DRAFT

North of the Delta
Offstream Storage Investigation

Progress Report

Appendix F: Sacramento River Diversion and Its Potential Impacts

June 2000

Integrated
Storage
Investigations

CALFED
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Appendix F: Sacramento River Diversion and Its Potential Impacts

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California Department of Water Resources

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Executive Summary

The Environmental Services Office, Fish Facilities Section, recommends that, for a new diversion to offstream storage in the Sacramento Valley, the Department of Water Resources should pursue an on-river inclined flat-plate screen, at the appropriate diversion size and site. This preferred alternative is technically feasible, protects fish, reduces long-term operations and maintenance relative to other conceptual design alternatives, and meets all National Marine Fisheries Service and Department of Fish and Game criteria for fish screening. The interagency Central Valley Fish Facilities Review Team has also favorably reviewed this alternative, and the design is also consistent with those recently selected for the new, larger, fish facilities in the Sacramento Valley (e.g., Glenn-Colusa Irrigation District, Reclamation District 1004, Reclamation District 108, Princeton-Codora-Glenn Irrigation District/Provident Irrigation District). However, during the OSI design process, current research on a number of critical fish facility issues (e.g., fish exposure time to screens) may change agency fish screening criteria and thinking, which could, in turn, significantly change our facility design. Needless to say, concepts and truths (if any) about effective fish screen design, operations, and maintenance are moving targets and constantly evolving. Further, we note that a 5,000 cfs diversion, if selected, will encounter substantial siting and regulatory obstacles, which DWR should carefully consider before proceeding with construction of such a relatively large fish facility.

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Introduction

The Environmental Services Office's offstream storage investigations related to fish screening began in January 1998. The purpose of our work was to assist Northern District and Central District with fish facility design alternatives and evaluations of the fish impacts from the alternatives. To do so, ESO evaluated alternatives of proposed diversion locations and, based on the location and diversion size, developed conceptual fish screen designs that should be considered in choosing a preferred diversion scenario. Additionally, the alternative designs received informal review from regulating agencies for guidance in identifying possible design flaws or other issues that would eliminate some alternatives. We also compared the conceptual alternative designs with information available from existing fish facilities of similar design and function for fishery impacts, operations and maintenance issues, sediment deposition, facility complexity, and estimated construction costs.

This report primarily provides the information gathered to date on the fish screen alternatives for a new diversion location on the upper Sacramento River. First, we generally discuss fish screen design criteria, current screening issues, and biological impacts of screens to fish. Next, we present our analysis of conceptual design alternatives and diversion sites (originally presented to Northern District in our October 1998 report). We then summarize agency comments on our conceptual design alternatives. Finally, based upon the information gathered from field site visits to existing fish screen diversion facilities, studies of fish screen designs, and agency comments, ESO recommends and develops, with the assistance of the Division of Engineering, a preferred alternative fish screen design to a pre-feasibility level.

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Fish Screen Design Criteria

Legal, Regulatory, Policy

In California, the National Marine Fisheries Service, the U.S. Fish and Wildlife Service, and the California Department of Fish and Game, regulate fish screens in order to reduce fish loss, especially of threatened and endangered species. Both NMFS and DFG have adopted fish screening criteria, on February 24, 1997, and April 14, 1997, respectively. NMFS criteria specifically govern anadromous salmonids, while DFG criteria cover all fish species. The third agency, USFWS, has adopted only one specific criterion.[1]

NMFS implements its criteria under authority granted to it by the federal Endangered Species Act, the Federal Power Act, and the federal Fish and Wildlife Coordination Act. DFG screen criteria have their own independent statutory authority (found in the California Fish and Game Code), which is also often combined with DFG authority under the California Endangered Species Act, California Environmental Quality Act, and Fish and Wildlife Coordination Act. DFG may also require fish screens as part of Federal Energy Regulatory Commission, Army Corps of Engineers, State Water Resources Control Board, and Regional Water Quality Control Board permits. USFWS authority for requiring screens and establishing the criteria the screens must meet is granted by the federal Endangered Species Act, Fish and Wildlife Coordination Act, and Central Valley Project Improvement Act.

Except for screen approach and sweeping velocities, NMFS and DFG criteria are general in nature. Further, implementation of both NMFS and DFG criteria is flexible, in that, on a project-by-project basis, the agencies may permit modifications, waivers, or variances from the standing criteria if the project or site conditions justify. Alternatively, the agencies can also make criteria more stringent on a project-by-project basis. For example, site specific conditions, such as flooding, sediment and debris load, and quality of fish populations, may necessitate that a project meet more restrictive fish screening criteria. However, once established for a particular project, fish screen criteria become legal requirements (for example, as part of a Biological Opinion or a license from the Federal Energy Regulatory Commission).

While fish screen criteria include numeric values for screen approach and sweeping velocities and screen mesh sizes, both NMFS and DFG criteria address a much broader range of fish facility design and operation, including placement of civil works, screen materials, and cleaning and other operations and maintenance issues. The following discussion of NMFS and DFG criteria applies only to streams and rivers in the northern Sacramento Valley. Fish screens located in canals, lakes, reservoirs, and tidal areas (for example, the San Francisco

[1] That is the 0.2 foot per second (fps) screen approach velocity for protection of delta smelt, which is referenced and incorporated into both the DFG and NMFS criteria.

Bay and Sacramento - San Joaquin Delta) are governed by slightly different criteria. In addition, diversions of 40 cubic feet per second or less anywhere are also guided by different criteria.

Velocity

Approach velocity is the vector component of water velocity perpendicular to the screen face and, per NMFS, is measured approximately three inches in front of the screen. For self-cleaning or automatically cleaned screens in streams and rivers, DFG and NMFS call for a uniform approach velocity for fry (less than 60 mm in length) of 0.33 feet per second or less. DFG requires that design be flexible enough to allow for subsequent screen adjustment to achieve uniform velocity. NMFS recommends "adjustable porosity control" downstream of the screens (for example, baffles) for the same reason.

NMFS calls for the sweeping velocity, the velocity parallel to the screen face, to simply be greater than the approach velocity, while DFG calls for a sweeping velocity of at least two times the approach velocity. For sweeping velocity, then, the DFG criterion overrides the NMFS criterion.

Screen Materials

Pursuant to NMFS criteria for fry-sized salmonids, screen openings may not exceed 2.38 mm (3/32 inches) for perforated plate and woven wire screen materials, and 1.75 mm for profile bar (or other slotted openings), with a minimum open area of 27 percent. These same dimensions hold in the DFG criteria for streams and rivers with steelhead rainbow trout. Both NMFS and DFG recommend that screen materials be corrosion and foul resistant.

Civil Works Placement

To cause the least impacts to fish, the diversion location process must first consider all possible elevations and temperature effects in the river. Both NMFS and DFG prefer to keep fish in the river environment, so on-river screens are favored over off-river.[2] In addition, for large (i.e., long) diversions, on-river screens that incorporate resting spots are preferred over those that involve bypasses. The screens should be aligned with the streambank and roughly parallel to flow, with a smooth transition between screen and streambank. Such structural conditions are desirable because they will minimize eddies and stagnant flow that can provide habitat for predators. In general, a design should eliminate any hydraulic condition that could lead to fish delay or injury and/or provide predator habitat. Furthermore, the fish screen structure must be protected from debris or other damage.

NMFS and DFG both require that fish screens have a preventative maintenance program, including cleaning "as frequently as necessary" to ensure

[2] For the offstream storage project specifically, NMFS and DFG have already indicated their preference for an on-river screen

the proper operation of the facility. NMFS adds that the cleaning system must be automatic.

Other Requirements

For NMFS and DFG, designs for fish screens that fall under their jurisdiction (for NMFS, an ESA consultation or a FERC relicensing) must be submitted for approval. Both agencies also require that fish screen design include an operations and maintenance plan. Both DFG and NMFS may require a post-construction facility evaluation, monitoring, and reporting, including ongoing hydraulic monitoring at large facilities (per NMFS).

Both agencies entertain variance requests from their respective criteria.

Current Screening Issues

Before DWR builds any new diversion facility, we will need to address many fish screening issues. The following is a list of current screening issues that relate to the fish facility portion of the North of Delta Offstream Storage Investigation.

Fish Bypasses

For off-river fish facilities, the fish screens end in a fish bypass, which returns the fish to the river, downstream of the diversion intake. Long on-river screens may also require intermediate fish bypasses to prevent excessive fish exposure time to the screen. The regulating agencies (DFG, NMFS) discourage fish bypasses in fish screen designs, because they prefer that fish be kept in the river if possible. Thus, on-river fish screens without bypasses need to be evaluated first. If it is determined that on-river screens are not feasible, then off-river screens with bypasses can be investigated.

Exposure Time

The amount of exposure time that a fish endures when passing a fish screen is equal to the length of the screen divided by the water velocity. For example, if the water velocity is 2 ft/sec and the screen is 120 feet long, then the exposure time is 60 seconds, assuming the fish move at the water velocity. For in-canal (off-river) screens, the regulating agencies prefer an exposure time of 60 seconds or less. For screens built on riverbanks with no bypasses and satisfactory river conditions, exceptions can be made. Also, if multiple, on-river, flat-plate screens are used, the distance between the screens should be at least twice the length of one screen so that fish have time to recover before encountering the next screen.

Fish Lifts

Fish lifts are used to lift fish and water from the river or in a fish bypass system. Fish lifts could be used at the entrance to the Tehama-Colusa Canal in Red Bluff to lift fish and water from the river into the drum screen forebay, which would allow the use of existing screens and fish bypasses. In a bypass system, the fish lifts elevate the fish so they can return by gravity to the river below the diversion intake. Consequently, velocities in the bypass lines will be greater than if the bypass flowed by gravity only. The NMFS requires bypass velocities to be greater than 2.0 fps.

Baffles

Adjustable flow control baffles are placed behind the screen to control and better distribute the flow, thereby helping to provide consistent approach velocities across the screen face. If baffles are not used, high velocity “hot” spots can occur, possibly impinging fish on the screen face. Baffles should be placed close enough behind the screen to affect a small portion of the screen panel. If baffles are too far away from the back of the screen face, they will tend to affect the entire screen panel, not just a small portion of the panel. Also, baffle controls should be readily accessible above the water surface and individually controllable.

Flow Control

As opposed to velocity control with baffles, the regulatory agencies also need assurance that actual diversion flow will be at or less than the screen design flow. Consequently, every diversion facility should incorporate flow control, whether it is gates, weirs, valves, or pumps. If flow cannot be controlled, then regulatory screening criteria may be exceeded, possibly impinging fish on the screen.

Screen Cleaning

Screen cleaning, whether brush, airburst, or waterburst, is one of the most important components of a fish facility. Regulatory criteria state that screens must be cleaned as frequently as necessary to prevent flow impedance. A cleaning cycle once every five minutes meets this standard. When a fish screen collects debris, the total available screen area is reduced, increasing the approach velocity above the accepted criteria and possibly impinging fish. If debris loading without cleaning continues, screen damage could occur if the water surface differential between the front and the back of the screen becomes too large.

Sediment

In Northern California, sediment is a major problem due to high river velocities. High velocities in the river suspend sediment, which is deposited throughout a fish facility, especially in front of and just behind the screen. If not removed, sediment can accumulate and reduce available screen area. Therefore, all fish screening facilities should be designed and built with provisions for sediment removal.

Trash Boom and Trash Racks

Large floating objects, such as trees, can damage a fish screen and its cleaning system. Therefore, trash booms and racks must be considered. Where applicable, a floating trash boom or piles should be placed in the water in front of the facility to deflect any large floating objects away from the facility. A trash rack should be placed across the intake to stop any objects that avoid the trash boom or piles (the last line of defense for a fish screen).

Structural Integrity and Flood Protection

The facility structure should be built to withstand high flows and debris loads. As mentioned earlier, if screen cleaning fails and debris collects on the fish screen, a water surface elevation differential between the front and back of the screen will develop. An alarm system should be in place to warn of such an emergency, but if the alarm fails also, the structure needs to be strong enough to handle this increase in load. Blowout panels above the screen or in a non-screened bay can be installed to open, or a switch can turn off the pump, if the load gets too great.

Undesirable Hydraulic Effects

NMFS criteria state that the civil works design shall attempt to eliminate undesirable hydraulic effects, such as eddies or stagnant flow zones, that may delay or injure fish or provide predator opportunities. The criteria add that upstream training walls or other structures shall be used to control hydraulic conditions and define the angle of flow to the screen face. Large facilities may require hydraulic monitoring to identify and correct areas of concern.

Isolated Bays

To increase reliability and facilitate maintenance, fish screening facilities should have isolated bays. For instance, a 1,000 cfs diversion could have five bays at 200 cfs each, so that if a tree damages a screen panel or a pump fails, that bay can be taken out of service and the other bays can continue to operate. This applies to both on-river and off-river diversions.

Access

All fish facility components should be readily accessible for maintenance or repair.

Maintenance

Maintenance is the single most critical aspect of an installed fish facility. Screen cleaners, pumps, valves, and gates are all mechanical systems that need care to function properly. Screen removal and cleaning, trash boom and rack cleaning, and sediment removal must be performed on a regular basis. Brush screen cleaners need to be checked for wear and proper orientation and contact pressure to the screen. The nozzles used in water backwash screen cleaners must be monitored for erosion. Air and water backwash systems need to be checked for leaks that lower pressure and, therefore, cleaning ability. Trash booms and racks need to be inspected for debris loads. Most importantly, each facility must have and follow an operations and maintenance plan.

Corrosion and Fouling

DFG criteria recommend that stainless steel or other corrosion-resistant material be used for screens to reduce clogging due to corrosion. Active and passive corrosion protection systems can also be considered. In addition, strong consideration should be given to the use of anti-fouling materials to reduce biological growth. Initial costs for corrosion and anti-fouling materials could save many future maintenance dollars.

River Flows and Stages

An adequate area of screen must be submerged to meet regulatory screening criteria. Historical flows and stages must be studied so that the fish screen is placed at the proper elevation. Improper placement of the fish screen could result in not enough submerged screen available and approach velocity criteria exceedence.

New Diversion Location

Finding a good place on the river is a key component to building a functional fish facility. If a bad location is chosen, sweeping velocities may not be adequate, sediment deposition may occur, or the river may change course and leave the facility in the dry. A good location for a fish facility is one that is in the non-meandering portion of the river, has deep, fast water, and is not an area in which fish congregate.

Biological Impacts of Fish Screen Alternatives

Potential Impacts of Screened Diversion Facilities on Fish

Protection Criteria

As stated previously, fish protection from water diversion facilities falls under the jurisdiction and regulation of the California Department of Fish and Game and the National Marine Fisheries Service and in some instances U.S. Fish and Wildlife Service. NMFS fish screen criteria identify that the three main causes of delay, injury, and loss of fish at water diversion intakes are entrainment, impingement, and predation. Entrainment occurs when a fish swims or is drawn into a diversion. Impingement is defined as a fish contacting a screen, a trashrack, or debris at the intake of the diversion with their entire body for more than five minutes (Kavvas et al. 1998). Predation losses are related to facility designs that create predator holding areas or hydraulic conditions that are stressful to bypassed juvenile fish, thus increasing their exposure or susceptibility to predators.

The swimming ability of fish is a primary consideration in designing a fish screen facility and depends upon multiple factors, including species, physiology, environmental conditions, and biological interactions. Factors influencing a specific fish's swimming ability include the following: genetics, physiological development (life stage, growth), behavioral characteristics, physical condition (health, reproductive maturity, injuries), endurance, water quality, temperature, light levels, and water velocities. Because the swimming ability of any fish species is variable and influenced by complex interactions with its environment, screen criteria are applied conservatively.

Screens

Injuries

Contact of fish with diversion structures can cause bruising, descaling, and other injuries. Impingement is perceived as the greatest source of potential physical damage to fish. Impingement, if prolonged, repeated, or caused by high intake (approach) velocities, can cause direct mortality for some species and life stages.

Swimming Fatigue and Exposure Times

Injuries to fish can occur if exposure times to an intake screen are extended in combination with conditions requiring constant swimming at or near a fish's maximum ability. As exposure time to diversion facilities increases, the chances also increase for injuries or mortality, as well as fatigue. When fish become fatigued, thier loss of swimming ability increases the chance for contacts with screens or other facility structures, leading to possible injuries and impingement. As swimming ability is impaired, the fish's ability to escape predators is also compromised.

Predation

Fish near diversion intakes may have a greater susceptibility to predation. Fish screen structures can provide hiding places for larger predators to prey on smaller fish either passing a screen or entering or exiting bypasses. Small or juvenile fish may be more susceptible to predation when they are disoriented from turbulent flow near the bypass exit or fatigued from swimming at the limits of their ability for long periods. If juvenile fish are injured from screen or bypass contacts, they will also be susceptible to predation.

Entrainment

Entrainment of fish through a screened diversion (built to meet current screen criteria) is unlikely for most juvenile fish larger than 20 mm total length (depending on body morphology). For screened diversions located where steelhead fry are present, current criteria for screen mesh size is set at 1.75 mm. This protects very small fish from entrainment through the screen. However, entrainment potential increases if the screens are not sealed well against the structure or if there are holes that a fish can pass through. To eliminate or reduce the chance of entrainment, all screens must be inspected for complete seals and gaps larger than the screen mesh size.

Bypass Systems

NMFS criteria define bypass systems as channels that transport juvenile fish from the face of a screen to a relatively safe location in the main migratory route of the river or stream. Juvenile bypass systems are necessary for screens located in canals because anadromous fish must be returned to their main migratory route. Depending on the screen configuration and location, NMFS may not require bypasses if other configurations provide higher degrees of fish protection (NMFS 1997). DFG criteria are not specific to bypass design; however, the agency reserves the right to include supplemental criteria and to grant variances that are at least as protective of fish as existing criteria.

Screens and bypasses are required to work in unison hydraulically to move fish to the bypass outfall with minimum injury or delay. Flows should gradually increase leading into the bypass entrance. Flow in the conduit needs to be at atmospheric pressures, at least 2.0 fps velocity or greater (with no free falls or hydraulic jumps), and have a minimum depth of 9 inches. Bypass pipes should have smooth interior surfaces and be no less than 24 inches in diameter without valves, extreme bends, or pumps. Bypass outfalls should enter ambient river velocities of greater than 4.0 fps, with sufficient depths depending on flows and velocity of river and bypass, to avoid injuring fish. Bypass exit impact velocities should not exceed 25 fps, and the discharges should not create adult salmon attraction or jumping injuries (NMFS 1997).

Injuries

Injuries to fish entering and exiting bypass systems include descaling, fin erosion, bruising, eye hemorrhaging, or internal injuries. Bypass systems that are not internally smooth or that create adverse hydraulic conditions for fish passage have the potential for delaying or injuring fish due to disorientation, startling, and fatigue, resulting in increased contact with structures.

Swimming Fatigue and Exposure Time

Fish that have passed into bypass systems have either entered on their own or been carried there by currents that are beyond the fish's swimming ability. If a fish has to work at maximum effort to try to maintain itself in strong currents, it will experience fatigue more quickly than in slower, calmer water. High velocities in a bypass help to pass a fish away from screens and diversions quickly; however, the bypass needs to be fairly short to reduce the efforts of the fish and its exposure to stressful flow conditions. Stressed or fatigued fish are more susceptible to predation and can show latent effects of stress in reduced health, reduced growth rates, and overall reduced survival.

Predation

Entrainment of fish into bypasses may subject fish to predators either near the intake or near the outfall of bypass conduits. Hydraulic conditions at the bypass entrance and outfall determine how well juvenile fish can maintain their orientation, the amount of effort expended through the bypass, and the amount of energy left to avoid predators, seek refuge, and continue downstream passage. Proper bypass design reduces predator accumulation at entrances or outfalls; however, predators will take advantage of structure or flow conditions that favor their ability to hold in higher velocities and provide opportunity for feeding.

Impact Evaluations

Monitoring Requirements

Under NMFS criteria, new fish screen facility construction will be required to have biological and hydraulic evaluations to verify that design and protection objectives are met. Monitoring requirements are discretionary in DFG screen criteria. For any variance to current agency screen criteria, evaluation and monitoring may be required to ensure the variance still meets protection objectives. For many current fish screen projects, NMFS, DFG, and USFWS are requiring project proponents to develop and implement evaluation and monitoring plans for fish screens. The agencies require proponents to establish the success of the facility at meeting screen criteria and protection levels. The information gathered also enables agencies and proponents to determine if any modifications are required to meet criteria and protection goals. In addition, agencies are requiring operations and maintenance plans and their implementation. This requirement ensures the screen and appurtenant facilities are operated and maintained at optimum operational conditions for the life of the facility.

Monitoring Programs at Existing Screens

Monitoring and evaluation programs are currently being implemented at many new or retrofitted diversion points along the Sacramento River. These programs will be or are collecting hydraulic and biological measurements to determine the ability of the facility to meet criteria under expected operation conditions.

GCID Fish Screen Improvement Project

The Glenn-Colusa Irrigation District has expanded its screening facility to meet diversion and fish protection needs. The facility is designed to divert nearly 3,000 cfs under maximum diversion demands. Evaluation plans for the facility are detailed in a *Guidance Manual for the GCID Fish Screen Improvement Program* (Montgomery Watson 1998).

Hydraulic Measurements

The purpose of hydraulic testing is to calibrate and adjust the flow control mechanisms to optimize hydraulic operation of the facility and to record the optimum hydraulic performance of the facility and compare it to model data and design criteria. For the fish screen, measurements will include intake channel velocities, screen approach and sweeping velocities, and evaluation of screen cleaning performance. Internal fish screen bypasses, the water control structure that regulates flow in the bypass channel, and the bypass channel hydraulics will also be checked for design criteria velocities and operation during diversion pumping.

Biological Tests

Testing the fish screen for biological impacts will include evaluating fish entrainment, overall fish survival, fish survival in front of screens, survival through the water control structure and in the downstream bypass channel, and fish survival in the internal screen bypass conduits.

These tests, when completed, will provide valuable information regarding impacts to fish of large flat-plate screen diversion facilities with bypasses. The information will provide guidance to design considerations for other large diversions (3,000+ cfs) that might be considered on the Sacramento River.

Screen Impacts Research and Evaluation for Alternative Screen Designs for Offstream Storage

Off-River "V" Screen Designs

The "V" or wedge screen design is a popular fish screen design for larger diversion facilities. The design includes a pair of vertical flat-plate screens angling towards an apex entrance to bypass conduits that return entrained fish below the diversion facility. This style of fish screen is common in the Pacific Northwest.

For example, the White River Project, a fish screen facility constructed by Puget Sound Power and Light Company, consists of angled flat-plate screens. Each flat-plate screen (each side on the "V" configuration) is approximately 160 feet long by 17 feet high. The entrance of the bypass at the apex of the screens has secondary vertical plate screens (4 feet high, 9 feet long), that further reduce the volume of water and help guide fish into the bypass. The screen design flow is between 2,000 cfs and 20 cfs, with 0.4 fps approach velocity and 2.0 fps sweeping flow past 2 mm wedge wire screen. These design criteria was based on protecting pink salmon fry.

Similar facilities have been installed at a variety of other sites in the Pacific Northwest, but many of these facilities have not been subjected to biological evaluations (or evaluation data are unavailable). Most of the screen facilities have been designed to meet the resources agencies' criteria protective of juvenile salmonids, targeting an effective protection goal of 100 percent survival.

On-River Modular Inclined Screen (MIS)

High-velocity screening systems, with water velocities ranging from 5 to 10 fps, are beginning to gain acceptance from regulators on the East Coast and in the Pacific Northwest. The primary advantage of high-velocity systems is their small size (they require only 10-20 percent of the screen area of low-velocity systems), which helps reduce their cost to about half that of low-velocity systems. Also, because the water is flowing more swiftly, passing fish are not as vulnerable to predators as they can be in low-velocity screening systems. High-velocity screens are typically installed on an incline, with a pivot supporting the center (as in a seesaw). The fish are guided over the screen and into a bypass system (EPRI 1994). Accumulated debris can be washed away by simply pivoting the screen so that the debris is forced toward the downstream side.

One high-velocity screen that has been successfully demonstrated (the Eicher penstock screen) is designed for installation inside a penstock of an on-river power generating facility. Electric Power Research Institute sponsored studies over the past decade that have contributed to the refinement of the Eicher screen, and efficiencies for fish diversion now typically surpass 99 percent. For instance, a power company in Canada has employed the Eicher penstock screen with great success, saving $4.4 million over the cost of a low-velocity screening system. Regulatory agencies in Canada and the United States have accepted the technology for certain hydro plants (Amaral 1998). Biological evaluations of the Puntledge Eicher Screen facility in British Columbia in 1993 and 1994 showed a bypass efficiency of 99 percent for coho and chinook salmon smolts. Bypass efficiencies for steelhead, sockeye, and chum salmon fry were 100 percent, 96 percent, and 96 percent, respectively. The screens have also proven to be very reliable, requiring little maintenance (Amaral 1998).

A variation in design and application of an angled, high velocity screen, called the Modular Inclined Screen has been developed and tested by EPRI and others (EPRI 1994, 1996; ARL and SWEC 1996). The design is a shallowly angled (10 to 20 degrees), tilting screen completely encased as an individual unit or "module." The MIS screen's modularity enables it to be used at any type of water intake. It is designed to operate at relatively high sweeping water velocities across the screen ranging from 2 to 10 fps. Biological tests in laboratory settings conducted on a number of different species, including chinook and coho salmon, American shad, and rainbow trout, showed exceptional passage rates of 99 percent at velocities up to 8 fps. Latent mortality of these fish following testing was 0 percent to 5 percent. Field application of a full scale MIS was conducted at Green Island Hydroelectric Project on the Hudson River in New York and had similar results to the lab studies. Rainbow trout showed diversion and survival rates of 100 percent under most test conditions (Amaral 1998). Improvements to the system's hydraulics have provided a more uniform flow over the entire screen surface than with other screens, such as the Eicher, which reduces the likelihood of fish injuries due to screen contact.

On-River Archimedes and Centrifugal-helical Lift Pumps

The Red Bluff Research Pumping Plant, completed in 1995, is evaluating the use of Archimedes lift and centrifugal-helical lift pumps for diverting water and passing fish into screen facilities and returning them to the river via a bypass. Initial trials with both lift-pumps showed promising fish survival for multiple species including juvenile chinook salmon. A total of 2,281 fish of 20 species entrained from the Sacramento River during 1995 and 1996 evaluations of the pumps (29, 24-hour trials) showed 96.2 percent survival (47.9 percent of test fish were chinook salmon juveniles). Survival of juvenile chinook salmon subjected to the Archimedes pump, screens, and bypass facilities was very high. Experimental trials (n = 119) with 3,805 hatchery-reared salmon had >99 percent survival of recovered fish and very low injury rates from the pumps or bypasses (Liston et al. 1997).

Bypass Systems

Tehama-Colusa Canal Rotary Drum Screen Bypass Research

The Tehama-Colusa Canal facility was constructed in 1964 with louver fish screens and bypasses. Studies of the facility conducted in 1982 (Vogel et al. 1988; Vogel 1989) resulted in the replacement of ineffective fish louvers and bypass at the Tehama-Colusa Canal with rotary fish screens and a new bypass facility in 1990. Testing of the fish bypass system in 1994 included 58 groups of juvenile chinook salmon distributed between four bypass conduits to assess injury rates and survival associated with individual bypass conduits (USFWS 1997). No direct mortality occurred in recaptured treatment (n = 5,253) fish released directly into the bypass entrances and control (n = 6,080) fish released and recaptured at the bypass outfall. Survival was high three days after treatment (99.4 percent, n = 5,244), with no significant difference in survival between treatment and control groups. After seven days, survival was greater than 90 percent for control (91.8 percent) and treatment fish (92.8 percent). Injury rates (descaling, frayed fins, hemorrhaging) were also low with no significant difference in injury levels between control and treatment groups (P > 0.05). In comparison, the previous bypass design had an associated mortality rate to juvenile chinook salmon estimated at 1.6 percent to 4.1 percent mortality (Vogel et al. 1988).

In all, the Tehama-Colusa evaluations showed that bypasses up to 500 m (1,500 feet) long can pass juvenile fish with negligible losses and injuries. However, regulatory agencies in California still prefer facilities that do not create a need to separate fish from diverted water and send them through bypasses.

Current Screen Impacts Research

UC Davis Fish Treadmill Investigations (Kavvas et al. 1998; Cech et al. 1999)

Excerpted from *Advances in Fish Passage Technology*, edited by Mufeed Odeh, PhD., P.E. (in progress)

Collaborative research by the University of California, Davis, the California Department of Water Resources, and the California Department of Fish and Game using the Fish Treadmill is in its second year. The Fish Treadmill is a unique and versatile annular flume designed to simulate a large, positive barrier, screened diversion and to allow detailed, quantitative observations of fish behavior exposed to controlled, realistic, two-vector flows near a fish screen for prolonged periods. The Fish Treadmill project was designed to produce results applicable to determine optimal approach velocities for fish protection and water diversion, optimal sweeping velocities that maximize fish protection and screen passage, screen passage velocities and maximum allowable screen exposure durations, and the effects of season (i.e., temperature, fish size) and time of day (i.e., day vs. night) on fish performance and behavior near fish screens to develop adaptive management strategies for screened water diversions.

As of May 1999, more than 250 experiments with juvenile and adult delta smelt (*Hypomesus transpacificus*, a federally and state listed species under the ESA), young-of-the-year splittail (*Pogonichthys macrolepidotus*, a federally listed species under the ESA), and hatchery source fall-run chinook salmon (*Oncorhynchus tshawytscha,* California Central Valley winter-run state and federally listed endangered, spring-run state listed threatened) parr and smolts have been completed. For each of these species, experiments have been conducted at ten different approach and sweeping flow combinations, two seasonal temperatures (12° C in winter and spring, and 19° C in summer and fall), and under lighted (day) conditions and dark (night) conditions. We observed and videotaped fish using infrared sensitive equipment in all experiments, including night/dark; a comprehensive suite of biological responses were measured during and after the exposure period.

Preliminary analyses of data already demonstrate the effectiveness and potential of this experimental approach for providing information useful to develop and refine screen design, flow, and operational criteria. There are clear differences in the performance and responses of the different species and, within species, significant effects of life history stage and environmental conditions (temperature and light level). This suggests that a single criterion (for example, a specific approach and sweeping flow requirement) probably will not benefit all species equally nor be equally protective during different seasons or times of day.

At least for these California fish, adaptive management of screened water diversions based on species presence and environmental conditions may be required to meet protection goals.

Some of these preliminary results have been published in technical reports to the California Department of Water Resources and presented at several technical and scientific meetings (including the International Congress on the Biology of Fishes in 1998, and the annual meetings of the California-Nevada Chapter of the American Fisheries Society and the AAAS, in 1999). Several journal articles are being prepared. Some examples of preliminary results are outlined below.

For all species tested so far, there were dramatic differences in performance and behavior between the day and night experiments. At night, screen contact rates (temporary contact with the fish screen) were often ten times higher than during the day at the same flow. During the day, most fish exhibited rheotaxis, swimming either upstream or downstream relative to the sweeping flow. Thus, contrary to common assumption, screen passage velocities were not equal to sweeping velocity but instead were dependent on fish swimming behavior (rheotaxis and swimming velocity). At night, rheotactic behavior and swimming velocities were reduced and screen passage velocities were similar to the sweeping velocity.

For most species, injury rates (for example, scale loss, fin and eye damage) were positively related either to screen contact rates or flow velocities (particularly sweeping velocity) or both.

Potential Impacts Analysis of Alternatives

Analysis Approach

If an offstream storage design proceeds further, analysis of the potential impacts of each proposed alternative screen design could be based on modeling data of alternative diversion operations, including daily, seasonal, and annual diversion periods, volume of diversion, water year type, and expected or predicted environmental conditions. Seasonal migration timing of juvenile fish of concern (fall-, late fall-, winter-, and spring-run chinook salmon, steelhead trout, American shad, splittail, striped bass, sturgeon), and run size estimates in the vicinity of proposed diversions should also be compared against the possible diversion operation scenarios. Research results on screen impact evaluations could then be used to estimate or predict the possible impacts (losses) to fish species for which there are comparable data. Biological impact evaluations data, from screen facilities similar in design to the proposed screen alternatives, provide a measure of possible fish losses at proposed screen diversion facilities on the Sacramento River.

Fish Screen Conceptual Design Alternatives

Off-River Design

Folded "V" Screens

The folded "V" screen option (Attachment B, Figures 2 and 3) is similar to an alternative considered in 1995 as part of the GCID fish screen improvement project. Cost estimates for this design option are based on the GCID folded "V" estimates.

Issues to be addressed for off-river diversion facilities designs include the following: length of bypass; gravity run or pump-assisted bypasses; bypass outfall, design, and location; debris handling facilities; screen cleaning; water level or stage control structures; flood protection; sedimentation rates and sediment removal facilities; and other specifics that may develop based on site conditions.

General conceptual design features include the following:

- Individual "V" bays with a capacity of 1,000 cfs each
- Fish screen with dimensions of approximately 125 feet long x 12 feet high per side of each "V" bay
- Fish bypass pipes return downstream
- Fish bypass lifts or pumps
- Gated structure at intake to protect facility from floodflows
- Floating debris boom at intake
- Trash rack with cleaner
- Brush fish screen cleaning system
- Sediment removal system

General conceptual design attributes include the following:

- Bays individually isolated for dewatering capability (repairs and maintenance).

Advantages: The fish screens are off the river, which reduces the chance of damage to the screens by debris during high river flows and isolates the facility from the river during floodflows. The screens are arranged compactly; therefore the intake uses only a small area of the riverbank. There is operational flexibility with multiple bays. Sediment deposition can occur before it reaches the screens.

Disadvantages: The fish are removed from the river, requiring fish bypass or handling facilities, which increase the biological impacts and costs associated with these facilities. Bypass and handling stress on fish may increase susceptibility to predation; also, the associated structures of the bypass outfall and screen abutment bays provide potential predator cover. The facility has no water surface elevation control; therefore, the screen structure and levees would have to be built to handle very high water surface elevations.

On-River Designs

The options that are being evaluated for installation on-river include the following.

Inclined Flat-plate Screens

The inclined flat-plate screen option (Attachment B, Figures 4 and 5) incorporates individual 1,000 cfs units that can be combined to yield from 2,000 to 5,000 cfs. Examples of this design are currently being constructed at Princeton-Codora-Glenn Irrigation District/Provident Irrigation District and Reclamation District 1004 (RD1004).

General conceptual design features per 1,000 cfs unit include the following:

- Fish screen with dimensions of 135 feet long x 30 feet high
- Five separate bays of 200 cfs each
- Airburst cleaning system
- Sediment removal system
- Gated flow control behind screens
- Two 100 cfs pumps at the terminus of each bay
- Common sediment settling basin

General conceptual design attributes include the following:

- Minimum spacing between 1,000 cfs screen intakes of no less than twice the screen length (approximately 275 feet) as a rough guideline from regulating agencies (NMFS, CDFG)
- Individually isolated screens and pumps to facilitate regular maintenance
- The screen is always submerged; pump-controlled hydraulics at screens under all flows

Advantages: The inclined flat-plate screen eliminates the need for fish bypass or handling facilities, thereby lowering fishery impacts and long-term operation and maintenance costs. It has operational flexibility due to the individual 1,000 cfs units. Debris handling is minimized and possible fish screen damage from debris is reduced by having the entire screen submerged. Gated flow control behind the screens can be closed to protect the facility from river floodflows. The pump wet well can handle all ranges of flows; therefore, the facility can operate at high and low flow river conditions. Facility capital costs could be lower due to the elimination of structures associated with fish bypasses. The on-river inclined flat-plate screen design is already accepted by regulating agencies and is under construction at major Sacramento River diversions.

Disadvantages: Under a low flow condition, sweeping velocities along the screen surface could be dramatically reduced. The facility, divided into 1,000 cfs units, uses a relatively long section of the riverbank. Sediment deposition in front of and behind the screen could also be a problem, especially during high river flow conditions (an automated sediment removal system would be beneficial).

Archimedes Screw Lifts or Internal Helical Pumps with Folded "V" Screens Downstream of Lifts/Pumps

Conceptual design plans for this option (Attachment B, Figures 6 and 7) are based upon the U.S. Bureau of Reclamation's ongoing work at the Red Bluff Research Pumping Plant. These studies and evaluations of large (100 cfs) Archimedes screw lifts and internal helical pumps will determine feasibility and long-term costs and impacts to fish related to these pumps and their associated handling and bypass facilities.

General conceptual design features include the following:

- 100 cfs capacity Archimedes screw lifts (10 feet diameter x 38 feet long) or 100 cfs internal helical pumps
- Trash rack with cleaner
- Gate at intake to protect facility from flood flows
- One fish screen bay per 1,000 cfs
- Fish screens with dimensions of approximately 125 feet long x 12 feet high per side of each bay
- Brush fish screen cleaning system
- Fish bypass pipes return downstream
- Sediment removal system

General conceptual design attributes include the following:

- Lift or pump and fish screen bays can be individually isolated for dewatering capability (repairs and maintenance).

Advantages: The facility can be isolated from the river during flood-flows by isolation gates. The fish screens are not directly on the river, which reduces the chance of damage to the screens from debris during high river flows. There is operational flexibility due to the individual 100 cfs units. The existing 3,000 cfs capacity drum fish screens at the Tehama-Colusa Canal intake can be used, resulting in a cost savings.

Disadvantages: The fish are removed from the river, requiring fish bypass or handling facilities, which increase the biological impacts and costs associated with these facilities. The large size of the Archimedes screw lifts and internal helical pumps could result in more mechanical problems compared to pumps that do not have to pass fish. There may be problems associated with pump structures, bypass system, and outfall structures creating predator holding areas. *Fish lifts and pumps are not currently accepted by the regulating agencies.*

Modular Inclined Screens

Modular inclined screens (Attachment B, Figures 8 and 9) are patterned after Eicher penstock screens that are used at hydroelectric facilities in the United States. The MIS is a more recent concept design that was studied using models and scaled prototypes. A one-half scale prototype was investigated at Niagara Mohawk's Green Island Hydroelectric Project on the Hudson River in New York. EPRI studies on fish impacts of the MIS showed promising results from tests. For example, all fish that passed through the MIS facility showed low mortality and injury rates for bypassed juveniles and adults of a variety of species. However, the MIS is a unique screen design that was tested with greater approach velocities than current DFG and NMFS California screen criteria approach velocities; both NMFS and DFG consider the MIS an experimental technology.

General conceptual design features include the following:

- Bays with a capacity of 100 cfs
- Fish screen with dimensions of approximately 12 feet wide x 30 feet long at 0.33 fps approach velocity
- Fish bypass pipes return downstream
- Fish bypass lifts or pumps
- Sediment removal system
- Trash rack with cleaner
- Gates before and after screen

General conceptual design attributes include the following:

- Always submerged and hydraulically controllable under all river flows by pumps
- Bays individually isolated for dewatering (repairs and maintenance)
- No structure necessary at intake to control water surface elevation in front of the screens

Advantages: The facility can be isolated from the river during floodflows by gates. The fish screens are not directly on the river, which reduces the chance of debris damaging the screens during high river flows. Individual 100 cfs units provide operational flexibility. The MIS can be operated at higher approach and sweeping velocities with little or no survival impact to fish based on lab and field evaluations.

Disadvantages: The fish are removed from the river, requiring fish bypass or handling facilities, which increase the costs associated with these facilities. Sediment deposition could also be a problem, especially during high river flow conditions (an automated sediment removal system would be beneficial). As with other screen facilities that require bypasses, the associated structures could create predator holding areas and may increase potential predation losses of bypassed fish. *The MIS design is not currently accepted by the regulating agencies.*

Additional information on construction and size requirements of an MIS screen facility is still required to refine the design and narrow cost estimates. Questions remain on the size of individual screen modules: can multiple screen modules be operated by one pump or does each module require its own pump for best operation and flow control? Also, if more than one screen module can be operated by one pump, what number of screen modules per pump unit is optimal, and is flow control adequate through multiple modules when operated by a single pump?

As stated earlier, fishery impact analysis of the MIS facility option is based on the studies conducted by EPRI and additional information gathered from communications with researchers involved with those studies. Results of the EPRI studies showed high survival (99 percent) of juvenile fish species in lab and field tests and low injury rates for fish up to 50 mm (chinook, coho, and Atlantic salmon, rainbow trout, brown trout, herring, catfish, bluegill, walleye, and shiners). EPRI concluded that the MIS could be the lowest cost screen for fish protection because the increased approach velocities, if accepted by the regulatory agencies, result in a smaller screen area per volume of water.

Conclusions

Conceptually, the MIS, Archimedes screw lifts, and internal helical pumps are feasible. The Red Bluff Research Pumping Plant has conducted ongoing studies and evaluations of the large (100 cfs) Archimedes screw lifts and internal helical pumps to determine feasibility and long-term costs and impacts to fish related to handling and bypass facilities. EPRI has studied the MIS with scale models, computer models, and in half-scale, full operation at a hydroplant facility on the East Coast. For both the fish lifts and pumps, and the MIS, results were very good for fish handling impacts with low to no injuries or mortalities, depending on operating configurations and flows. However, the MIS has not yet been tested on the West Coast and would require additional investigations to determine feasibility and gain acceptance by regulating agencies.

The folded “V” screens and inclined flat plate screens are better known alternatives and are currently accepted by regulating agencies. However, folded “V” screens require extensive fish bypass and handling facilities and, thereby, have greater impacts on fish drawn into the diversion. Inclined flat-plate screens minimize fisheries impacts because no fish bypass and handling facilities are necessary. The inclined flat-plate design is being applied currently at larger Sacramento River diversions.

Attachment B, Table 1 provides a comparison of each of the alternatives based on information available and relative estimated costs from actual construction costs or bid information gathered for similar screen facilities. Attachment B, Figure 1 is a cost estimation curve for existing or evaluated fish facilities in the Central Valley.

Diversion Site Alternatives

Four locations are being investigated as diversion points for offstream storage: existing diversions at the Tehama-Colusa Canal intake near the Red Bluff Diversion Dam and the GCID intake near Hamilton City, and new diversion locations at Monroeville and Compton Landing (Attachment A).

Red Bluff Diversion Dam / Tehama-Colusa Canal Intake

Sacramento River water currently cannot be taken by gravity flow from September 15 through May 15 because the RBDD gates are required to be open to facilitate fish passage. DWR has discussed with the Tehama-Colusa Canal Authority possible alternatives for a new pumped diversion at RBDD that would meet current water demand as well as that for offstream storage.

Design alternatives being developed are listed below:

1. 2,100 cfs Pumped Diversion Capacity (Existing Canal Capacity at Funks Reservoir)

a. Two 1,050 cfs on-river inclined flat-plate screens (Attachment B, Figure 10)

Conceptual design plans have been developed for current capacity needs. Cost estimates are based on bids for installation of the PCGID/PID fish screens currently under construction on the Sacramento River.

b. 20 to 30 Archimedes screw lifts or internal helical pumps using existing drum screens

Conceptual design plans for this option have been developed. Cost estimates are based on information from USBR's 1992 *Summary of Appraisal Study for Red Bluff Diversion Dam Fish Passage Program*.

c. Modular inclined screens 21 x 100 cfs units, for a total 2,100 cfs diversion (Attachment B, Figures 8 and 9)

Current design sizes screens for operation within existing DFG and NMFS screen criteria. Site-specific topography data is required to determine fish bypass operational design criteria and location of bypass pipes or flumes.

2. 5,000 cfs pumped diversion capacity; increasing deliverable capacity by 2,900 cfs

a. Set of five on-river inclined flat-plate screens; 1,000 cfs per screen

Same issues as stated above in 1a.

b. 50 to 60 Archimedes screw lifts or internal helical pumps using existing drum screens and new "V" screens (Attachment B, Figure 7)

Sixty percent (3,000 cfs) of the Archimedes screw lifts or internal helical pumps would deliver water into a canal that would connect with the existing drum screens. New "V" screens would be built to handle the remaining 2,000 cfs.

c. Modular inclined screens 50 x 100 cfs units

This option has the same issues as stated above in 1c.

GCID Intake Screen Expansion

Construction is currently underway on the extension of the flat-plate screen to increase GCID screen capacity to 3,000 cfs. The project will provide current costs for a flat-plate screen facility in comparison to other diversion concepts under consideration for offstream storage at other locations.

1. Using expanded screen to divert up to 3,000 cfs during higher winter river flows

The existing and new screen are not designed to take water when the flow is above 60,000 cfs in the Sacramento River. To do so, the support structure for the screens would have to strengthened. Screen cleaning may also have to be modified to handle increased debris loads. At high river flows, pumping is not needed, but a gate structure would be needed to protect the canal from the river. In addition, during these high flows, water would have to be diverted around the pump station.

2. Adding new screens above existing screens to divert up to 5,000 cfs; modifying new screen facility to divert higher winter flows, operation at or above 60,000 cfs

   Expansion of the new facility to increase diversion capacity to 5,000 cfs and to take water under high flow conditions could be achieved by replacing the barrier panels above the existing screens with new screen panels, thereby increasing the height of the existing screens. Modifications as specified in the 3,000 cfs option would also be required.

New Sacramento River Diversion (Alternatives at Monroeville and Compton Landing)

Our conceptual designs have been developed primarily for new diversion fish facilities that could be sited at Monroeville or Compton Landing across from Moulton Weir. Feasibility cost estimates are based on actual costs, when available, from newer existing screened diversion facilities or facilities under construction on the Sacramento River.

Design alternatives being developed are listed below:

1. 2,100 cfs diversion at Monroeville
   a. Two 1,050 cfs on-river inclined flat-plate screens

      Cost estimates for our conceptual design are based on the 605 cfs PCGID/PID fish screen facility currently under construction on the Sacramento River.
   b. Modular inclined screens 21 x 100 cfs units, for a total 2,100 cfs diversion

      Current design option sizes screens for operation within existing DFG and NMFS fish screen criteria. Additional information, including site specific topography data is required to determine fish bypass operational design criteria and locate bypass pipes or flumes for this experimental screen.
2. 2,900 cfs diversion at Compton Landing
   a. Three 1,000 cfs on-river inclined flat-plate screens

      This option has the same issues as stated above in 1a.
   b. Modular inclined screens 29 x 100 cfs units, for a total 2,900 cfs diversion

      This option has the same issues as stated above in 1b.
3. 5,000 cfs diversion at Monroeville or Compton Landing
   a. Folded “V” screens with five 1,000 cfs bays (Attachment B, Figures 2 and 3)

Cost estimates for this design option are based on the GCID folded "V" estimates from 1996.

b. Set of five on-river inclined flat-plate screens; 1,000 cfs per screen bay (Attachment B, Figures 4 and 5)

This alternative requires a relatively large increase in right-of-way aquisition along the Sacramento River.

c. Modular inclined screens 50 x 100 cfs units

This option has the same issues as stated above in 1b.

Colusa Basin Drain

Colusa Basin Drain is a potential source of water for offstream storage. Based on communications with regulating agency personnel, the presence of fish species of concern in the basin requires a screen on any diversion from the drain. Based on this information, a diversion screen facility design will need to be developed. Further studies of fish species distribution and seasonal abundance may provide alternatives to diversion operations or facility designs, which will need to be discussed with regulating agency personnel as information is developed.

A proposed fish exclusion facility discussion paper (Attachment E) describes options to exclude adult salmon from the CBD and provide return access to the Sacramento River. The option described would still maintain access to the floodplains of the CBD for other migratory native fish. This option was presented as one possible solution to reducing potential impacts to migrating adult salmon attracted into the drain by diverted Sacramento River water used for irrigation and collected in the drain. Other options may be available and would need further investigation. Specific fisheries sampling will be necessary to evaluate habitat conditions and use by fish species of concern to fully evaluate all alternatives.

Agency Review and Comments on the Conceptual Design Alternatives

On January 6, 1999, the ESO Fish Facilities Section presented its conceptual design report to the Central Valley Fish Facilities Review Team. The team, composed of representatives from DFG, NMFS, USFWS, Natural Resource Conservation Service, U.S. Bureau of Reclamation, CALFED, and DWR, meets monthly to review fish facility matters under the auspices of the Interagency Ecological Program.

Despite two requests for comments, of the six agencies on the team only DFG and NMFS provided informal or formal feedback (verbal or written). In particular, USFWS was asked twice to provide comments.

DFG and NMFS provided remarkably similar feedback. For example, both agencies objected to the large size (5,000 cfs) of a new diversion from the Sacramento River. Depending upon Sacramento River flow, they believe that the impacts to the river and fishery could simply be unacceptable. Furthermore, from a facility perspective, such a large diversion would require the largest screen ever constructed on the Sacramento River, one that would probably have to incorporate bypasses or lengthy resting spots for fish. Further, NMFS would require multi-level assurances, both physical and contractual, to guarantee that water is not inappropriately diverted from the Sacramento River through a 5,000 cfs facility.

Regarding bypasses, both agencies prefer to keep the fish in the river; thus, DFG and NMFS did not support an off-river (or in-canal) fish facility, unless DWR demonstrated that an on-river facility was not technologically feasible. An on-river facility is consistent with how new facilities are being constructed on the Sacramento River, including Reclamation District 108, RD1004, GCID, and PCGID/PID. DFG also noted that the MIS would be considered an experimental technology, and should be tested first in California prior to proceeding any further with design.

Based upon these comments from DFG and NMFS, we narrowed the scope of our pre-feasibility design to an on-river, inclined flat-plate screen, at 2,000, 3,000, and 5,000 cfs. The 5,000 cfs capacity diversion facility, notwithstanding the regulatory advice, was maintained as an alternative at the request of Northern and Central Districts.

Preferred Pre-Feasibility Level Design Alternatives

Discussion: Selection of a Preferred Alternative

Based on the results of the regulatory and conceptual design review, the preferred pre-feasibility level design alternative for a new diversion site is the on-river inclined flat-plate screen.

The design is accepted by the regulatory agencies and is currently being used (albeit a smaller scale) on the Sacramento River. It is readily accepted because it eliminates the need for fish bypass or handling facilities and keeps the fish in the river, thereby lowering fishery impacts. Also, NMFS and DFG criteria state that for streams and rivers, where physically practical, the screen shall be constructed at the diversion entrance. The screen face should be generally parallel to river flow and aligned parallel with the adjacent bank. This design can readily handle a large range of flows in the Sacramento River, from floodflows to low flows. Further, having the entire screen submerged minimizes floating debris problems. It has built-in reliability due to the incorporation of five 200 cfs bays into each 1,000 cfs unit.

Conversely, submerged, neutrally-buoyant debris could damage screen panels. Sited on the river, the area in front of and just behind the screen cannot be dewatered. This specific area is also difficult to access, such that inspection and maintenance of screens, cleaners, and baffles would be difficult and have to be performed underwater. Also, sediment deposition in front of and behind the screen will be more of a problem for this design when compared with an off-river facility. Nonetheless, all of these issues are addressed to the extent practicable in our design.

The inclined flat-plate screen design will be divided into three different diversion capacities for study: 2,000; 3,000; and 5,000 cfs. Detailed design and cost estimates are presented only for the 3,000 and 5,000 cfs facilities.

Design and Cost Estimates of On-River Inclined Flat-plate Screen

1. **2,000 cfs Diversion**
   This design will incorporate two 1,000 cfs inclined flat-plate screen modules into one 2,000 cfs diversion facility. The distance between each module will be 275 feet, and it will use approximately 600 linear feet of the riverbank.
2. **3,000 cfs Diversion**
   This design will incorporate three 1,000 cfs inclined flat-plate screen modules into one 3,000 cfs diversion facility. The distance between each module will be 275 feet, and it will use approximately 1,000 linear feet of the riverbank. DWR's Division of Engineering total project cost estimate for this design is $30.1 million dollars. See Attachment C for pre-feasibility designs and cost estimates.
3. **5,000 cfs Diversion**
   This design will incorporate five 1,000 cfs inclined flat-plate screen modules into one 5,000 cfs diversion facility. The distance between each module will be 275 feet, and it will use approximately 1,900 linear feet of the riverbank. DWR's Division of Engineering total project cost estimate for this design is $50.8 million dollars. See Attachment C for pre-feasibility designs and cost estimates.

   > ***Note***: The 5,000 cfs diversion facility has a large footprint and consumes almost 2,000 feet of riverbank. Thus, the facility would enter into an area where the river meanders away from the levee, which may not be a good location. If the 5,000 cfs diversion facility continues to be examined, we recommend finding a location other than Compton Landing, one better able to handle a large facility. In contrast, the 2,000 and 3,000 cfs facilities should work well at the Compton Landing site.

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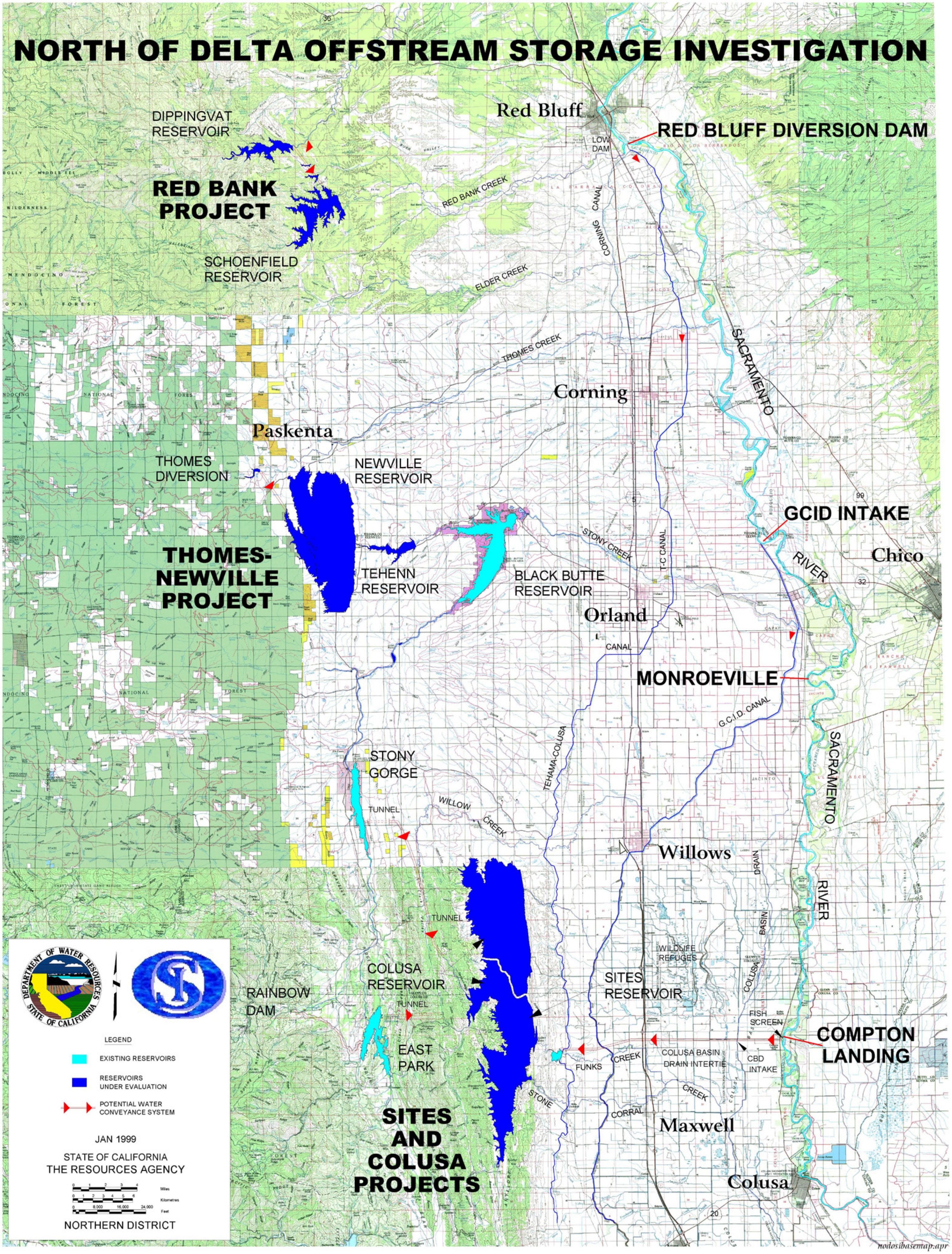
Attachment A: Diversion Location Map


NORTH OF DELTA OFFSTREAM STORAGE INVESTIGATION
Red Bluff
RED BLUFF DIVERSION DAM
LOW DAM
DIPPINGVAT RESERVOIR
RED BANK PROJECT
RED BANK CREEK
CORNING CANAL
SCHOENFIELD RESERVOIR
ELDER CREEK
THOMES CREEK
Corning
SACRAMENTO
Paskenta
THOMES DIVERSION
NEWVILLE RESERVOIR
GCID INTAKE
STONY CREEK
T-C CANAL
RIVER
Chico
THOMES-NEWVILLE PROJECT
TEHENN RESERVOIR
BLACK BUTTE RESERVOIR
Orland
CANAL
MONROEVILLE
G.C.I.D. CANAL
STONY GORGE
TEHAMA-COLUSA
SACRAMENTO
TUNNEL
WILLOW CREEK
Willows
DRAIN
RIVER
TUNNEL
BASIN
WILDLIFE REFUGES
COLUSA RESERVOIR
SITES RESERVOIR
COLUSA
RAINBOW DAM
TUNNEL
FISH SCREEN
COMPTON LANDING
EAST PARK
FUNKS
CREEK
COLUSA BASIN DRAIN INTERTIE
CBD INTAKE
CREEK
STONE
CORRAL
SITES AND COLUSA PROJECTS
Maxwell
Colusa
LEGEND
EXISTING RESERVOIRS
RESERVOIRS UNDER EVALUATION
POTENTIAL WATER CONVEYANCE SYSTEM
JAN 1999
STATE OF CALIFORNIA
THE RESOURCES AGENCY
NORTHERN DISTRICT
DEPARTMENT OF WATER RESOURCES
STATE OF CALIFORNIA
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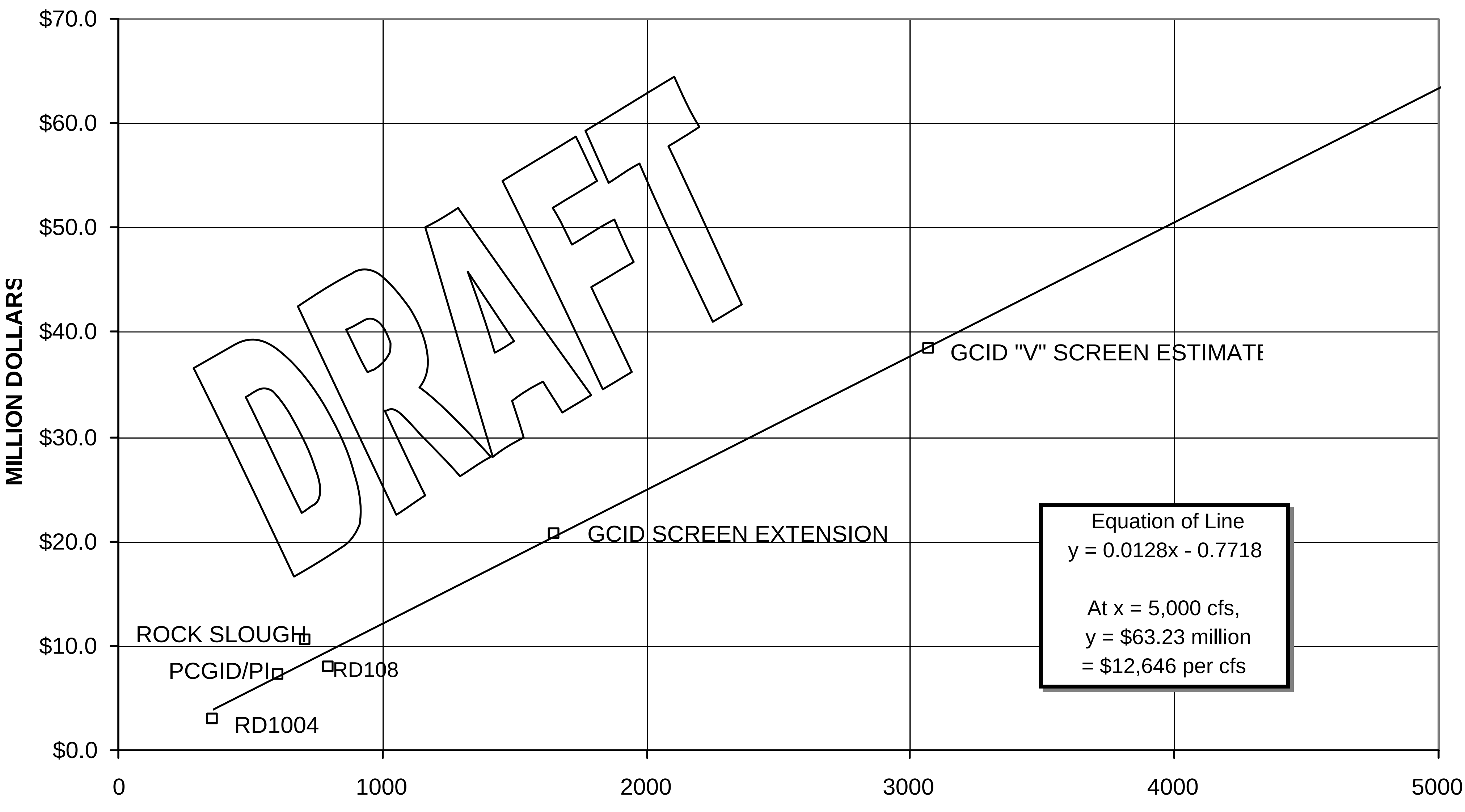
Attachment B: Conceptual Designs and Costs

Figure 1. Northern California Offstream Storage Diversion Intake Construction Cost Estimation



DWR-ESO-FISH FACILITIES

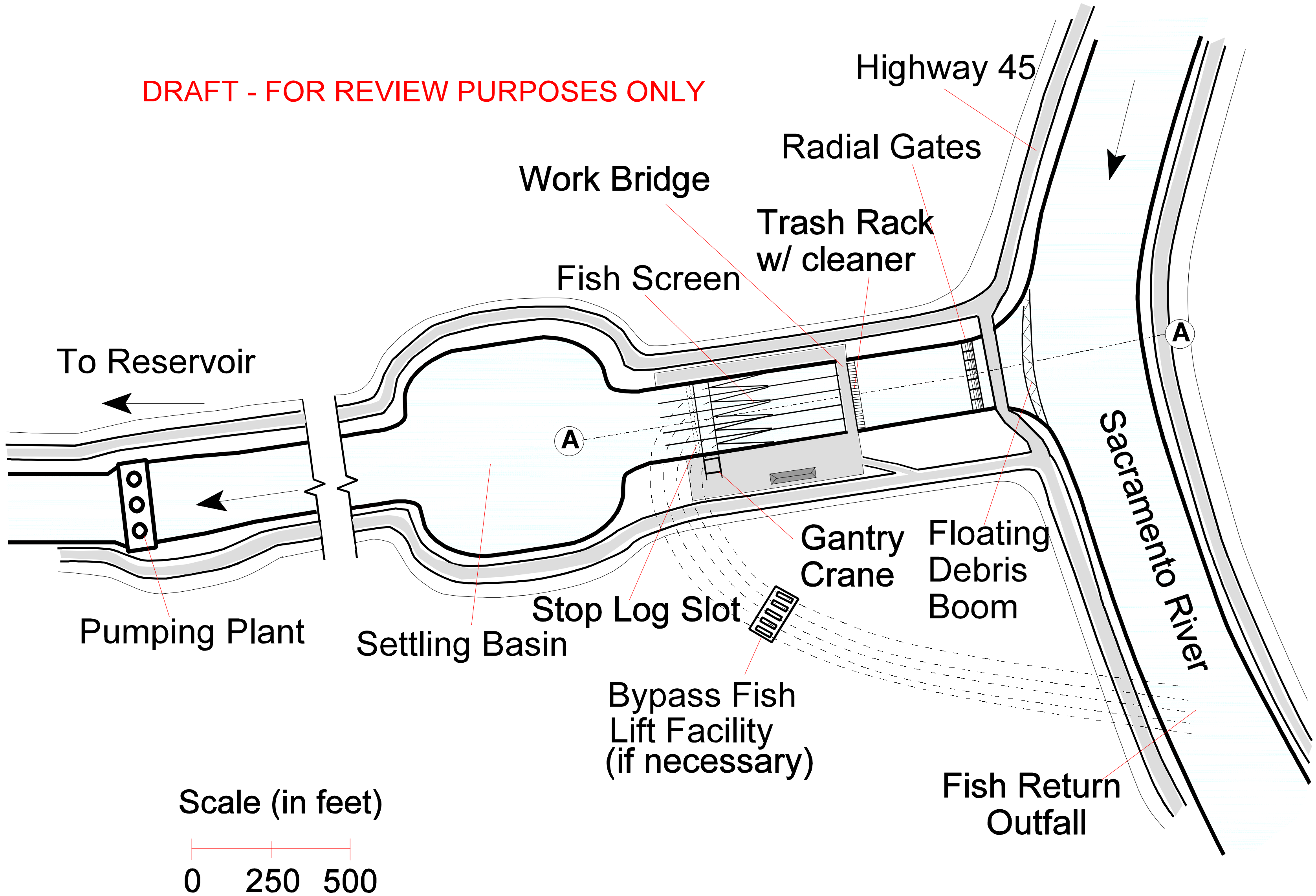


Figure 2. Folded "V" Screens. Off-River Diversion Facility

DWR-ESO-FISH FACILITIES

DWR-ESO-FISH FACILITIES

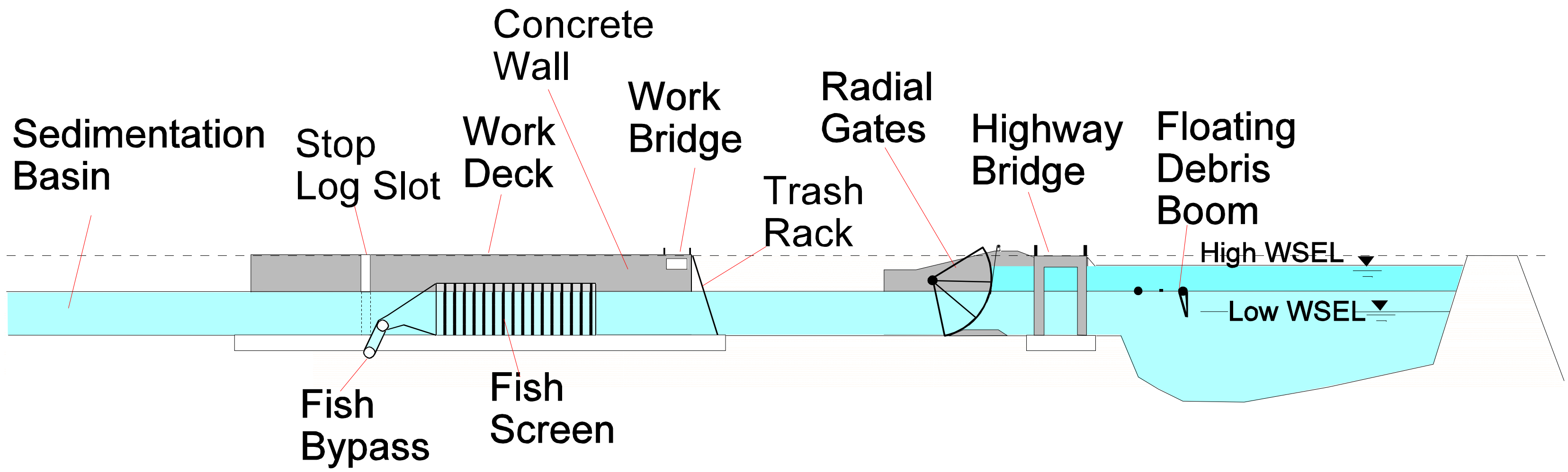


Figure 3. Section A - A Folded "V" Screens

DWR-ESO-FISH FACILITIES

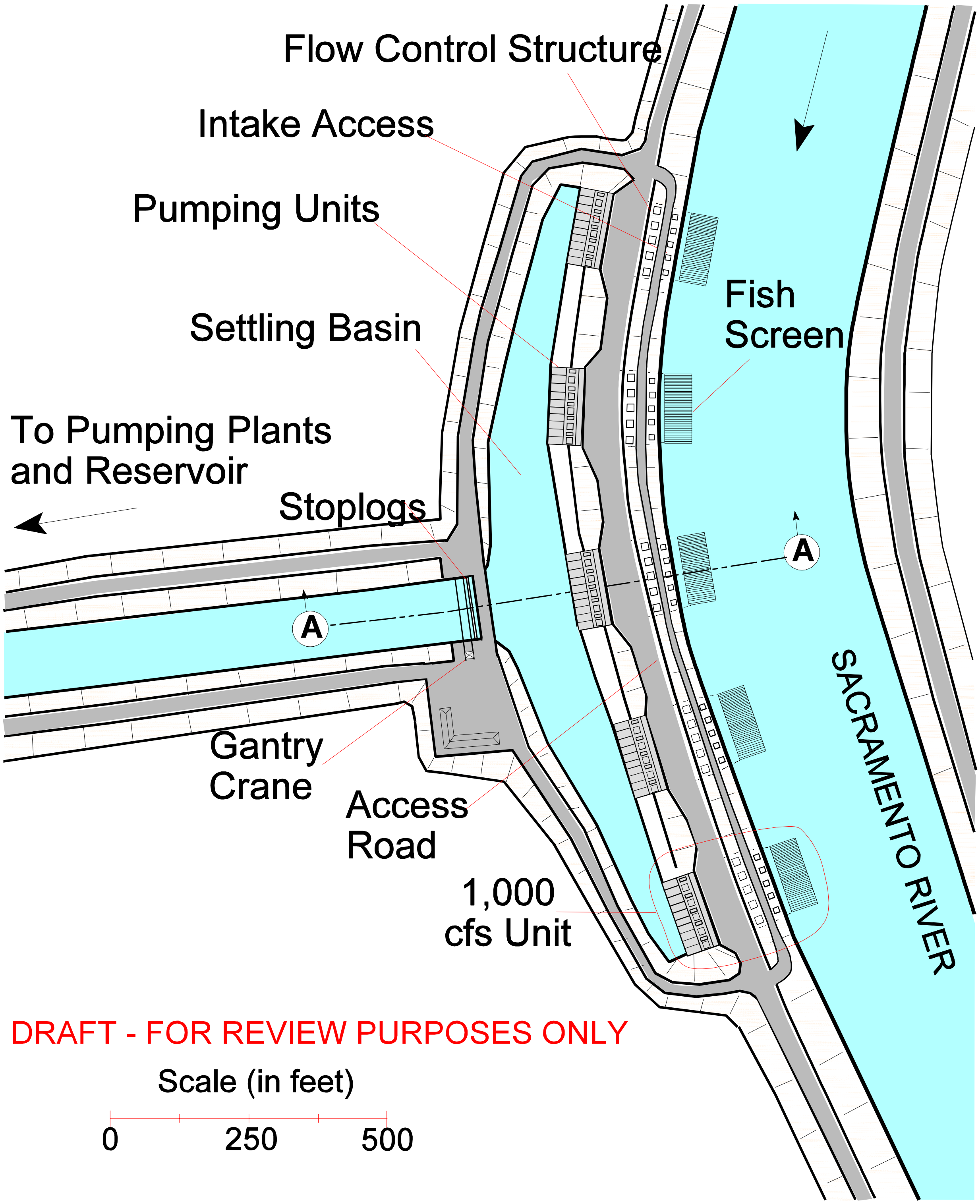


Figure 4. Inclined Flat-Plate Screens. 5,000 cfs On-River Diversion.

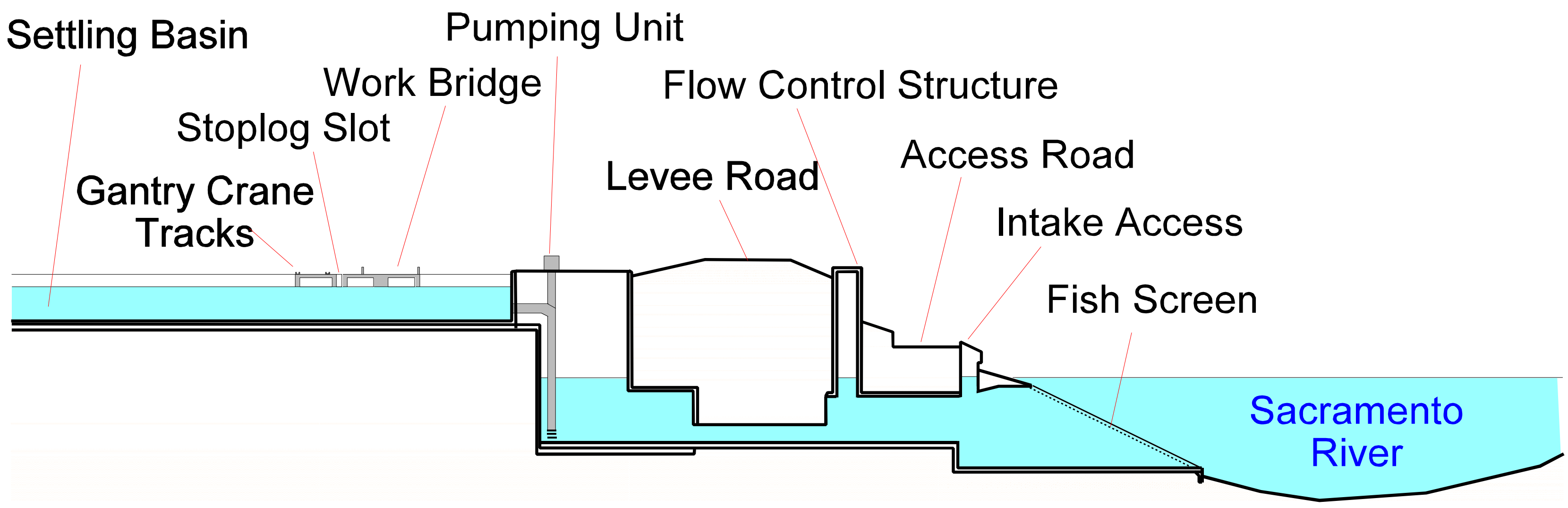


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Figure 5. Section A-A Elevation View of On-River Inclined Flat-Plate Fish Screen

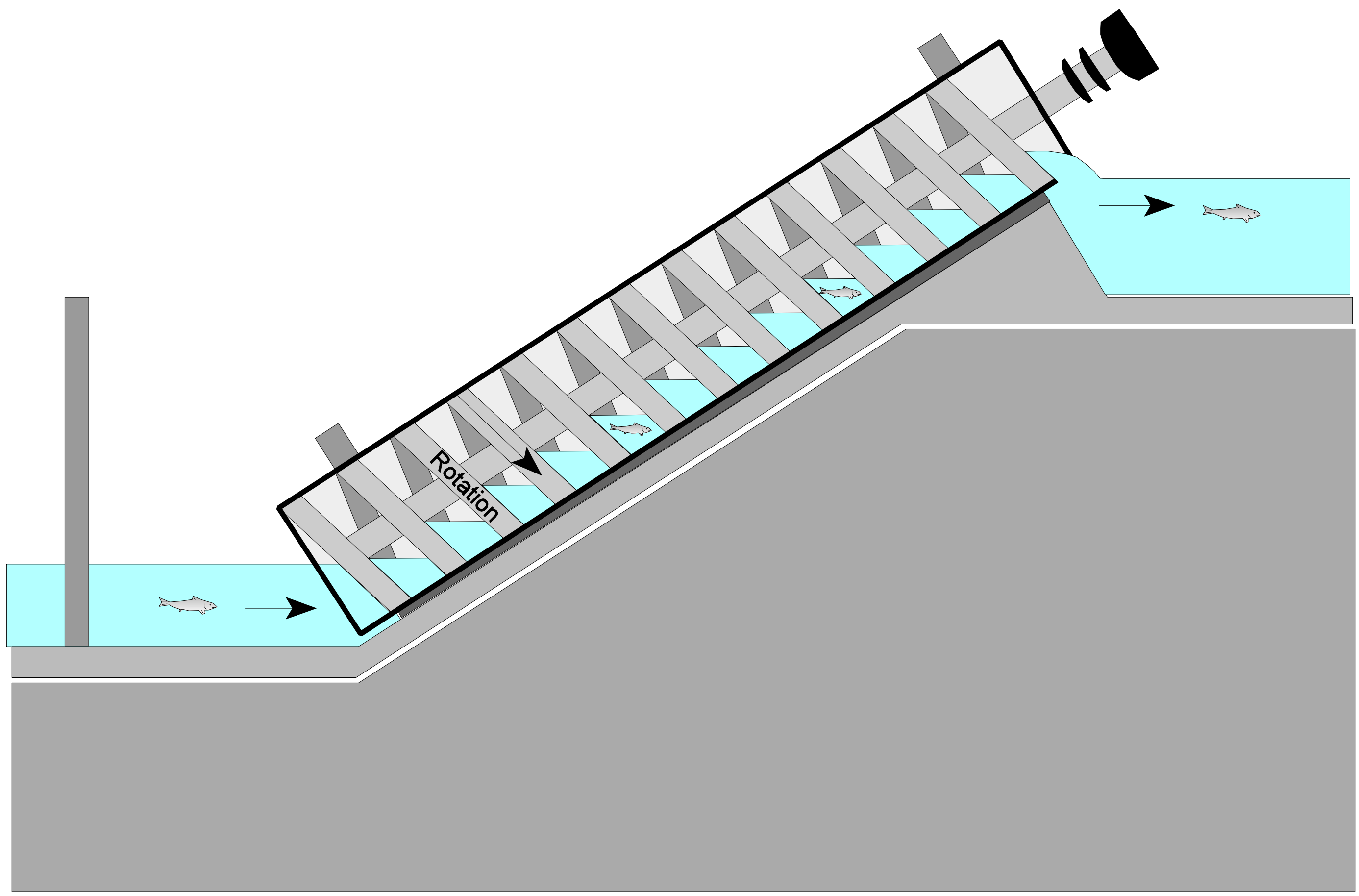


Figure 6. Archimedes Screw Fish Lift

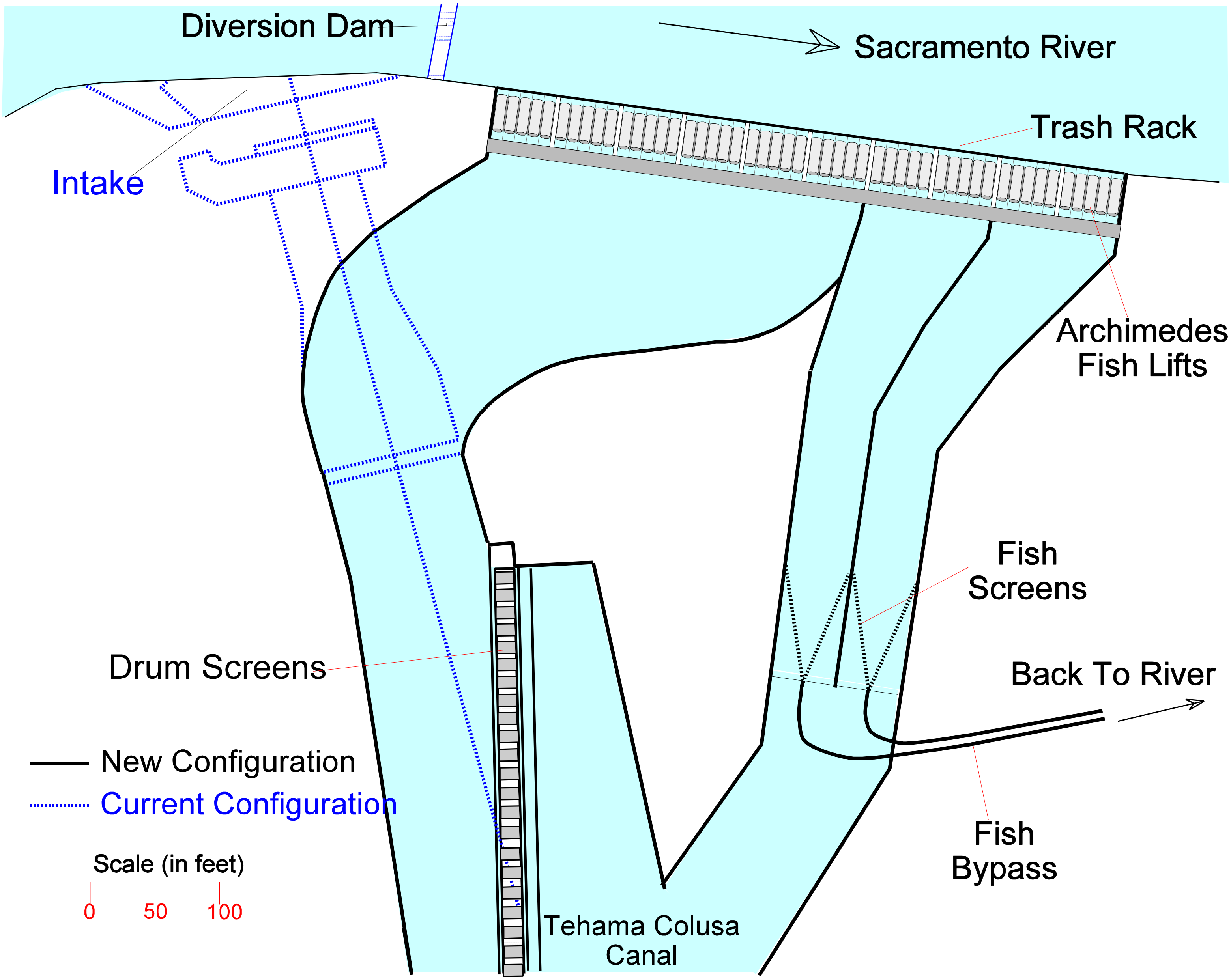
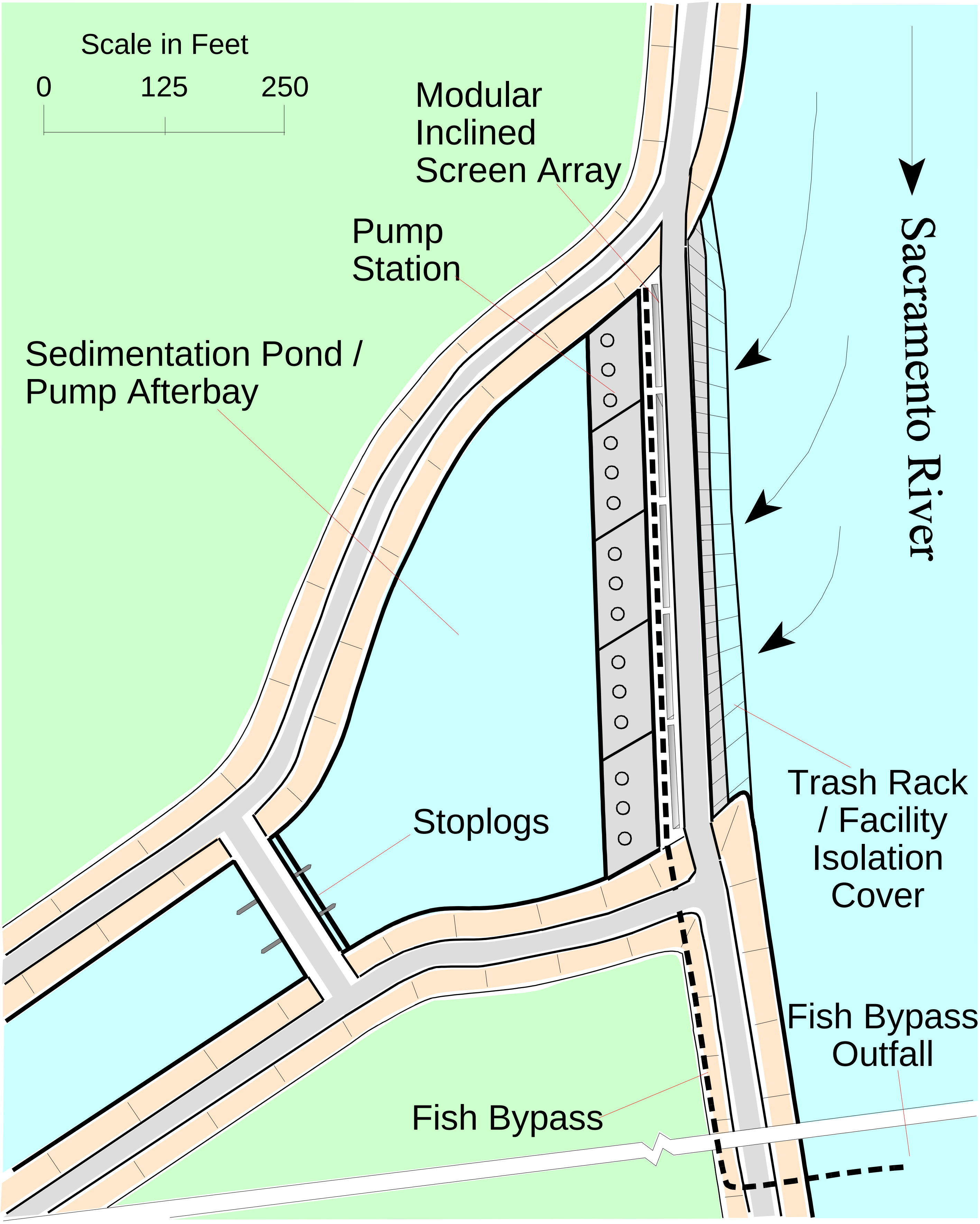


Figure 7. 5,000 cfs Diversion at Red Bluff using Archimedes Fish Lifts



DWR-ESO-FISH FACILITIES

Figure 8. Modular Inclined Screen Plan View

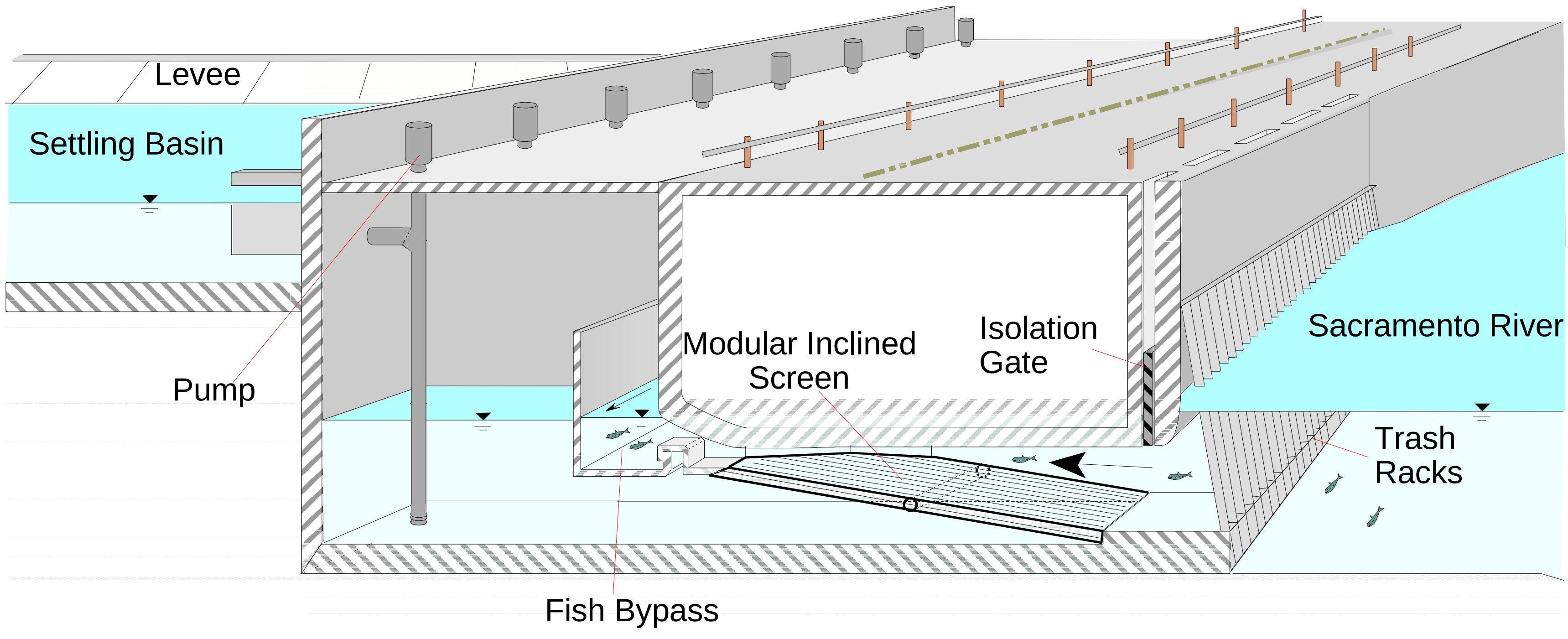


Figure 9. Elevation View Modular Inclined Screen

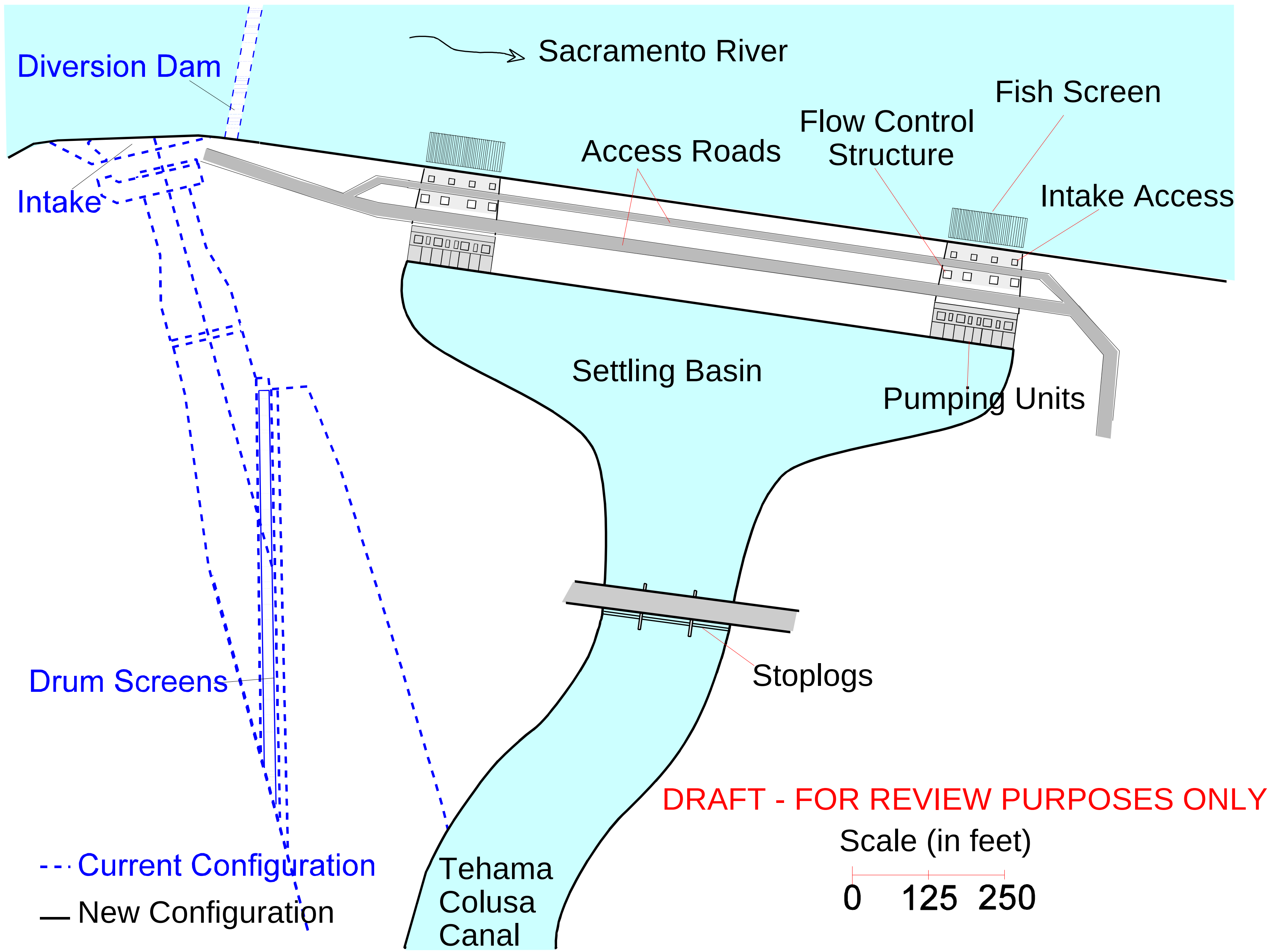


Figure 10. 2,100 cfs On-River Diversion at Red Bluff using Two 1,050 cfs Inclined Flat-Plate Units

Attachment C: Pre-Feasibility Costs

Project: Sites Diversion Structures - 3000 cfs
Feature: Cost Estimate - Flat Screens

Item No.	ITEM	UNIT	QUANTITY	UNIT COST	ITEM COST $
1	Mob/Demob and Site Preparation	LS	1	75,000.00	$ 75,000.00
2	Foundation Dewatering	LS	1	35,573.00	$ 35,573.00
3	Aggregate Base	TON	1,855	26.00	$ 48,230.00
4	Excavation	CY	115,267	4.00	$ 461,068.00
5	Backfill	CY	95,089	5.00	$ 475,445.00
6	Sheet Pile Wall (Steel)	SF	54,965	24.00	$ 1,319,160.00
7	6' Dia. Steel Pipe	LF	1,365	680.00	$ 928,200.00
8	Miscellaneous Metals	LB	72,000	2.00	$ 144,000.00
9	Steel Grating (Walkway System)	LB	50,160	3.00	$ 150,480.00
10	12'x30' Flat Screens (S.S.)	SF	10,800	10.00	$ 108,000.00
11	Screen Frame System (S.S.)	EA	3	15,069.00	$ 45,207.00
12	Structural Conc.(Intake, Radial Gate, Bridge)	CY	19,690	287.00	$ 5,651,030.00
13	Steel Reinforcement	LB	3,938,000	0.50	$ 1,969,000.00
14	Flap Gates	EA	30	21,973.00	$ 659,190.00
15	Sluice Gates	EA	15	121,955.00	$ 1,829,325.00
16	Radial Gates - Steel	LB	50,744	6.00	$ 304,464.00
17	Airburst Screen Cleaning System	LS	1	259,523.00	$ 259,523.00
18	Sediment Removal System	LS	1	215,126.00	$ 215,126.00
19	Electrical Conduit, Fittings & Wire	LS	1	75,000.00	$ 75,000.00
20	Power supply, Electronic Contain. Struct.	LS	1	60,000.00	$ 60,000.00
21	Stone Protection	TON	11,500	40.00	$ 460,000.00
22	Filter Fabric	SF	102,000	1.00	$ 102,000.00
23	Sand Bedding	TON	3,580	18.00	$ 64,440.00
24	Hand Rail	LF	2,120	19.00	$ 40,280.00
25	Equipment Fasteners	LB	10,000	5.00	$ 50,000.00
26	Flow Meters	EA	15	34,125.00	$ 511,875.00
27	Misc. Concrete - Float Anchor, Main. Pad	CY	214	209.00	$ 44,726.00
28	Furnish and Install Barrier Floats	EA	208	293.00	$ 60,944.00
29	Regulatory Floats	EA	7	1,628.00	$ 11,396.00
30	Baffles (Galv. Steel)	LB	106,600	4.00	$ 426,400.00
31	100 cfs Pumps	EA	30	65,520.00	$ 1,965,600.00
32	6' Chain Link Fence	LF	210	34.00	$ 7,140.00

Subtotal	$	18,557,822.00
35% Contingency	$	6,495,237.70
Direct Pay	$	25,053,059.70
Design&Administrative(10%)	$	2,505,305.97
Construction Supervision(10%)	$	2,505,305.97
Total Project Cost =	$	30,063,671.64

Project: Sites Diversion Structures - 5000 cfs
Feature: Cost Estimate - Flat Screens

Item No.	ITEM	UNIT	QUANTITY	UNIT COST		ITEM COST $
1	Mob/Demob and Site Preparation	LS	1	100,000.00	$	100,000.00
2	Foundation Dewatering	LS	1	35,573.00	$	35,573.00
3	Aggregate Base	TON	3,750	26.00	$	97,500.00
4	Excavation	CY	159,933	4.00	$	639,732.00
5	Backfill	CY	179,745	6.00	$	1,078,470.00
6	Sheet Pile Wall (Steel)	SF	83,915	24.00	$	2,013,960.00
7	6" Dia. Steel Pipe	LF	3,000	681.00	$	2,043,000.00
8	Miscellaneous Metals	LB	120,000	2.00	$	240,000.00
9	Steel Grating (Walkway System)	LB	83,640	3.00	$	250,920.00
10	12'x30' Flat Screens (S.S.)	SF	18,000	10.00	$	180,000.00
11	Screen Frame System (S.S.)	EA	5	15,069.00	$	75,345.00
12	Structural Conc.(Intake, Radial Gate, Bridge)	CY	32,370	287.00	$	9,290,190.00
13	Steel Reinforcement	LB	6,474,000	0.50	$	3,237,000.00
14	Flap Gates	EA	50	21,973.00	$	1,098,650.00
15	Sluice Gates	EA	25	121,955.00	$	3,048,875.00
16	Radial Gates - Steel	LB	50,744	6.00	$	304,464.00
17	Airburst Screen Cleaning System	LS	1	431,143.00	$	431,143.00
18	Sediment Removal System	LS	1	344,614.00	$	344,614.00
19	Electrical Conduit, Fittings & Wire	LS	1	150,000.00	$	150,000.00
20	Power supply, Electronic Contain. Struct.	LS	1	100,000.00	$	100,000.00
21	Stone Protection	TON	26,220	40.00	$	1,048,800.00
22	Filter Fabric	SF	233,000	1.00	$	233,000.00
23	Sand Bedding	TON	8,160	18.00	$	146,880.00
24	Hand Rail	LF	3,550	19.00	$	67,450.00
25	Equipment Fasteners	LB	16,000	5.00	$	80,000.00
26	Flow Meters	EA	25	34,125.00	$	853,125.00
27	Misc. Concrete - Float Anchor, Main. Pad	CY	356	209.00	$	74,404.00
28	Furnish and Install Barrier Floats	EA	329	293.00	$	96,397.00
29	Regulatory Floats	EA	11	1,628.00	$	17,908.00
30	Baffles (Galv. Steel)	LB	178,000	4.00	$	712,000.00
31	100 cfs Pumps	EA	50	65,520.00	$	3,276,000.00
32	6' Chain Link Fence	LF	210	34.00	$	7,140.00

Subtotal	$	31,372,540.00
35% Contingency	$	10,980,389.00
Direct Pay	$	42,352,929.00
Design&Administrative(10%)	$	4,235,292.90
Construction Supervision(10%)	$	4,235,292.90
Total Project Cost =	$	50,823,514.80

Attachment D: Field Visits

Table 1. Field Visits

Date	Site	Purpose
June 12, 1998	Colusa Basin Drain	Tour of lower portion of the drain
June 19, 1998	Colusa Basin Drain	Tour of upper portion of the drain
July 1, 1998	Colusa Basin Drain	Tour of drainages that empty into the drain
November 4, 1998	Rd108 Intake On The Sacramento River	Investigate vertical flat-plate fish screen
November 1998	Rancho Esquon Intake (Adams Dam) On Butte Creek	Investigate inclined flat-plate fish screen
November 1998	Rd1004 Intake On The Sacramento River	Investigate inclined flat-plate fish screen
November 1998	Durham Mutual Intake On Butte Creek	Investigate inclined flat-plate fish screen
November 30, 1998	Gcid Intake On The Sacramento River	Investigate vertical flat-plate fish screen
November 30, 1998	Stony Creek	Investigate siphon under stony creek
November 30, 1998	Pcgid/Pid Intake On The Sacramento River	Investigate inclined flat-plate fish screen
January 19, 1999	Los Vaqueros Intake On Old River	Investigate flat-plate fish screen
May 4 And 5, 1999	Gorrill Ranch Intake On Butte Creek	Hydraulic investigation of vertical flat-plate fish screen

Attachment E: Colusa Basin Drain Discussion Paper

State of California   The Resources Agency

DEPARTMENT OF WATER RESOURCES

OFFICE MEMO

TO: Naser Bateni

DATE: August 4, 1998

SUBJECT: Colusa-Basin Drain diversion

FROM: Leslie Millett, (916) 227-1076
Ted Frink, (916) 227-0177
Environmental Services Office

This memo contains information that we have gathered about the Colusa-Basin Drain (CBD), sensitive fish species that may use the area, and an option for diverting water from the CBD. In previous discussions, the question was raised as to whether it would be necessary to screen a diversion on the CBD for juvenile chinook salmon, steelhead and splittail. There are three ways that salmonids and splittail could enter the CBD.

The first way these species could enter the drain is through the Yolo Bypass. At the southern end, the Yolo Bypass (Bypass) begins at Prospect Slough at Little Holland Tract. The Yolo Bypass Toe Drain (Toe Drain) flows directly into Prospect Slough. Prospect Slough is an off shoot of Cache Slough which connects to the Sacramento River at southern tip of Ryer Island. The Toe Drain contains water year round and runs the entire length of the Bypass. The Knights Landing Ridge Cut connects the Bypass to the CBD. An employee of Rosemount Farms informed us that water from the CBD flows year round through the Knights Landing Ridge Cut and into the Toe Drain. However, DFG (1982) reported that flow in the Knights Landing Ridge Cut was less than 1 cfs in the summer of 1980. Therefore, the connection between the CBD, the Yolo Bypass, and the Sacramento River is unobstructed and may allow for year round continuity in some years.

DWR staff began monitoring for splittail and salmon in the Yolo Bypass in 1997. They have seen adult chinook salmon, possibly spring-run, within the Bypass and have heard consistent reports of fall-run chinook salmon migrating up the Toe Drain in autumn (Sommer, personal communication). Juvenile chinook salmon and adult and juvenile splittail are captured within the Bypass from January through June. Juvenile salmon have been shown to migrate 12 kilometers upstream for rearing in tributaries to the Sacramento River (Maslin *et al.* 1997). Salmon and splittail could move from the Bypass and into the CBD. Additional sampling would be necessary to determine the upstream extent of any movement by both adults and juveniles.

The second place fish species may enter the CBD is through the Knights Landing Outfall Gates (Outfall Gates). The purpose of the Outfall Gates is to let CBD water into the Sacramento River. The Outfall Gates are operated electronically and triggered by stage levels in the CBD and in the Sacramento River. The Outfall Gates are opened when stage levels in the CBD are higher than levels in the Sacramento River, and closed when the reverse occurs.

The third way fish species may enter the CBD is through reclamation district diversions off the Sacramento River. There are 140 unscreened diversions on the west side of the Sacramento River from Knights Landing to Red Bluff Diversion Dam. Many of these fall within the CBD's 75 mile alignment. Within the Colusa-Basin drainage area, Provident Irrigation District and Princeton-Cordura-Glenn Irrigation District divert Sacramento River water year round (Boyd, personal communication). The Sacramento River water is used first on agricultural fields and then put into the CBD. Because water temperatures may not be lethal to salmon in the winter months, we can not rule out the possibility of salmon surviving within distribution ditches and being transferred into the CBD. Department of Fish and Game staff reported that there are numerous unscreened diversions along the CBD that entrain young salmon (Odenweller, personal communication). More work would need to be done to determine the number of unscreened Sacramento River diversions along the drain, the path of Sacramento River water through agricultural fields and ditches to the CBD, and sampling for juvenile salmon.

The sources of water in the CBD are the Glenn-Colusa Canal, which contains Sacramento River water, return flows from agriculture, diversions off the Sacramento River which use the CBD for conveyance (e.g. Maxwell Irrigation District), treatment plant effluent, and west side tributaries. The importance of the origins of the waters in the CBD leads to whether the adult salmonids migrating upstream are doing so as strays from the Sacramento River or whether they are returning to natal streams in the tributary streams.

The main question is whether or not there is a sustainable population of salmonids. There may not be a sustainable population of steelhead in the west side tributaries because the summer rearing habitat is probably not adequate. However, surveys of the tributaries should be done to definitely determine this. At this time, critical habitat for steelhead within California has not been proposed by National Marine Fisheries Service (NMFS) and information on steelhead use in the Colusa-Basin drainage is not available from Department of Fish and Game. Critical habitat has been proposed for Chinook salmon by NMFS. One critical habitat area for fall-run Chinook salmon includes Salt Creek and Stone-Corral Creek, both tributaries to the Colusa-Basin Drain. These creeks may not be included in the final critical habitat decision but are currently included in the proposed areas.

Anecdotal observations are plentiful that chinook salmon migrate up the CBD beginning in mid-August, specifically in the vicinity of the Delevan National Wildlife Refuge. Documentation is not available. In 1988 or 1989, a fish passage facility was installed at Maxwell Irrigation District's Delevan weir. The fish passage facility provides salmon access to the CBD and tributaries upstream from the weir. An employee at the Delevan National Wildlife Refuge has seen adult salmon trapped in the fields that were flooded with water from the Glenn-Colusa canal. In addition, a resident who lives on Walker Creek, tributary to Willow Creek, has often seen adult salmon in the creek. The resident said the creek is spring-fed, although the local warden has seen it dry in September.

Future investigations should document whether there is successful reproduction in the tributaries to the CBD. The most likely run that could be sustained would be the fall-run simply because low flows and high temperatures during much of the year would not support other salmon runs or steelhead. The question remains whether the substrate of the stream channels is sufficiently free of fines, whether flows remain at suitable levels, and whether water temperatures remain low enough to allow successful incubation of salmon eggs. Future surveys and sampling would be necessary to resolve these questions.

If reproduction of salmon within the tributaries to the Colusa-Basin Drain can be ruled out, it may be preferable to prevent adult salmonids from moving into the CBD. One possible option would be to block access into the CBD at a location where the fish could have access back into the Sacramento River. An adult salmon exclusion/guidance and passage facility could be constructed at the junction of the CBD and the Knights Landing Ridge Cut near the Outfall Gates. The facility would consist of two parts: 1) A guidance/exclusion structure which could be either a bar trash rack with 3 - 4 inch spacing, or a louver screen similar to those used at the State and Federal pumps and fish facilities in the south Delta; and 2) a fish ladder constructed at the Outfall Gates to allow salmon passage back into the Sacramento River. In combination, these facilities could guide adult salmon away from the channels leading into the upper CBD and allow them passage back into the Sacramento River.

The trashrack-louver guidance structure placement would be at the junction of CBD and the Knights Landing Ridge Cut (T. 11 N., R. 2 E., Sect. 15). The structure design could be an upstream pointed "V", of narrow spaced trashrack bars or a series of angled louver panels within the CBD just upstream of the confluence with the Knights Landing Ridge Cut. A second possible design could have the trashrack or louvers angle (approximately SW to NE) across the confluence of the CBD at the Knights Landing Ridge Cut to direct adult salmon around the corner toward the Outfall Gates. Either of these design options would have to be removable, require sizing to have some ability to function well under high flow conditions, and be able to withstand debris loads or have cleaning facilities designed for them.

The benefits of the trashrack/louver system is that it will have narrow spacing of the bars or louvers so that adult salmon would not be able to pass through the barrier. However, other native species that are smaller than salmon as adults would still be able to move into the CBD or tributaries. DFG staff indicated that if juvenile salmon use the Colusa-Basin Drain for rearing similar to their use of upper Sacramento River tributaries (Maslin *et al.* 1997), it would not be desirable to block juvenile salmon movement into and out of the CBD (McKee, personal communication).

The adult salmon guided away from the CBD toward the Knights Landing Outfall Gates would then need an opportunity to access the Sacramento River to continue their upstream migration. The Outfall Gates are a barrier to fish passage currently, since they are closed most of the time. When the Outfall Gates are open, it is only to allow floodwater to spill into the Sacramento River from the CBD. The gates themselves are only gated pipes, which would not provide adequate passage opportunities for adult salmon. A relatively straightforward solution to provide passage would be to construct a fish ladder that could provide continuous access over the Outfall Gates to the Sacramento River. A ladder would also provide attraction flow to help guide the salmon to the ladder entrance.

Currently, some water leaks from the Outfall Gates. Additional water drawn through a ladder and put into the lower portion of the CBD would provide some additional attraction to adult salmon, however the ladder would allow salmon to pass back into the Sacramento directly. The amount of water contributed by a ladder would not have a significant effect on flood levels downstream from the dam.

There are many designs of fish ladders that could possibly be constructed at the Outfall Gates. Additional surveys and site specific information would be necessary to select an appropriate ladder design. The ladder design would need to take into account flood water levels and the water surface level fluctuations, and debris loads that occur on the Sacramento and within the CBD. From this information, a ladder could be designed to operate under the flow variations at the site and over a range of seasons. The goal is to maximize the operational flow range of a ladder and provide the most continuous time period that adult salmon could functionally pass through the ladder.

Additional work would also be required to research possible designs of the trashrack/louver system. Once designs were drafted out then estimates of construction costs could be made for any feasible options. This option to exclude salmon from traveling up the

CBD would rely on additional information and data gathered on numbers of adult salmon and spawning locations, if any. Additional data is critical, especially on the reproductive success of adult salmon that enter the CBD and travel into the upper drainage. Also, additional information regarding the use of the CBD by native fishes would need to be considered in any facility that aims to selectively exclude fish based on size, and in the design of a fish ladder that could pass many species.

If flow is diverted from the CBD, additional evaluations should be done to determine how much water the CBD contributes to the Yolo Bypass. The impact of reducing flows from the CBD to the Bypass should be assessed since the Bypass is an important spawning and rearing area for splittail and chinook salmon (Sommer 1998).

Unless data are gathered that indicates otherwise, staff from NMFS and DFG recommend we plan for a screen on the diversion within the CBD (McKee and Mobley, personal communications). ESO staff recommend that if a Colusa Basin Drain diversion is considered and depending on results of investigations mentioned above, the feasibility analysis should include a screening facility on the diversion structure to screen out juvenile salmonids and splittail and/or a screening facility to keep adult salmonids out of the CBD. If there is a continued interest to divert from the drain, then staff recommend that a sampling program be developed to evaluate the nature of salmonid and splittail use of the CBD.

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