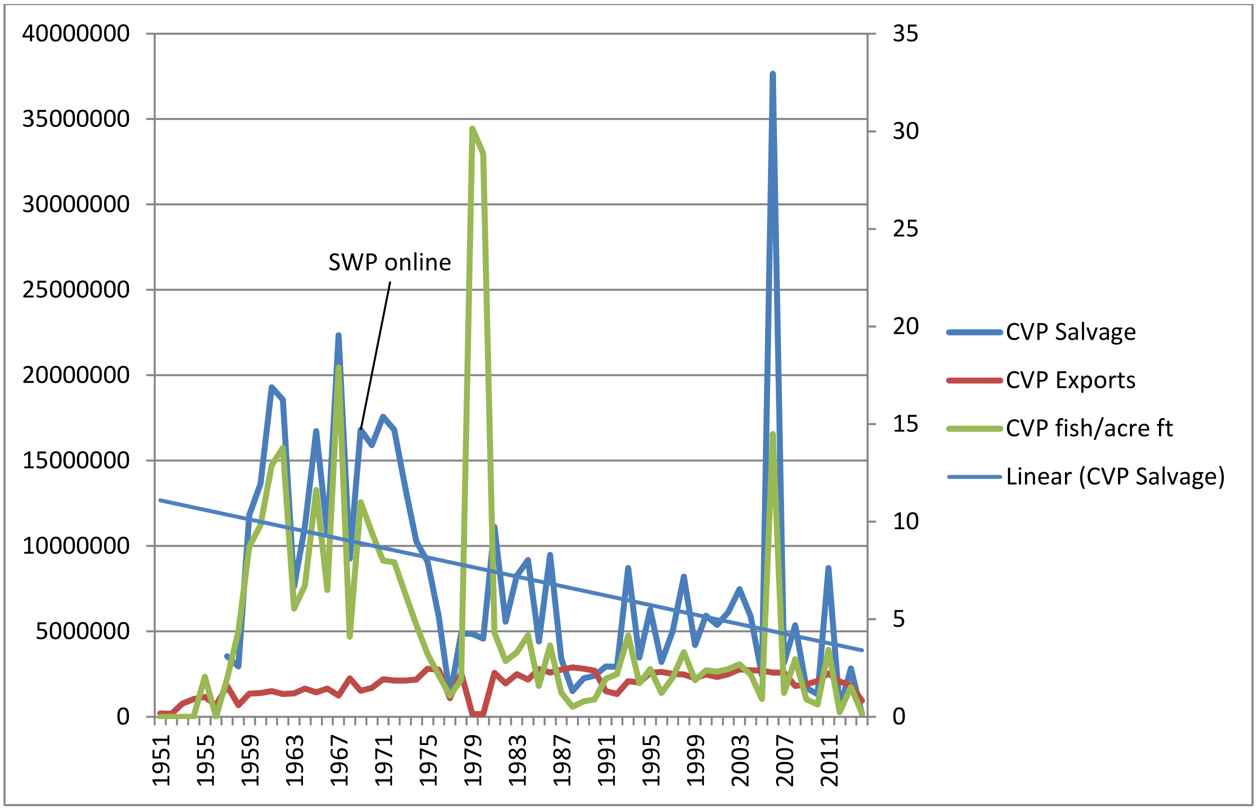


A.



B.

Appendix 2 Salvage and Water Export from 1951–2014



Note: Years are by water year (October 1–September 30 the following year). Water exports are in acre feet.

3. The Service shall make available competent personnel to supervise and perform the biological phases of the program as jointly adopted, the total program to be appurtenant to the operation and maintenance of the Tracy Fish Collection Facility by the Bureau through the Chief, Tracy Operations Field Branch.

4. A joint monthly progress report shall be prepared by the Bureau and the Service covering both the mechanical and biological phases of the program and copies of said report shall be supplied to the California Department of Fish and Game. A final joint report covering the procedures, analyses, and findings of the entire testing, appraisal, and evaluation program shall also be prepared.

5. Office space, stenographic service, supplies, and equipment as needed will be furnished to Service personnel by the Bureau.

6. Expenditures made by the Service will be reported to the Bureau at the end of each calendar quarter.

This agreement shall be effective as of January 15, 1957, and shall continue until February 1, 1959.

BUREAU OF RECLAMATION

By /s/ A. N. Murray
Acting Regional Director

U. S. FISH AND WILDLIFE SERVICE

By /s/ Paul T. Quick
Acting Regional Director

APPROVED: 3/19/57

/s/ Hatfield Chilson

Acting Secretary of the Interior

2

Appendix 4 1978 State Water Resources Control Board Decision 1485

Table II
DECISION 1485
WATER QUALITY STANDARDS
FOR THE SACRAMENTO-SAN JOAQUIN DELTA AND SUISUN MARSH 1/

FISH PROTECTIVE FACILITIES

Maintain appropriate records of the numbers, sizes, kinds of fish salvaged and of water export rates and fish facility operations.

STATE FISH PROTECTIVE FACILITY

The facility is to be operated to meet the following standards to the extent that they are compatible with water export rates:

(a) King Salmon – from November through May 14, standards shall be as follows:
  (1) Approach Velocity – 3.0 to 3.5 feet per second
  (2) Bypass Ratio – maintain 1.2:1.0 to 1.6:1.0 ratios in both primary and secondary channels
  (3) Primary Bay – not critical but use Bay B as first choice
  (4) Screened Water System – the velocity of water exiting from the screened water system is not to exceed the secondary channel approach velocity. The system may be turned off at the discretion of the operators.

(b) Striped Bass and White Catfish – from May 15 through October, standards shall be as follows:
  (1) Approach Velocity – in both the primary and secondary channels, maintain a velocity as close to 1.0 feet per second as is possible
  (2) Bypass Ratio
    (i) When only Bay A (with center wall) is in operation maintain a 1.2:1.0 ratio
    (ii) When both primary bays are in operation and the approach velocity is less than 2.5 feet per second, the bypass ratio should be 1.5:1.0
    (iii) When only Bay B is operating the bypass ratio should be 1.2:1.0
    (iv) Secondary channel bypass ratio should be 1.2:1.0 for all approach velocities.
  (3) Primary Channel – use Bay A (with center wall) in preference to Bay B
  (4) Screened Water Ratio – if the use of screened water is necessary, the velocity of water exiting the screened water system is not to exceed the secondary channel approach velocity
  (5) Clifton Court Forebay Water Level – maintain at the highest practical level.

TRACY FISH PROTECTIVE FACILITY

The secondary system is to be operated to meet the following standards, to the extent that they are compatible with water export rates:

(a) The secondary velocity should be maintained at 3.0 to 3.5 feet per second whenever possible from February through May while salmon are present

(b) To the extent possible, the secondary velocity should not exceed 2.5 feet per second and preferably 1.5 feet per second between June 1 and August 31, to increase the efficiency for striped bass, catfish, shad, and other fish. Secondary velocities should be reduced even at the expense of bypass ratios in the primary, but the ratio should not be reduced below 1:1.0

(c) The screened water discharge should be kept at the lowest possible level consistent with its purpose of minimizing debris in the holding tanks

(d) The bypass ratio in the secondary should be operated to prevent excessive velocities in the holding tanks, but in no case should the bypass velocity be less than the secondary approach velocity.

FOOTNOTES

1/ Except for flow, all values are for surface zone measurements. Except for flow, all mean daily values are based on at least hourly measurements. All dates are inclusive.

2/ Footnote 2 is set forth on next sheet.

3/ When no date is shown in the adjacent column, EC limit in this column begins on April 1.

4/ If contracts to ensure such facilities and water supplies are not executed by January 1, 1980, the Board will take appropriate enforcement actions to prevent encroachment on riparian rights in the southern Delta.

5/ For the purpose of this provision firm supplies of the Bureau shall be any water the Bureau is legally obligated to deliver under any CVP contract of 10 years or more duration, excluding the Friant Division of the CVP, subject only to dry and critical year deficiencies. Firm supplies of the Department shall be any water the Department would have delivered under Table A entitlements of water supply contracts and under prior right settlements had deficiencies not been imposed in that dry or critical year.

6/ Dry year following a wet, above normal or below normal year.

7/ Dry year following a dry or critical year.

8/ Scheduled water supplies shall be firm supplies for USBR and DWR plus additional water ordered from DWR by a contractor the previous September, and which does not exceed the ultimate annual entitlement for said contractor.

NOTE: EC values are mmhos/cm at 25°C.

Appendix 5 1983 Reclamation/CDFG Agreement (partial) Regarding Fish Salvage Operations at the TFCF

AGREEMENT BETWEEN THE UNITED STATES
AND THE STATE OF CALIFORNIA
REGARDING FISH SALVAGE OPERATIONS AT THE
TRACY FISH COLLECTION FACILITY

THIS AGREEMENT, made this 8th day of March, 1983, between the UNITED STATES OF AMERICA through the Bureau of Reclamation, hereinafter referred to as the Bureau; and the California State Department of Fish and Game, hereinafter referred to as Fish and Game provides for a fish monitoring program to be funded by the Bureau at the Tracy Fish Collection Facility.

WITNESSETH THAT:

EXPLANATORY RECITALS

WHEREAS, the Bureau acquired lands for and operation under the authority of the Act of June 17, 1902 (32 Stat. 388), and act amendatory thereof, or supplementary thereto, the Tracy Fish Collection Facilities (TFCF), a feature of the Delta Division of the Central Valley Project; and,

WHEREAS, the Fish and Game currently is providing a fish monitoring program at the John E. Skinner Delta Fish Protective Facility, a feature of the State Water Project; and,

WHEREAS, the Fish and Game is willing to monitor fish salvage operations at the TFCF in addition to their monitoring activities at the John E. Skinner Delta Fish Protective Facilities.

NOW THEREFORE, in consideration of the covenants herein contained, it is agreed as follows:

FISH SALVAGE MONITORING ACTIVITIES

1. The Bureau will reimburse Fish and Game for the costs of a Fishery Biologist (Range A/B) position to be provided by Fish and Game for the monitoring of fish salvage operations at the TFCF.

a. The duties of the biologist while at the TFCF will typically include the following:

(1) Monitor the total fish salvaged by a routine sampling program conducted by the Bureau when the facilities are operating.

(2) Monitor the random subsamples from routine samples for species composition, size, and other life history information conducted by the Bureau.

(3) Collect the data sheets from the Bureau and analyze data and provide monthly and annual reports.

(4) Assemble, analyze, and maintain records of salvage operations of the facilities.

(5) Provide biological expertise to facility operations.

(6) Conduct other evaluations related to the facilities and their operation as required and mutually agreed upon by the Bureau and Fish and Game.

b. Reports. Monthly reports shall include a summary of pertinent activities, and a tabulation of each species of fish salvaged at the TFCF.

Annual reports shall cover the calendar year and shall summarize the year's activities including significant program accomplishments or deficiencies, a total count of the fish of each species salvaged, and appropriate comments concerning the occurrence and abundance of fish.

SAMPLING PROGRAM AT THE TRACY FISH COLLECTION FACILITIES

2. a. Two types of daily fish sampling at the TFCF will be obtained by Bureau employees with technical supervision as necessary from the Fish and Game biologist. One sampling known as a Stage I count will include only enumeration of fish in each sample. Stage II counts will include information on numbers of fish, length, weight, and species composition. The duration of each sample collection shall not be less than one minute and shall be long enough to meet the requirements of Appendix A (attached). In an effort to enable TFCF operators to remain available for operation and maintenance activities, no Stage II counts and only one Stage I count will be made between 8:00 a.m. and 4:00 p.m. The Stage I count will be taken at approximately 12:00 noon daily. Other Stage I counts may be made before or after the hours specified above as necessary in accordance with the statistical analysis appended to this Agreement. Stage II counts shall be made at 6:00 a.m. and 6:00 p.m. or at other times mutually agreeable to both parties.

b. The Bureau will provide the following information regarding Stage I counts to Fish and Game: date, time, duration, primary flow, secondary flow, primary depth, secondary depth, daily acre-feet pumped, bypasses used, and holding tank flow. In addition, the Bureau will provide the Fish and Game the truck hauling sheet information as required.

Appendix 6 1995 Reclamation/CDFG Agreement (partial) Regarding Fish Salvage Operations at the TFCF

SECTION A. SCHEDULE

A.1. Project Title. Fish Biological Support to Monitor, Assemble, Analyze and Evaluate Fish Salvage Operations at the Tracy Fish Collecting Facility, and Fish Monitoring and Reporting at the Contra Costa Canal, and Mallard Slough.

A.2. Background. The Bureau of Reclamation (Reclamation) constructed and is operating the Tracy Fish Collecting Facility (TFCF) to divert and salvage fish that would be otherwise entrained in the Delta-Mendota Canal (DMC) by the Tracy Pumping Plant (TPP). The TFCF has been in operation since 1957. Both the TFCF and the TPP are features of Reclamation's Central Valley Project (CVP) which among other benefits, provides water for irrigation, municipal, and industrial uses. Fish that are salvaged at the TFCF are trucked to points in the Sacramento-San Joaquin Estuary (Delta) beyond the influence of the pumping plants.

The Water Rights Decision 1485 requires the maintenance of appropriate records of the numbers, sizes, kinds of fish salvaged and of water export rates and fish facility operations. Also, the biological opinions under the Endangered Species Act require certain monitoring and reporting activities be conducted at the TFCF.

Reclamation provides water to the Contra Costa Canal. The Canal is operated and maintained by the Contra Costa Water District. Several biological opinions (for both OCAP and Los Vaqueros) require Reclamation monitor for fish at that unscreened diversion. The biological opinions also requires reporting and evaluation of the monitoring.

Mallard Slough is not a feature of the CVP, however, the biological opinion for Delta smelt requires that Reclamation conduct fish monitoring at that intake. The biological opinions also requires reporting and evaluation of the monitoring.

A.3. Purpose. Reclamation acquired lands for the operation of the Central Valley Project by the Act of June 17, 1902 (32 Stat. 388), and acts amendatory thereof or supplementary thereto. The Fish Collecting Facility, a feature of the Central Valley Project (CVP), mitigates against project effects upon fisheries in California. The Contra Costa Canal is part of the CVP and is currently an unscreened diversion. Mallard Slough is not a part of the CVP, however, the Delta Smelt biological opinion requires Reclamation to monitor at that location. The State of California has given the Department of Fish and Game (Recipient) responsibilities over fisheries in California. In accordance with Pub. L. 93-205 entitled "Endangered Species Act of 1973," Reclamation and the Recipient's purpose is to reduce and offset the annual direct losses of striped bass, chinook salmon, Delta smelt and other species of concern associated with the diversion of water at the Tracy Pumping Plant, the contra Costa Canal, and Mallard Slough.

A.4. Benefits. The Recipient has as its principal purpose through their Fish Biological Support Program, an on-going commitment to resolve water resource issues in concert with conservation of endangered species.

A.5. Responsibilities of the Parties. The Recipient agrees to perform the following tasks:

a. Maintain records of the numbers, sizes, kinds of fish salvaged and of water export rates and fish facility operations at the TFCF.

b. Provide monitoring and reporting for the TFCF as required by the biological opinions under the Endangered Species Act.

c. Annually by October 1 of each year, prepare a draft Annual Study Plan for Contra Costa Canal and Mallard Slough, as required by the biological opinions for OCAP and Los Vaqueros.

d. Conduct fish monitoring at the Contra Costa Canal and Mallard Slough in accordance with the approved Annual Study Plan.

e. Annually by October 1 of each year, prepare annual reports summarizing monitoring results for both the Contra Costa Canal and Mallard Slough.

f. Submit monthly invoices. The last monthly invoice for the previous fiscal year shall be submitted not later than November 15 of the new fiscal year. Statements will be sufficiently detailed to enable their evaluation by Reclamation. The invoice shall clearly identify each facility separately with the total amount charged to each facility. The facilities are: (1) Tracy Fish Collection Facility, (2) Contra Costa Canal, and (3) Mallard Slough

AGREEMENT BETWEEN
U.S. BUREAU OF RECLAMATION
AND
THE CALIFORNIA DEPARTMENT OF FISH AND GAME
TO REDUCE AND OFFSET DIRECT FISH LOSSES ASSOCIATED WITH THE
OPERATION OF THE TRACY PUMPING PLANT AND THE
TRACY FISH COLLECTION FACILITY

I. INTRODUCTION

A. The Bureau of Reclamation (Reclamation) constructed and is operating the Tracy Fish Collection Facility (TFCF) to divert and salvage fish that would be otherwise entrained in the Delta-Mendota Canal (DMC) by the Tracy Pumping Plant (TPP). The TFCF has been in operation since 1957. Both the TFCF and the TPP are features of Reclamation's Central Valley Project (CVP) which among other benefits, provides water for irrigation, municipal, and industrial uses. Fish that are salvaged at the TFCF are trucked to points in the Sacramento-San Joaquin Estuary (Delta) beyond the influence of the pumping plants.

B. The California Department of Fish and Game (Fish and Game) is charged with the responsibility by the State of California to manage and protect the fish and wildlife resources in California.

C. Based upon initial studies conducted jointly by the U.S. Fish and Wildlife Service (Service), Fish and Game, and Reclamation, the TFCF was expected to have a salvage efficiency normally exceeding 90 percent. After 30 years of operating experience, Reclamation, and Fish and Game have determined that the TFCF is not experiencing the high salvage efficiencies originally expected and is not meeting currently accepted criteria for efficient salvage, especially for small striped bass during periods of low tides and high water deliveries. Fish which pass through the TFCF and are entrained into the DMC, those lost to predation at the TFCF, as well as those fish lost during handling and trucking operations are termed annual direct losses for the purposes of this Agreement.

D. Reclamation and Fish and Game recognize that fish populations of the Delta, especially striped bass and chinook salmon, have been on the decline for several years. This decline has been influenced by many complex interacting factors including the operation of the CVP facilities. While the complexity of factors makes it difficult to quantify the specific impacts of the CVP on Delta fish populations, it is probable that the annual direct losses at the TFCF have contributed to the observed decline.

E. Reclamation and Fish and Game desire to reduce and offset the annual direct losses of striped bass and chinook salmon associated

b. Primary Bypass Operations - The primary bypasses shall be operated according to the procedures outlined by Mecum, 1977 (Appendix A) and the criteria in Table 1, until other procedures can be developed which are mutually agreeable to both parties to this Agreement. The primary bypasses shall be closed when necessary to maintain proper velocities in the secondary channel.

c. Secondary Channel Velocities - The parties agree that the secondary channel velocities are dependent, to a large degree, on primary channel velocities. Some flexibility in regulating the secondary velocities to the criteria established in Table 1 can be achieved by closing primary bypasses. Reclamation shall attempt to maintain the secondary channel velocities to meet the criteria in Table 1 to the extent feasible as may be permitted by the primary channel velocities and closure of the primary bypasses. Full compliance with Table 1 criteria for secondary channel velocity cannot be assured until resolution of primary channel velocity difficulties as discussed in A.2.a. above.

d. Screened Water System Operation - The operation of the screened water system shall be minimized, consistent with the amount of debris in the secondary channel and the need to keep debris loads in the holding tanks at acceptable levels so that fish will be attracted to the bypasses. The screened water discharge velocity shall not exceed the velocity in the secondary channel unless needed to minimize debris loads in the holding tank, but in no event shall it exceed 1.6 times the holding tank inflow.

e. Secondary Bypass Ratios - The secondary bypass ratios shall be maintained in accordance with the criteria provided in Table 1 and checked once each hour and after any change in pumping operations at the TPP.

f. Table 1 will be modified by mutual agreement to remain consistent with best available operating information.

3. Fish Collection and Holding Tank Flows

The flow of water into the holding tanks shall be adjusted so that the flow into any one tank shall not exceed 10 cubic feet per second. This will be accomplished by using as many holding tanks as are available (excluding the designated counting tank) to gather fish. Fish from several tanks may be consolidated into a single truck by loading them separately from each tank. Until trucks with sufficient capacity to consolidate several tank loads are operational (See 4.a. below) the holding tank flows shall be kept within the specified criteria by controlling the amount of water entering the holding tanks by closing off a primary bypass, or by reducing the flow in the secondary channel.

4. Fish Loading and Transportation

a. Fish Hauling Trucks - The 2 existing fish hauling trucks shall be replaced with 2 trucks each having a capacity of 2000 gallons in Federal fiscal year 1992. Each truck will be designed to accommodate the use of salt, or some other stress reducing agent, be supplied with compressed oxygen for aeration, and meet other Fish and Game requirements as necessary. When these trucks are on line, salt shall be added to all loads as directed by Fish and Game.

b. Frequency of Fish Hauling - Fish hauling shall be scheduled in accordance with the most recent set of fish hauling tables (Appendix B). At no time shall fish remain in the holding tanks for more than 24 hours without prior approval from Fish and Game.

5. Fish Release Sites

The existing fish release sites shall be maintained in good condition permitting their use for offloading fish from fish tank trucks. Other sites shall be obtained for use in case both of the existing sites are not available.

6. Fish Counting, Identification, and Record Keeping

During operation of the TFCF, fish count samples shall be taken by Reclamation every 2 hours and for a time period as may be specified by Fish and Game. Species composition and length counts shall be taken four times a day, at 0100, 0500, 1300, and 1700 when the TFCF is in operation. Monthly and annual reports, as requested by Fish and Game shall be maintained of the numbers, sizes, and kinds of fish salvaged, and of facility operations and water exports.

7. To improve salvage efficiencies at the TFCF when primary approach velocities are excessive or when the TFCF is removed from operation for other than normal maintenance purposes, consideration will be given to reducing the number of pumps in operation at the TPP as long as an equal amount of water can be recovered in a timely manner.

8. Fish and Game will continue to provide oversight of the fish salvage and enumeration aspects of TFCF operations. Reclamation will provide funds for this oversight as appropriate.

9. Reclamation, with input from Fish and Game, shall develop and implement a predator control program at the TFCF to regularly remove and/or control predator fishes in the vicinity of the primary louvers, the primary bypasses and the secondary bypasses and channels.

B. Modification of the TFCF

1. The measures described in this Agreement, at a minimum, provide short-term solutions for reducing and offsetting annual direct losses. Long-term solutions to all the fish salvage problems of the TFCF will require a comprehensive analysis of modifications and options for improving the performance of the TFCF. Such an analysis should consider alternative pumping operations to control approach velocities, predator management, screen-water alternatives, automation of important features, and other modifications which will facilitate salvage operations. Reclamation agrees to initiate such an analysis with an expected completion date of January 1994. If the analysis cannot be completed by January 1994, the parties agree to review accomplishments to date and determine appropriate steps for completion.

Appropriate modifications of the facilities and its operation will be made as soon as feasible after measures are identified.

IV. ANTICIPATED REPLACEMENT OF DIRECT LOSSES

A. Beginning in Federal fiscal year 1993 and for 5 consecutive years through 1997, Reclamation will provide funds annually to Fish and Game to be used for mutually agreed upon programs to offset and replace direct losses of striped bass and chinook salmon resulting from the operation of the TPP. During this 5-year period, a total of $6.51 million will be provided to Fish and Game as described in paragraphs B and C below.

B. For fiscal years 1993 and 1994, funds provided by Reclamation will be limited to $600,000 for each year. Beginning fiscal years 1995 and through 1997, funds provided by Reclamation will be $870,000 annually.

C. Reclamation will provide an additional $2.7 million to Fish and Game in one lump sum by the end of fiscal year 1995, to accelerate mutually agreed upon programs for the replacement and or recovery of striped bass and chinook salmon populations impacted by the TPP.

D. Fish and Game will be responsible for ensuring that programs funded by Reclamation under this Agreement will be implemented in such a manner that they will, to the maximum extent possible, offset and replace the annual direct losses resulting from the export of water at the TPP.

E. Prior to October 1996, Reclamation and Fish and Game shall agree on a second 5-year program, to be implemented during Federal fiscal years 1998-2002, for offsetting and replacing direct fish losses. Funds provided by Reclamation shall be $762,000 per year, plus or minus adjustments based upon:

1. Changes in fish replacement costs since 1991;

2. changes in the effectiveness of fish salvage at TFCF in relation to the effectiveness estimated for 1984-1988 (reference: Fish and Game Exhibit 17, 1987 State Water Resources Control Board, Bay-Delta Hearings);

3. changes in pumping at the TPP in relation to 1984-1988, and;

4. results of any other program that has changed direct losses in relation to 1984-1988.

F. If substantial direct fish losses are still occurring at TFCF in 2002, Reclamation shall meet with Fish and Game to negotiate, in good faith, an amendment that addresses future actions for offsetting and/or replacing annual direct fish losses which shall be in effect by Federal fiscal year 2003.

G. Annually, by January 15, Fish and Game will submit an accomplishment report to Reclamation, for the previous Federal fiscal year, which will identify how the funds provided to Fish and Game, pursuant to this Agreement have been expended, results achieved, and future anticipated activities. Fish and Game and Reclamation will periodically review the direct loss programs to determine if adjustments to the programs are needed.

V. MEASURES TO OFFSET OTHER FISHERY IMPACTS

Until agreement is reached between parties on measures to offset CVP fishery impacts not covered by this Agreement, no additional diversion of CVP water through the Harvey O. Banks Delta Pumping Plant will be made when the total diversion rates exceed those set forth in the U.S. Corps of Engineer,s Public Notice 5820A, amended, dated October 13, 1981, and the capacity of the TPP will not be increased above 4,600 cubic feet per second.

VI. ENDANGERED SPECIES

This Agreement is not intended to satisfy any obligations Reclamation may have pursuant to the Federal Endangered Species Act or the California Endangered Species Act.

VII. IMPLEMENTATION OF THIS AGREEMENT

The amounts shown in item IV. "Anticipated Replacement of Direct Losses" are proposed funding levels. While no fiscal obligation on the part of the Federal Government is created by this Agreement, the programs to be accomplished pursuant to this Agreement will be implemented by subsequent actions and agreements in accordance with applicable Federal law. The subsequent agreements will provide any funding required for implementing the direct loss programs discussed in this Agreement.

VIII. GENERAL PROVISIONS

A. This Agreement shall become effective when signed by the designated representatives for the parties hereto.

B. Amendments to this Agreement may be proposed by either party to this Agreement and shall become effective upon approval by both parties in writing.

APPROVED:

Roger K. Patterson
Regional Director
Mid-Pacific Region
U.S. Bureau of Reclamation
Date: JUL 1 1992

APPROVED:

Boyd Gibbons
Director
Department of Fish and Game

Date: June 25, 1992

TABLE 1 - TRACY FISH COLLECTION FACILITY PREFERRED OPERATIONAL CRITERIA

A. Chinook Salmon Criteria - November 1 - May 14

1. Primary Channel approach velocity ------- 3.0-3.5 feet per second.

2. Primary Bypass ratio -------------------- 1.2:1.0 to 1.6:1.0*

3. Secondary Channel velocity --------------- 3.0-3.5 feet per second.

4. Secondary Bypass ratio ------------------ 1.2:1.0 to 1.6:1.0

B. Striped Bass Criteria - May 15 - October 31

1. Primary Channel approach velocity -------- 1.0 feet per second (preferred)
2.5 feet per second (maximum)

2. Primary Bypass ratio -------------------- 1.2:1.0 to 1.5:1.0*

3. Secondary Channel velocity -------------- 1.0 feet per second (preferred)
2.5 feet per second (maximum)

4. Secondary Bypass ratio ------------------ 1.2:1.0

*All primary bypass valves should be at least half open when in use, to reduce stress on fish

Appendix 8 Section 3406(b)(4) of the Central Valley Project Improvement Act. Fish, Wildlife, Improved Water Management & Conservation

(b) Fish and Wildlife Restoration Activities.—The Secretary, immediately upon the enactment of this title, shall operate the Central Valley Project to meet all obligations under state and federal law, including but not limited to the federal Endangered Species Act, 16 U.S.C. s 1531, et seq., and all decisions of the California State Water Resources Control Board establishing conditions on applicable licenses and permits for the project. The Secretary, in consultation with other State and Federal agencies, Indian tribes, and affected interests, is further authorized and directed to:

> (4) Develop and implement a program to mitigate for fishery impacts associated with operations of the Tracy (Jones) Pumping Plant. Such program shall include, but is not limited to improvement or replacement of the fish screens and fish recovery facilities and practices associated with the Tracy Pumping Plant. Costs associated with this paragraph shall be reimbursed in accordance with the following formula: 37.5 percent shall be reimbursed as main project features, 37.5 percent shall be considered a nonreimbursable Federal expenditure, and 25 percent shall be paid by the State of California. The reimbursable share of funding for this and other facility repairs, improvements, and construction shall be allocated among project water and power users in accordance with existing project cost allocation procedures.

Appendix 9 **Current fish species and codes used at the TFCF**

Code	Species	Code	Species
1	Chinook Salmon	37	Surf Smelt
2	Steelhead	39	Pacific Staghorn Sculpin
3	Striped Bass	40	Riffle Sculpin
4	White Catfish	41	White Crappie
5	Brown Bullhead	42	Pacific Herring
6	Channel Catfish	43	Yellow Perch
7	American Shad	44	Black Bullhead
8	Threadfin Shad	45	Sacramento Perch
9	Sacramento Splittail	46	Tui Chub
10	Sacramento Pikeminnow	47	Silver Salmon
11	Threespine Stickleback	48	Pacific Brook Lamprey
12	Hardhead	49	Redear Sunfish
13	Golden Shiner	50	Sacramento Sucker
14	Common Carp	51	Fathead Minnow
15	Goldfish	52	California Roach
16	Hitch	53	Speckled Dace
17	Sacramento Blackfish	54	Pumpkinseed
18	Black Crappie	55	Blue Catfish
19	Green Sunfish	60	White Bass
20	Warmouth	61	Chameleon Goby
21	Bluegill	62	Pink Salmon
22	Largemouth Bass	63	Freshwater Eel
23	Bigscale Logperch	64	Red Shiner
24	Tule Perch	65	Wakasagi
25	Longfin Smelt	66	Shimofuri Goby
26	Delta Smelt	67	Rainwater Killifish
27	White Sturgeon	68	Northern Pike
28	Green Sturgeon	69	Shokihaze Goby
29	Prickly Sculpin	70	Spotted Bass
30	Yellowfin Goby	71	Large-scaled Loach
31	Inland Silverside	80	Mitten Crab
32	Starry Flounder	90	misc.
33	Lamprey (all spp.)	117	Striped Mullet
34	Western Mosquitofish	158	Pacific Lamprey
35	Yellow Bullhead	208	River Lamprey
36	Smallmouth Bass	256	Redeye Bass

Appendix 10 Summary of operational and structural changes at the TFCF

A. Operational

Event	Year	Comments
1957 Memorandum of Agreement	1957–1959	Two-year monitoring of TFCF by USFWS
1978 SWRCB Decision 1485	1978–recent	Implementation of salmon and Striped Bass criteria affecting water velocities at the TFCF
U.S. Bureau of Reclamation/CDFG Agreements Regarding Fish Salvage Operations at the TFCF	1983–recent	Allowed outside monitoring of TFCF salvage
Direct Loss Mitigation Agreement	1992–recent	Power outages to be reported, predator removal program developed and implemented
Central Valley Project Improvement Act	1992–recent	Replacement of screens using improved fish screen technology
Endangered Species Act	1973–recent	Increased monitoring of federally-listed species
California Endangered Species Act	1984–recent	Increased monitoring of state-listed species
Biological Opinions	1993–recent	Monitoring of Delta Smelt, Chinook Salmon, Steelhead, and Green Sturgeon
2000 SWRCB Decision 1641 (VAMP)	2000–2010	Limited water export in April and May
Fish count duration	1957–1967	No raw data records were located therefore fish count duration is unknown, only fish data summaries/reports were located
Fish count duration*	1968–1993	No standardization of fish count duration(counts varied from 1 to 60 minutes)
Fish count duration	1993–2009	Fish count duration standardized to 10 minutes
Fish count duration	2009–recent	Fish count duration standardized to 30 minutes increasing salvage estimation accuracy and fish detection
Fish species enumeration and identification	1957–1967	Enumeration and identification of fish were tallied mainly from May to October which corresponded with agricultural demands
Fish species enumeration and identification*	1968–1977	Enumeration and identification were done for Striped Bass, salmon, catfish, spiny ray, shad, smelt, and miscellaneous; inconsistencies in fish nomenclature was common, limited counts per day were common
Fish species enumeration and identification	1979–1991	Questionable fish identification
Fish species enumeration and identification	1992–present	Resident biologist(s) at the TFCF, fish identification program initiated, salmonid DNA program, coded wire tag program, larval sampling program, rapid salmon genetics program
Frequency of fish count identification	1957–1967	Inconsistent record keeping
Frequency of fish count identification	1968–1974	12 times per day usually at odd hours
Frequency of fish count identification*	1975–1979	2 times per day
Frequency of fish count identification	1980–1992	2-3 times per day usually at 0500 and 1700, counts outside of these times were done but only the total number of fish were recorded
Frequency of fish count identification	1992–recent	12 times per day at even hours
Salvage data reporting	1957–1959	Fish and operational data were sent to USFWS
Salvage data reporting*	1959–1982	Fish data summary were reported monthly or quarterly via correspondence with CDFW
Salvage data reporting	1983–1992	Fish data were QA/QCed by CDFW
Salvage data reporting	1993–recent	Fish data are initially QA/QCed by TFCF biologists then by CDFW, CDFW distributes data online
Primary louver cleaning	1957–1959	Once a week
Primary louver cleaning	1960s	3 times a week
Primary louver cleaning	1970s, 1980s	No records
Primary louver cleaning	1990–recent	1-3 times per day
Predator removal (primary channel)	1957–2016	No predator removal program
Predator removal (primary channel)	2016–recent	Experimental use of CO_2
Predator removal (bypasses/secondary channel)	1957–1992	No predator removal program
Predator removal (bypasses/secondary channel)	1993–2013	Manual removal of predators using fyke nets, done inconsistently
Predator removal (bypasses/secondary channel)	2014–recent	Predator removal program using CO_2, done monthly

* no fish data collected in 1978

B. Structural

Component	Year Installed	Year Replaced*	Comments
Pilot Fish Screen	1952	1956	Discontinued use
Release site (Brannan Island State Park)	1952	1969	Discontinued use
Release site (Rio Vista)	1952	1969	Discontinued use
Trash rack	1956	1994	Temporarily removed between Feb–Apr 2010
Trash rack cleaner	1956	2010	Trash rack cleaner was replaced with an automated rake system (EIMCO)
Primary louvers (36 panels)	1956	1990	
Primary louver guide rods	1956	1997	
Primary louver cleaner (4-ton gantry)	1956	original	
Bypass transition boxes (4)	1956	2004	
Bypass pipes (4)	1956	original	
Bypass slide gate valves (4)	1956	1996	
Secondary channel louver^	1956	2014	Discontinued and removed
Clean water loop system^	1956	2014	Not used between 1999–2014
Velocity control (VC) pumps (6)	1956	2001–2007	
Holding tank influent 20” knife-gate valves (4)	1956	1996	
Holding tank aeration system	1956	2012+	Original system not functional by 1967 and was removed in the 1990s
Holding tank screens (4)	1956	2001	
Holding tank floor	1956	1997	Epoxy coated
Holding tank baffles (3/tank)	1956	2006–2013	Removed permanently
Holding tank auxiliary pumps (2)	1956	2003, 2006	In 2014, corroded steel pipe was replaced
Dewatering sump pumps (2)	1956	within decade	
Fish count station	1956	2013	
Fish count station screen	1956	1999, 2014	
Fish sampling bucket	1956	original	
Fish haul bucket	1956	2008	
Fish haul truck	1956	2008	
Trash deflector boom	1960	1999	
Trash conveyer	1960	2003	
Release site (Emmaton)	1970	—	
Release site (Antioch)	1975	—	Remodeled in 1982, 2019
Crab removal screen	1999	2014	Discontinued and removed
Secondary channel traveling fish screen (Hydrolox)	2014	—	
Debris sweep arm	?	2003	

* Lists only the year(s) component was most recently replaced or changed. ^ Secondary louvers and clean water loop system screen were replaced with Hydrolox^{TM} screens, + Currently offline.

Appendix 11 Timeline of historical events related to the CVP and the Delta

Year	Event or Change
1902	Congress passed the Reclamation Act of 1902 to fund irrigation projects on arid lands of twenty states, including California, and stipulated that farmers must live on their land and only receive subsidized water for 160 acres.
1915	California State Legislature considered a "State Water Plan" (Marshall Plan) for irrigation.
1929	Snowpack monitoring to forecast water supplies initiated.
1933	State of California passed Central Valley Project Act but was unable to fund it during the Depression.
1935	State transferred Central Valley Project (CVP) to the federal government. The Central Valley Project was authorized by President Franklin D. Roosevelt.
1937	Rivers and Harbors Act prioritized improvement of navigation, regulation, and flood control of the Delta; construction of the first CVP project, the Contra Costa Canal, began.
1938–1945	Shasta Dam was constructed.
1940	Contra Costa Canal completed and was the first CVP unit to use Delta channels to move water.
1940–1949	Friant Dam was constructed.
1942	Westside Landowners Association (now called Westlands Water District) formed to help finance studies of developing an alternative water supply for the west side of the San Joaquin Valley. They contracted with the Bureau of Reclamation, to determine if surface water from the CVP off-stream site at San Luis could reach west side lands.
1945	Location for the Delta Cross Channel (DCC) was chosen.
1946	Reclamation proposed concept of Peripheral Canal by proposing two canals taking water from the Sacramento River and American River, bypassing the Delta, and draining into San Luis Reservoir and Mendota Pool. Reclamation awards first contract for Delta-Mendota Canal (DMC) construction.
1947	Reclamation awarded contract for construction of Tracy Pumping Plant.

1947–1950	USFWS (Erkilla et al. 1950) studied and published findings of the negative effects to the Delta fishery with the TPP operation. USFWS recommended traveling water screens be installed. Erkilla et al. (1950) also recorded “pond smelt” (*Hypomesus olidus*) as one of the most abundant fish in the San Francisco Estuary in 1947–1948.
1947–1951	Tracy Pumping Plant was constructed.
1948–1956	Folsom Dam was constructed on the American River.
1950	Spring-run Chinook Salmon of San Joaquin River became extinct because of Friant Dam.
1950–1951	Construction of the Pilot Fish Screen, developed jointly by Reclamation and USFWS.
1951–1952	Tracy Pumping Plant, DCC, and DMC completed; water delivery of Sacramento River to the San Joaquin Valley using the DMC began.
1952	Owners of 400,000 acres of west side of San Joaquin Valley formed the Westlands Water District, which became the largest agricultural water district in the U.S.
1952–1955	Pilot Fish Screen tested and used as fish screening facility. A prototype-size louver system was tested at the Pilot Fish Screen in 1953. Agreement reached amongst Tracy Fish Screen Advisory Council members for louver installation for the TFCF in 1954. Design and contract for the construction of the TFCF finalized in 1955.
1956–1957	Construction and completion of the TFCF.
1957	TFCF fish salvage operation began (spring); net-fishing of salmon was banned in the Delta.
1957–1959	TFCF efficiency evaluations conducted (Bates et al. 1960).
1960	Trash deflector boom at the front of the TFCF intake installed; voters authorized State Water Project (SWP) through the passage of the Burns-Porter Act formally known as Proposition 1: California Water Resources Development Bond Act.
1961	Delta Smelt was recognized as distinct species from Pond Smelt.
1962	SWP began construction of Oroville Dam on the Feather River.
1963	Construction of SWP’s Harvey O. Banks Pumping Plant began.

1967	CDFW Fall Midwater Trawl sampling program established for Striped Bass and currently the best long-term record of Delta Smelt abundance; San Luis Reservoir completed allowing year-round pumping; Banks Pumping Plant completed; construction of Clifton Court Forebay began.
1968	Oroville Dam was completed; SWP made first delivery of water using Banks Pumping Plant; SWP's Skinner Delta Fish Protective Facility began fish salvage operation off of Italian Slough.
1969	SWP began pumping off of Clifton Court Forebay; 118,000 winter-run Chinook Salmon returned to the upper Sacramento River to spawn (Yoshiyama et al., 1969).
1970s	USFWS's Delta Juvenile Fish Monitoring Program was created to monitor effects of the water projects on the abundance, distribution, and survival of fall run Chinook Salmon in the Delta.
1970	Clifton Court Forebay at the Skinner Delta Fish Protective Facility was put into operation; Four Agency Program was created and was the beginning of the cooperative state and federal interagency program later was named Interagency Ecological Program or IEP.
1971	State Water Resources Control Board issued Delta Water Rights Decision 1379 establishing water quality standards to be met by CVP and SWP.
1972	Striped Bass salvage at TFCF peaked at over 15 million fish; first SWP deliveries to southern California.
1978	State Water Resources Control Board issued Decision 1485 (D 1485), establishing operating criteria for the TFCF; first CWT collected from Chipps Island Mid-Water Trawl Survey.
1979	Measuring fish length as part of fish counts was added to salvage monitoring at the TFCF.
1981	Delta Smelt salvage peaked at over 274,000 at TFCF.
1982	Reclamation Reform Act of 1982 increased allowable acreage for water subsidies from 106 acres to 960 acres; Proposition 9 which included wording on Peripheral Canal was defeated by voters.
1986	Last recorded large Chinook Salmon salvage (>750,000) at TFCF; last Sacramento Perch salvaged at the TFCF; earliest record of Chinook Salmon with CWT collected from the TFCF salvage.

1989	Delta Smelt considered fish species of special concern by CDFW; Winter-run Chinook Salmon designated endangered under CESA; Tracy Fish Facility Improvement Program (TFFIP) was initiated.
1990	Original primary louvers were replaced; Sacramento winter-run Chinook Salmon listed ESA threatened and CESA endangered; petition to list Delta Smelt as threatened species was filed by USFWS.
1991	South Delta Temporary Barriers Project was initiated; 191 winter-run Chinook Salmon were counted at the Red Bluff Diversion Dam.
1992	Section 3406(b)(4) of Central Valley Project Improvement Act was implemented; Direct Fish Loss Mitigation Agreement between Reclamation and CDFG was signed; preliminary analysis of predator removal effects at the TFCF was conducted; Reclamation biologists were stationed at the TFCF; winter-run Chinook Salmon was federally-listed as endangered; fish counts at the TFCF were conducted on the even hour.
1993	Delta Smelt was listed as ESA/CESA threatened; NMFS Biological Opinion was released; TFCF biologists discovered holes in primary louver transition boxes.
1994	CALFED, a federal/State-coordinated program composed of 23 federal and State agencies that have regulatory or management responsibility for some aspect of the Delta, was formed; Sacramento winter-run Chinook Salmon was reclassified as ESA endangered; USFWS declared entire Delta and Suisun Bay as critical habitat for Delta Smelt; initial studies of use of hydroacoustic equipment to detect predators at the trash rack; Liston et al. (1994) published predator removal activity at the TFCF; transition boxes were temporarily repaired.
1995	USFWS Biological Opinion stated that Delta Smelt shall not be held for more than eight hours for the period of December 1 to March 30 whenever the number of Delta Smelt reached 0.5 per count minute; Chameleon Goby at the TFCF was verified as Shimofuri Goby.
1996	Second temporary repair of transition boxes; rearing of Delta Smelt at UC Davis' Fish Conservation and Culture Laboratory commenced.
1997	Chinook Salmon DNA program implemented at the TFCF; salmon race determination using the Delta Model size criteria, a modified version of the Fisher Model, was implemented at the TFCF; Tracy Aquaculture Facility (TAF) was built for holding research fish; winter floods inundated the Sacramento and San Joaquin rivers.
1998	Central Valley Steelhead was listed as ESA threatened; Bowen et al. (1998) published the secondary louver efficiency of the TFCF; a crab cage was

	implemented at the TFCF to remove mitten crabs; Reclamation transferred the operation of the JPP to the San Luis & Delta-Mendota Water Authority.
1999	Traveling crab screen (Crabzilla) installed at the TFCF by Reclamation and SLDMWA; Sacramento River drainage spring-run Chinook Salmon was listed as CESA threatened.
2000	CALFED Bay-Delta Program Record of Decision to improve all Tracy facilities included plans for a fish test facility called the Tracy Fish Test Facility (which was later abandoned) at Tracy, which would have provided data on the effectiveness of screening facilities in the South Delta; VAMP was officially initiated as part of the SWRCB Decision 1641.
2002	Primary louver cleaner-pump implemented and decommissioned; primary transition boxes were patched a third time; NMFS Biological Opinion was released.
2003	Conveyer sweep crane and trash conveyer belt were replaced.
2004	New transition boxes were fabricated and installed; NMFS and USFWS Biological Opinions were released.
2005	Fall Midwater Trawl abundance index for Delta Smelt of 26 was recorded; Wang et al. (2005) published Wakasagi-Delta Smelt identification; Pelagic Organism Decline Group was formed.
2006	Use of CO_2 as secondary channel predator removal alternative was initiated; Bay Delta Conservation Plan (BDCP) initiated; Splittail salvage at the TFCF was > 5 million; Green Sturgeon (southern DPS) was listed as ESA threatened.
2007	Low numbers of Delta Smelt from CDFW survey; court mandate to sample larval smelt at TFCF was received; Sutphin et al. (2007) published comparing current and historic TFCF count screen; Tracy Pumping Plant was renamed C.W. “Bill” Jones Pumping Plant; refuge population of Delta Smelt was cultured and maintained at the FCCL.
2008	New fish transport trucks delivered to TFCF; first season of larval smelt sampling at TFCF; FWS Biological Opinion released; new fish haul bucket for the TFCF; Delta Smelt listed as endangered under CESA.
2009	Thirty-minute fish counts became standard practice; initial testing of Hydrolox™ at the TFCF secondary channel; NMFS Biological Opinion released; Longfin Smelt listed as threatened under CESA.
2010	Trash rack removed from February to April while JPP was pumping water; TransVac (fish vacuum pump) tested at the Technical Service Center in Denver

in March and April; EIMCO Cleaner installed in May; zebra mussel (Dreissena polymorpha) monitoring implemented at the TFCF; change of Delta Smelt federal status to "Endangered" was deemed "*warranted but precluded*" by other higher priority listing actions; lowest salvage of Delta Smelt (< 100) recorded at the TFCF.

2011 Alternative loss calculation for salmonid and Green Sturgeon proposed; coded wire tags (CWT) from Chinook Salmon processed at the TFCF; new Biology Building completed; underwater camera recording of holes in the Antioch release site pipe, dive team hired to patch holes and shorten pipe; use of electricity for primary channel predator removal was tested at the TSC in Denver; TransVac tested at a TFCF holding tank; beginning of long-term State-wide drought; Striped Bass salvage at TFCF at all-time low (< 35,000 fish); Splittail salvage at TFCF at all-time high (> 7 million fish); slight increase in Delta Smelt Fall Midwater Trawl index of 343 because of wet year after six consecutive years of 50 individuals or less.

2012 Pacific Lamprey ammocoetes secondary louver efficiency studied; Intertie completed which linked the Delta-Mendota Canal (DMC) and the California Aqueduct (CA) to improve water supply reliability south of the Delta [DMC to CA: 13 m^3/s (467 cfs); CA to DMC: 25 m^3/s (900 cfs)].

2013 Fish count station revamp; Crabzilla dismantled; replacement of secondary channel louvers with Hydrolox™ began and completed in May 2014, Governor Jerry Brown and the BDCP proposed the construction of two underground tunnels to divert water from the Sacramento River water underneath the Delta and then deliver the water to the Central Valley and Southern California; lowest recorded Fall Midwater Trawl index of 18 for Delta Smelt.

2014 Wu and Bridges (2014a) published on effectiveness of CO_2 for predator removal; lowest recorded index of abundance for Delta Smelt reported by CDFW Fall Midwater Trawl.

2015 An expanded amount of 71 Delta Smelt were salvaged at the TFCF.

2016 CDFW Spring Kodiak Trawl collected only 13 Delta Smelt, resulting in the lowest recorded index of 1.8; no Delta Smelt larvae detected at the TFCF; rapid genetic testing of older salmon juveniles that are winter-run length-at-date was implemented.

2017 Feasibility of using environmental DNA (eDNA) to detect Delta Smelt at the TFCF was initiated; first Large-scaled Loach salvaged at the TFCF during heavy rain.

Appendix 12 TFCF measurements

Location	Description	Metric	Imperial	
Trash rack	Length	32.9 m	108 ft	
	Spacing of bars	5.7 cm	2.25 in.	
	Angle of bars to flow			90°
Primary channel	Length (from trash rack to last bypass opening)	122 m	400 ft	
	Width	25.6 m	84 ft	
	Length of louver system	98 m	322 ft	
	Angle of louver system to flow			15°
	Louver slat spacing	2.54 cm	1 in	
	Angle of louver slat to flow			90°
	Elevation	-4.27 m	-14 ft	
Bypasses	Width of opening	15.2 cm	6 in	
	Length between bypasses	22.9 m	75 ft	
	Width of bypass opening	15.2 cm	6 in	
	Length of transition box	3 m	10 ft	
	Width of bypass pipes	0.91 m	3 ft	
Secondary channel	Length	36.6 m	120 ft	
	Width of channel	2.4 m	8 ft	
	Length of louver system (in tandem; pre-2014)	8.2 m/each	27 ft/each	
	Angle of louver system to flow			15°
	Louver slat spacing	2.54 cm	1 in	
	Angle of louver slat to flow			90°
	Length of Hydrolox™ traveling screen (current)	17 m	56 ft	
	Angle of Hydrolox™ traveling screen to flow			7°
	Hydrolox™ traveling screen opening	1.5 mm x 50 mm slit	0.06 in x 1.97 in slit	
	Elevation	-0.91 m	-3 ft	
Bypass to holding tanks	Width of opening	15.2 cm	6 in	
	Diameter of pipe to holding tank	0.5 m	20 in	
Holding tank	Diameter of tank	6.1 m	20 ft	
	Height of tank	4.7 m	15.5 ft	
	Diameter of holding tank screen	2.4 m	7 ft 10 in	