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Managing Water in the West

Technical Report No. SRH-2015-26

Conceptual Hydraulic Design of the Mendota Bypass

San Joaquin River Restoration Project
Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

August 2015

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San Joaquin River Restoration Project
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prepared by

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Bureau of Reclamation
August 2015

United States Department of the Interior

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86-68240 August 26, 2014

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Subject: Submittal of the Conceptual Hydraulic Design of the Mendota Bypass

The San Joaquin River Restoration Program Office of Reclamation requested that the Technical Service Center perform a conceptual hydraulic design of the Mendota Bypass for San Joaquin River Restoration Program (SJRRP). Enclosed you will find two hard copies of the following report:

- *Conceptual Hydraulic Design of the Mendota Bypass*, Technical Report No. SRH-2015-26. Prepared for San Joaquin River Restoration Program, Mid-Pacific Region, US Bureau of Reclamation, Technical Service Center, Denver, CO

Any questions regarding the document should be directed to me at (303) 445-2563.

Attachments

Cc:
Timothy Randle (86-68240)
Nathan Holste (86-68240)

Technical Report No. SRH-2015-26

Conceptual Hydraulic Design of the Mendota Bypass

Peer Review Certification

This document has been peer reviewed per guidelines established by the Technical Service Center and is believed to be in accordance with the service agreement and standards of the profession. Questions concerning this report should be addressed to Timothy Randle, Group Manager of the Sedimentation and River Hydraulics Group (86-68240) at 303-445-2557.

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Contents

Appendix

Figures

Tables

Acronyms and Abbreviations

1D	one dimension
2D	two dimensional
ArcGIS	a geographic information system
ASCE	American Society of Civil Engineers
Bypass	Mendota Pool Bypass
CA	California
cfs	cubic feet per second
Ch	chapter
CO	Colorado
Corps	U.S. Army Corp of Engineers
DH	drill holes
EM	Engineering Manual
Eq.	equation
ft	foot/feet
GIS	geographic information system
HEC-GeoRAS	Hydrologic Engineering Centers River Analysis System extension for use in ArcGIS
HEC-RAS	Hydrologic Engineering Centers River Analysis System
ID	identification
JBP	Fresno Slough into Mendota Pool are recorded by James Bypass
JSA	Jones and Stokes Associates, Inc.
LiDAR	Light Detection and Ranging
LWD	large woody debris
MEI	Mussetter Engineering Inc.

NAD83	North American Datum National Readjustment
NAVD88	North American Vertical Datum of 1988
No.	number
NRCS	Natural Resources Conservation Service
Passage Memo	San Joaquin River Restoration Program Passage Memo, 2014
prep	preparation
Project	Mendota Pool Bypass and Reach 2B Improvements Project
Reclamation	Bureau of Reclamation
RM	river mile
Secretary	Secretary of the U.S. Department of the Interior
Settlement	Stipulation of Settlement
SJR	San Joaquin River
SJRRP	San Joaquin River Restoration Program
SJRRW	San Joaquin River Restoration Daily Flow Model
SONAR	Sound Navigation and Ranging
SRH-1D	Sedimentation and River Hydraulics – One Dimension
SRH-2D	Sedimentation and River Hydraulics – Two-Dimensional
TSC	Technical Service Center
U.S.	United States
USBR	U.S. Bureau of Reclamation (Reclamation)
USGS	U.S. Geological Survey
WY	water year
yd	yard

Technical Report No. SRH-2015-26

Conceptual Hydraulic Design of the Mendota Bypass

1 Introduction

The San Joaquin River Restoration Project Office of the Bureau of Reclamation (Reclamation) requested Reclamation's Technical Service Center (TSC), Denver, Colorado (CO), develop conceptual level designs for the compact bypass around Mendota Pool (Bypass) of the San Joaquin River (SJR) as described in the Bypass and Reach 2B Improvements Project (Project) [SJRRP, 2012b]. This analysis is a component of the San Joaquin River Restoration Program (SJRRP). The SJRRP was established in late 2006 to implement the Stipulation of Settlement (Settlement) in Natural Resources Defense Council, et al., *v.* Kirk Rodgers, et al.

The Settlement is based on two goals:

- **Restoration.—**To restore and maintain fish populations in "good condition" in the main stem of the SJR below Friant Dam to the confluence of the Merced River, including naturally reproducing and self-sustaining populations of salmon and other fish.
- **Water Management.—**To reduce or avoid adverse water supply impacts to all of the Friant Division long-term contractors that may result from the interim flows and restoration flows provided for in the Settlement.

The Bypass and the Project includes the construction, operation, and maintenance of the Bypass and improvements in the SJR in Reach 2B to convey at least 4,500 cubic feet per second (cfs) between levees. The Project area (figure 1-1 and figure 1-2) extends from approximately 0.3 miles above the Chowchilla Bypass Bifurcation Structure to approximately 1.0 mile below Mendota Dam; it comprises the area that could be directly affected by the Project. The Project may also indirectly affect nearby portions of Reach 2A and Reach 3. The Project area is in Fresno and Madera counties, near the town of Mendota, California (CA). The Bypass and Reach 2B improvements defined in the Settlement are [Settlement Paragraph 11(a)]:

1. Creation of a bypass channel around Mendota Pool to ensure conveyance of at least 4,500 cfs from Reach 2B downstream to Reach 3. This improvement requires construction of a structure capable of directing flow down the Bypass and allowing the Secretary of the U.S. Department of the Interior (Secretary) to make deliveries of SJR water into the Bypass when necessary;

2. Modifications in channel capacity (incorporating new floodplain and related riparian habitat) to ensure conveyance of at least 4,500 cfs in Reach 2B between the Chowchilla Bifurcation Structure and the new Mendota Pool Bypass channel.

The primary goals of this report are to:

- Present the conceptual hydraulic design of the Bypass.
- Provide information to assist in the selection of a channel design option for the Bypass.

The conceptual hydraulic design will include features relevant to the hydraulic, sediment transport, and vegetation conditions in the channel. Appurtenant features, including fish ladders, fish barriers, control gates, and levees, will be designed independently and are integrated here by location and water surface elevations. Channel features are developed to a conceptual level only in this document.

Regarding the second goal, this report includes two options for the conceptual channel design. Both options use the same Bypass channel alignment shown in figure 1-2. The channel alignment is consistent with that described in the Project description [SJRRP, 2012] with a slight modification to the confluence angle at the junction with Reach 3. The two channel design options correspond to different slopes and elevations of the Bypass channel.

All elevations in this report are stated in feet and in the North American Vertical Datum of 1988 (NAVD88) vertical datum.

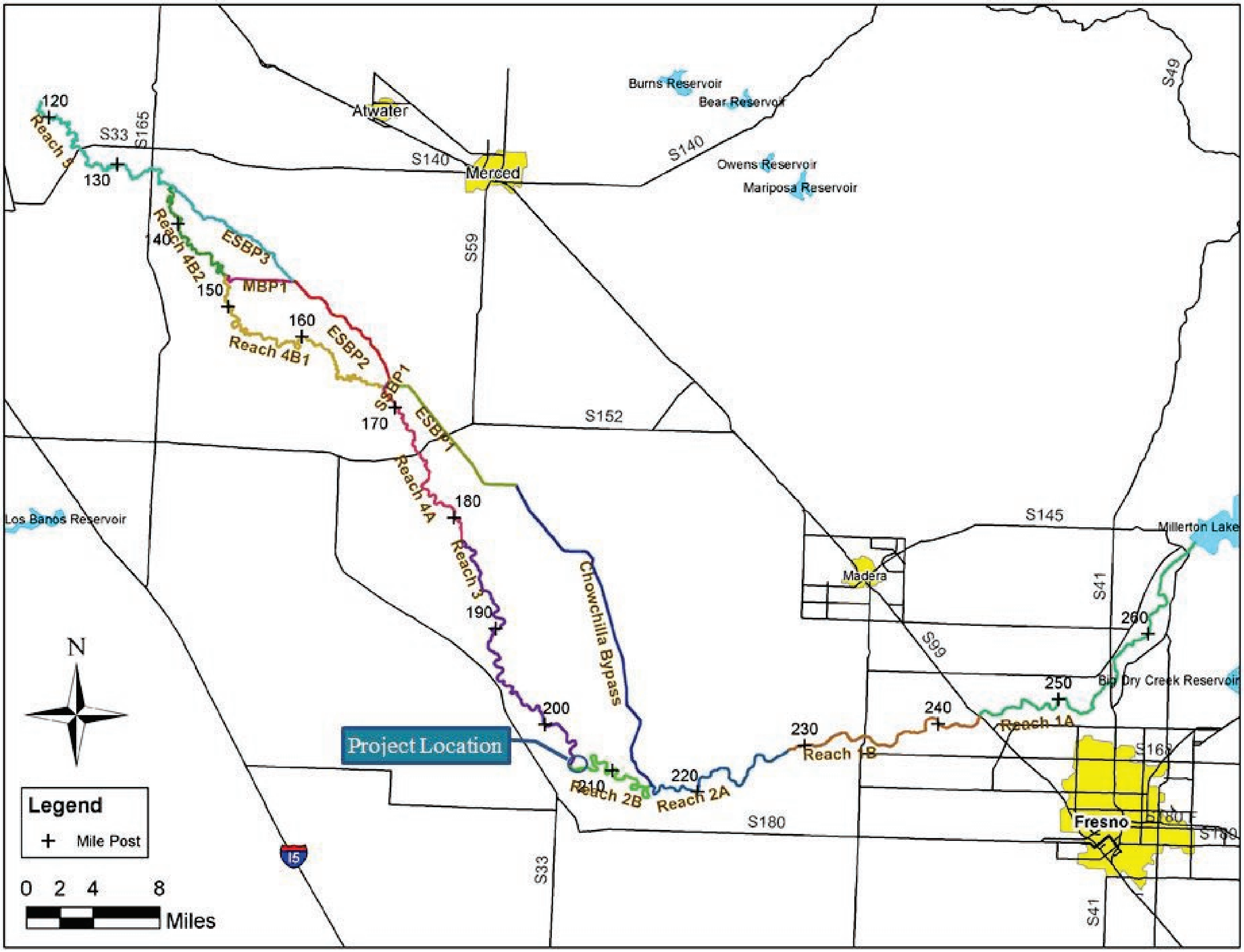


Figure 1-1.—Overview of reaches associated with the SJRRP.

Figure 1-2.—Mendota Bypass Project overview map.

2 Design Goals and Objectives

The overall design goals and objectives for the Project are described here and summarized below as project design criteria.

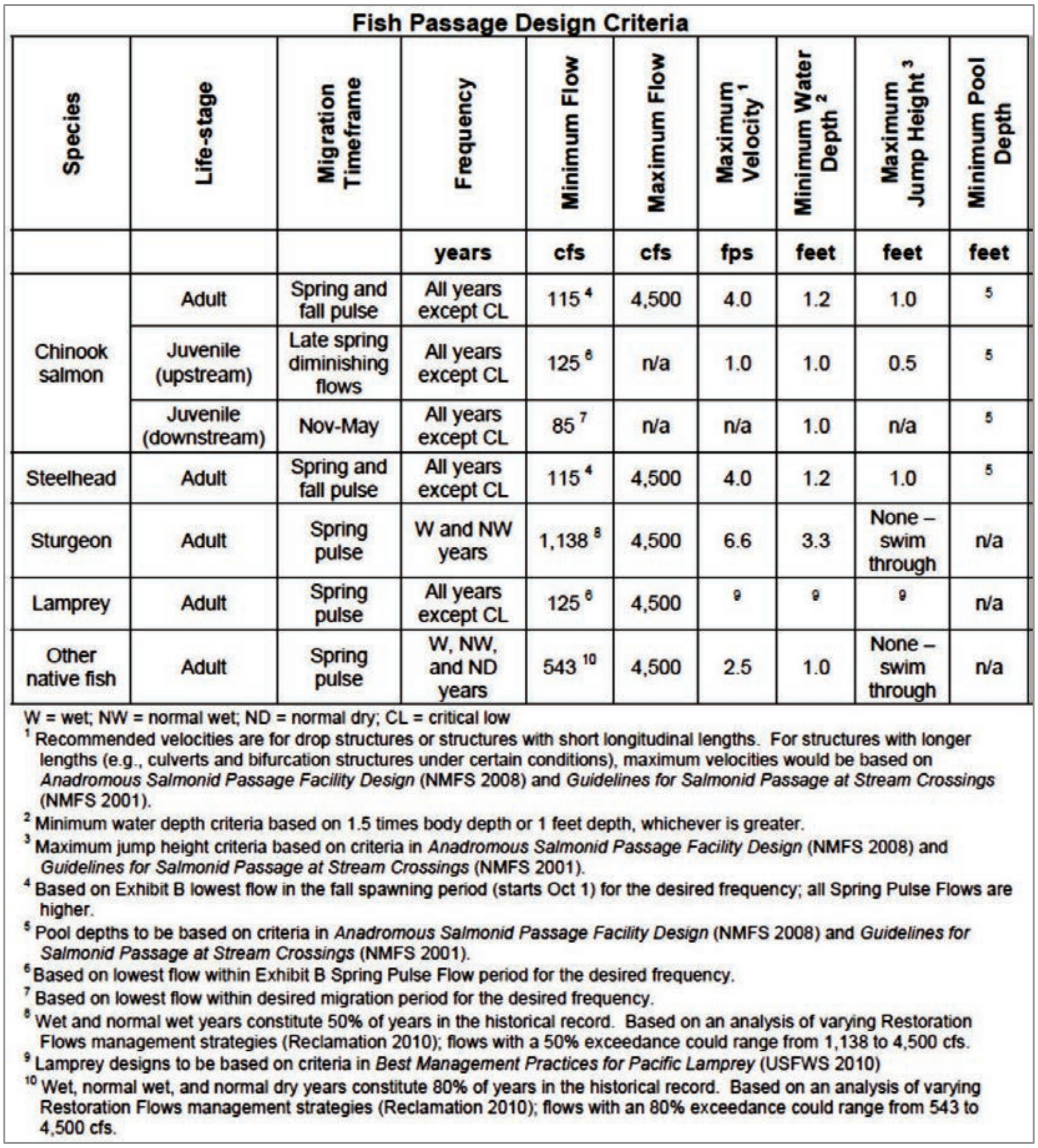
2.1 Fish Passage Objectives

Fish Passage Design Criteria Technical Memoranda [Passage Memo, SJRRP, 2014] describes the upstream fish passage strategy for the SJRRP to guide engineering modifications to structures within the SJR and Bypass between Friant Dam and the Merced River confluence. This document is used to guide the design of the hydraulic structures within the Bypass. The species of interest and passage criteria for each species are given in figure 2-1, taken from the Reach 2B Project Description [SJRRP, 2012b].

In the Passage Memo, four categories were proposed for fish passage, labeled “A” through “D.” These categories range from the most inclusive to the most limited passage requirements defined for the SJR. Category A is the most inclusive and includes the adult and juvenile life stage of Chinook salmon, sturgeon, and other native fish. Category B is primarily focused on sturgeon and would provide for both adult and juvenile sturgeon passage, and possibly some other species. Category C was designed primarily to focus on the juvenile Chinook salmon passage requirements, while possibly providing for some other native fish passage. Category D was designed primarily to focus on the adult Chinook salmon passage requirements, while possibly providing for some other native fish passage.

The nature-like fishway consists of constructed channel reaches with immobile structures usually made up of different sized rocks with smaller material. The rocks may or may not be grouted or concreted into place to help limit the amount of erosion from large storm events. Nature-like fishways have a wide variety of fish passage applications. Common configurations of nature-like fishways include rock ramps spanning a part or the entire width of the channel, step-pool or cascade-pool sequences, and bypass channels (roughened channels) around dams or drop structures. Overall, slopes of nature-like fishway structures commonly range from 2.5 to 6.5 percent [DFG, 2010].

One of the advantages of the nature-like fishway is the hydraulic diversity created that provides many pathways for smaller and weaker swimming fish along the margins of the channel. Another advantage is the structures work well for upstream and downstream passage of aquatic species. Also, nature-like fishways are generally efficient at passing high flows, wood, and sediment.



Fish Passage Design Criteria

Species	Life-stage	Migration Timeframe	Frequency	Minimum Flow	Maximum Flow	Maximum Velocity[1]	Minimum Water Depth[2]	Maximum Jump Height[3]	Minimum Pool Depth
			years	cfs	cfs	fps	feet	feet	feet
Chinook salmon	Adult	Spring and fall pulse	All years except CL	115[4]	4,500	4.0	1.2	1.0	[5]
	Juvenile (upstream)	Late spring diminishing flows	All years except CL	125[6]	n/a	1.0	1.0	0.5	[5]
	Juvenile (downstream)	Nov-May	All years except CL	85[7]	n/a	n/a	1.0	n/a	[5]
Steelhead	Adult	Spring and fall pulse	All years except CL	115[4]	4,500	4.0	1.2	1.0	[5]
Sturgeon	Adult	Spring pulse	W and NW years	1,138[8]	4,500	6.6	3.3	None – swim through	n/a
Lamprey	Adult	Spring pulse	All years except CL	125[6]	4,500	[9]	[9]	[9]	n/a
Other native fish	Adult	Spring pulse	W, NW, and ND years	543[10]	4,500	2.5	1.0	None – swim through	n/a

W = wet; NW = normal wet; ND = normal dry; CL = critical low

[1] Recommended velocities are for drop structures or structures with short longitudinal lengths. For structures with longer lengths (e.g., culverts and bifurcation structures under certain conditions), maximum velocities would be based on *Anadromous Salmonid Passage Facility Design* (NMFS 2008) and *Guidelines for Salmonid Passage at Stream Crossings* (NMFS 2001).

[2] Minimum water depth criteria based on 1.5 times body depth or 1 feet depth, whichever is greater.

[3] Maximum jump height criteria based on criteria in *Anadromous Salmonid Passage Facility Design* (NMFS 2008) and *Guidelines for Salmonid Passage at Stream Crossings* (NMFS 2001).

[4] Based on Exhibit B lowest flow in the fall spawning period (starts Oct 1) for the desired frequency; all Spring Pulse Flows are higher.

[5] Pool depths to be based on criteria in *Anadromous Salmonid Passage Facility Design* (NMFS 2008) and *Guidelines for Salmonid Passage at Stream Crossings* (NMFS 2001).

[6] Based on lowest flow within Exhibit B Spring Pulse Flow period for the desired frequency.

[7] Based on lowest flow within desired migration period for the desired frequency.

[8] Wet and normal wet years constitute 50% of years in the historical record. Based on an analysis of varying Restoration Flows management strategies (Reclamation 2010); flows with a 50% exceedance could range from 1,138 to 4,500 cfs.

[9] Lamprey designs to be based on criteria in *Best Management Practices for Pacific Lamprey* (USFWS 2010)

[10] Wet, normal wet, and normal dry years constitute 80% of years in the historical record. Based on an analysis of varying Restoration Flows management strategies (Reclamation 2010); flows with an 80% exceedance could range from 543 to 4,500 cfs.

Figure 2-1.—Fish passage criteria from SJRRP Reach 2B project description [SJRRP, 2012b]

One of the disadvantages of the nature-like fishway is the large footprint needed due to the low slope; if it is not designed properly, higher flow events can cause overtopping of the barriers and may wash out of the resting pools. Additionally, large flood events can result in high maintenance costs to restore the barriers to their original configuration.

It is important to understand that typical average channel velocities, in the SJR at Reach 2B after levee setback, vary between 1 to 3 ft/s for flows between 100 and 4,500 cfs. Therefore, it is not practical to require that the velocities in the Bypass be lower than the naturally formed river, especially since the Bypass will have a slightly shorter length than the original river did at this location.

The final recommended minimum depths and maximum velocities for various categories of fish passage are given in table 2-1. The juvenile upstream passage maximum velocity of 1 ft/s in culverts or 1.5 ft/s through passage facilities is not included because this is typically exceeded in the naturally formed channel and it will not be possible to reduce average channel velocities to below 1 ft/s. The advantage of constructing nature-like fishways is that there will be diversity of velocity across the section and there will likely be multiple resting areas and slower velocity regions that can be used for passage.

The design objective for the Bypass is to accomplish Category B passage for high flows (greater than 1,000 cfs) and Category C passage for low flows (less than 1,000 cfs) during passage of restoration flows. The Passage Memo recommends that a roughened channel nature-like fishway option be selected to meet Category A passage, however, it will not be possible to maintain greater than 3.3 ft of flow depth during low flows.

During deliveries to Mendota Pool, which happen infrequently only during flood flows or very dry years, a fish passage facility will be constructed around the compact bypass control structure and will accomplish Category C passage.

Table 2-1.—Fish passage design categories [Passage Memo, SJRRP, 2014]

Category	Minimum Depth (ft)	Maximum Hydraulic Jump Height s (ft)	Maximum Recommended Design Velocity (ft/s)
A	3.3	0	2.5
B	3.3	0	4.0
C	1.2	1	2.5
D	1.2	1.5	4.0

2.2 Rearing Habitat Objectives

A description of juvenile Chinook salmon rearing habitat objectives for the SJRRP is described in a Rearing Habitat Design Objectives memo [SJRRP, 2014]. The Bypass may not be a primary location of rearing habitat, but there will be an effort to incorporate as much rearing habitat as possible into the design. The overall juvenile Chinook salmon rearing habitat design objectives for the SJRRP were as follows [SJRRP, 2014]:

- **Carrying Capacity.—**Provide adequate habitat quality and spatial extent to restore and maintain self-sustaining populations of Chinook salmon at an annual average adult return targets of 30,000 spring-run and 10,000 fall-run. This is a long-term objective that ties to the Settlement goals.

- **Temperature.—**Extend the duration of suitable rearing and migration temperatures for Chinook salmon in the spring to increase survival. This is a medium-term objective to be tackled once channel capacity exists.

- **Habitat Type Diversity.—**Restore natural diversity of in channel (also known as main channel or low flow channel), transitional zone, and seasonally inundated off-channel habitat, both spatially and temporally (i.e. at different flow levels or year-types), to increase life-history diversity, promote growth, reduce predation, facilitate outmigration, and increase survival. This is a long-term target to be accomplished with the site-specific projects, coarse sediment augmentation if needed, revegetation, and restored flow capacity.

- **Productivity.—**Increase primary and secondary production for a range of habitats within the SJRRP footprint, in order to promote higher prey densities, superior bioenergetics conditions, longer residence time, and increased growth. This is a medium-term target to be accomplished with site-specific project revegetation designs and passive restoration due to flows.

- **Vegetation Sustainability.—**Provide conditions for a self-sustaining native riparian community. This is a medium-term goal to be accomplished with flow releases, invasive species removal, and site-specific and other projects.

- **Sediment Stability.—**Provide conditions for a stable channel with an overall sediment equilibrium on a reach by reach basis. This is a long-term goal to be accomplished with site-specific and other projects, but that may not be achievable in all locations.

- **Manage Unnatural Stranding.—**This is a medium-term target to be accomplished with site-specific projects. When it is in conflict with other objectives, such as productivity, it is lower priority.

To meet these objectives, three general habitat areas were assumed to be needed as shown in figure 2-2.

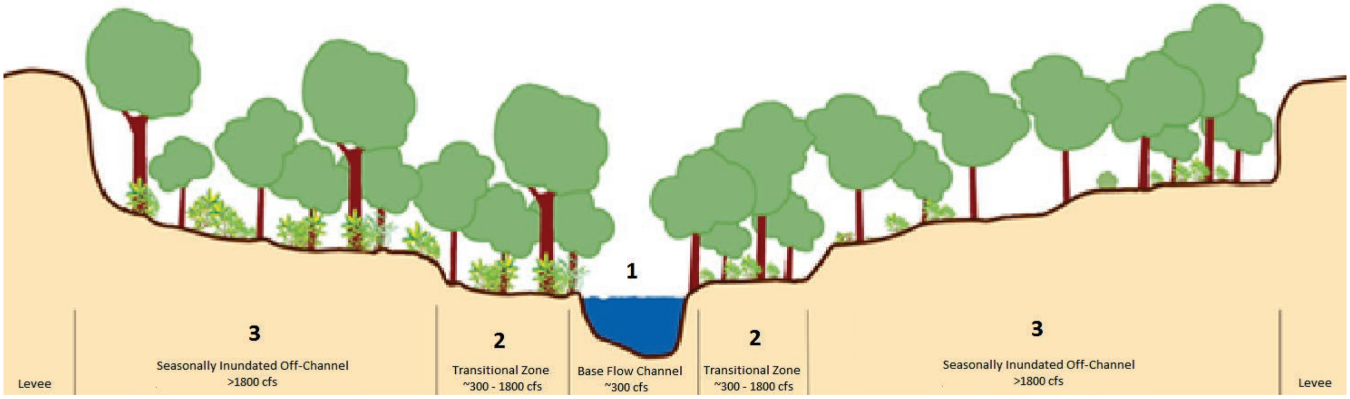


Figure 2-2.—Habitat areas identified in Habitat Rearing Objectives [SJRRP, 2014].

1. Base Flow Channel (Section 1)
    - Provides rearing habitat and migratory corridors during all years, at low flows, and during periods of elevated temperatures.
    - Widths minimized to keep temperatures low.
    - Fine structure, such as tules, to provide cover for juveniles, increasing survival, and keeping temperatures low.
2. Transitional Zone (Section 2)
    - Increases productivity and diversity of main channel habitats, reduces temperatures.
    - Forested in-channel shelves to optimize temperatures for late migrants.
    - Shelf habitat that inundates in the main channel at flows between 300-1,800 cfs; providing rearing habitat that optimizes food production, predator refuge, and migratory corridors.
    - Strategic planting of vegetation to narrow the channel, providing temperature benefits, channel stability, minimizing bank erosion, and sustaining bench inundation frequency.
3. Seasonally Inundated Off-Channel (Section 3)
    - Provides habitat diversity, escape from potential aquatic predators, and increased food and appropriate water temperatures and velocities for improved growth and survival.
    - Periodically inundated shallow aquatic habitat that contains appropriate features, such as large woody debris (LWD) and terrestrial vegetation, to provide juvenile Chinook salmon cover and refugia from predators, and high flows increasing juvenile salmon survival and reducing stress.
    - Side channels to provide juvenile Chinook salmon adequate depths, velocities, temperature, food production, and potential migration routes with reduced predation, with increased inundation frequency, increasing overall health and survival.
    - More floodplain/wetland plants in the lower reaches of the Project footprint, as appropriate to site conditions, to increase primary and secondary productivity. Strategic planting of vegetation to maximize solar radiation in winter, increase water residence time, and reduce temperatures in spring after leaf-out.

- Functions primarily during flood control releases and during pulse flow releases > ~1,800 cfs depending on the specific location.

There are various channel features that can be categorized in the above habitat areas.

1. Base Flow Channel

    - Permanent main channel habitat
    - In channel shelve and narrow low flow channels
    - Multiple low flow channels
    - Perennial marsh

2. Transition Zone

3. Seasonally Inundated Off-Channel Habitat

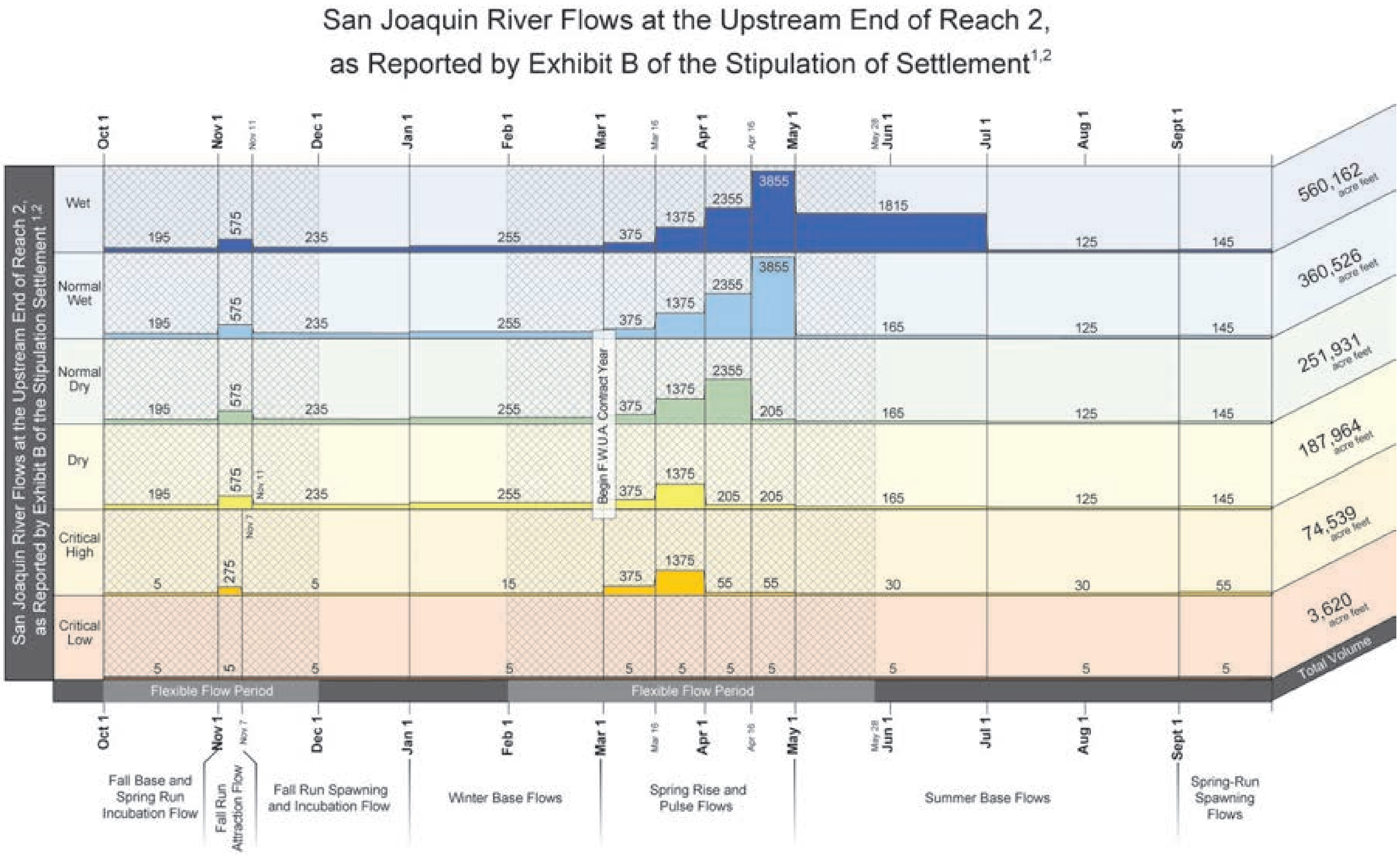
    - Seasonally inundated floodplain
    - Seasonally inundated side channel
    - Seasonally inundated depressions

2.3 Conveyance of Flows for Restoration, Flood and Diversion Operations

The SJRRP will restore perennial flow to Reach 2B, whereas prior to the SJRRP, the upstream end of Reach 2B only received water under flood release scenarios. The SJRRP will also increase the flow capacity of Reach 2B to 4,500 cfs. The original design capacity of Reach 2B was 2,500 cfs and currently is limited to 1,120 cfs [SJRRP, 2015] because of concerns of water seepage and levee stability.

The restoration flow schedules for Reaches 2 and 3, as defined by the Settlement, are given in figure 2-3 and figure 2-4, respectively. However, the actual flows in the reach will also be influenced by flood operations, which can increase or decrease flows in a given year. Hydrologic simulation is necessary to develop a full range of hydrologic scenarios, which will be used to analyze the performance of the floodplain design. A RiverWare hydrologic model was developed by the TSC [Reclamation, 2012b]. The RiverWare model uses historical tributary and inflow data and operates the San Joaquin system consistent with the Settlement.

The RiverWare simulated flows under SJRRP for the period using the historical inflows from 1923 to 2003 is shown in figure 2-5 for the stream gage SJR, which is located at the upstream end of Reach 2B. The highest flows are limited to 4,500 cfs in Reach 2B. The flow is zero more than 10 percent of the time in Reach 2B during the month of May. This is because there is a forecast component in the RiverWare model in which a 90 percent flow forecast is used to

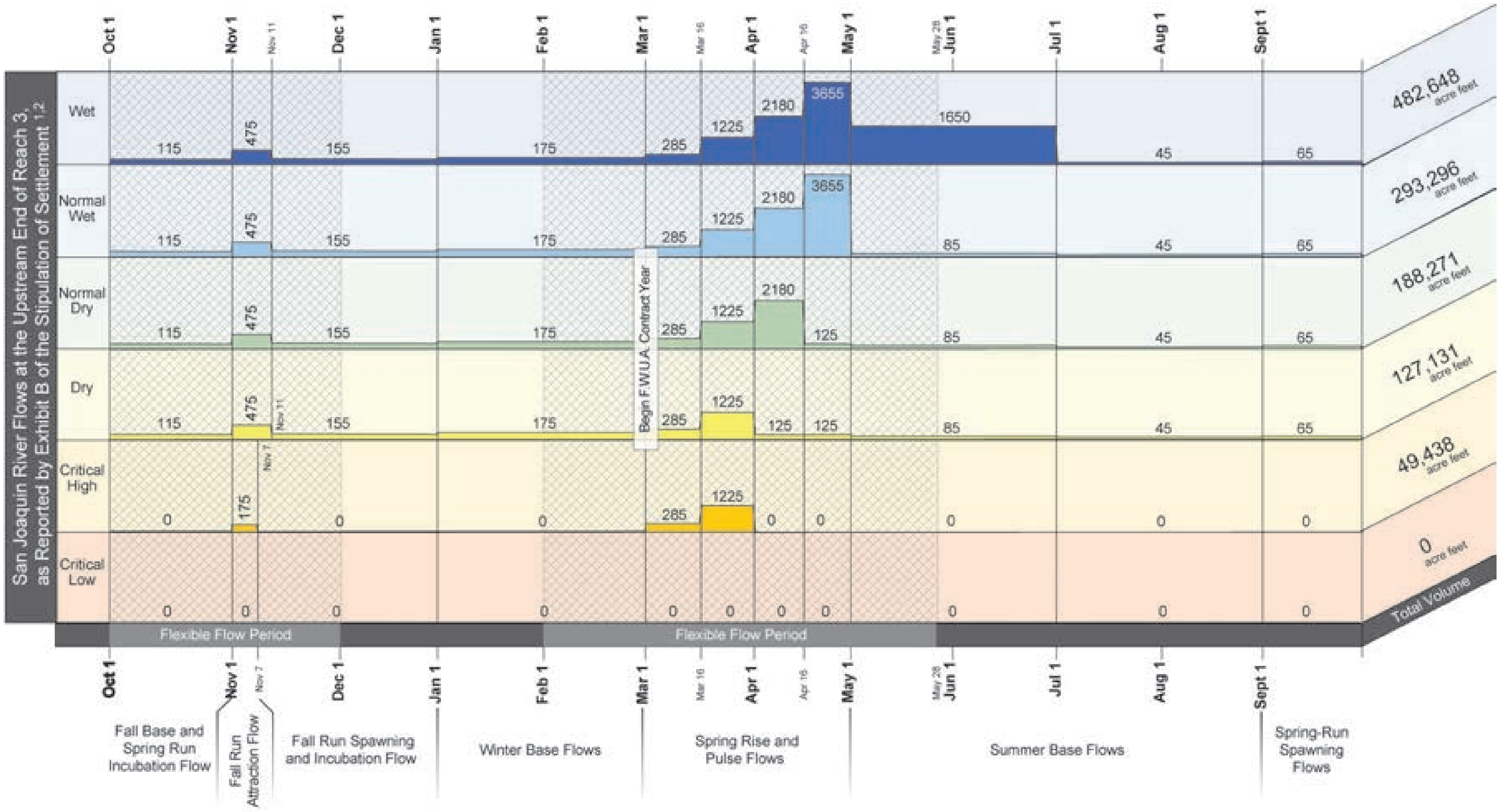


1 - NRDC v Rodgers, Stipulation of Settlement, CIV NO. S-88-1658 - LKK/GGH, Exhibit B, September 13, 2006

2 - Hydrographs reflect assumptions about seepage losses and tributary inflows which are specified in the settlement

Figure 2-3.—San Joaquin River flows at upstream end of Reach 2 as reported in Exhibit B of Stipulation of Settlement.

San Joaquin River Flows at the Upstream End of Reach 3, as Reported by Exhibit B of the Stipulation of Settlement[1,2]



1 - NRDC v Rodgers, Stipulation of Settlement, CIV NO. S-88-1658 - LKK/GGH, Exhibit B. September 13, 2006
2 - Hydrographs reflect assumptions about seepage losses and tributary inflows which are specified in the settlement

Figure 2-4.—San Joaquin River flows at upstream end of Reach 3 as reported in Exhibit B of Stipulation of Settlement.

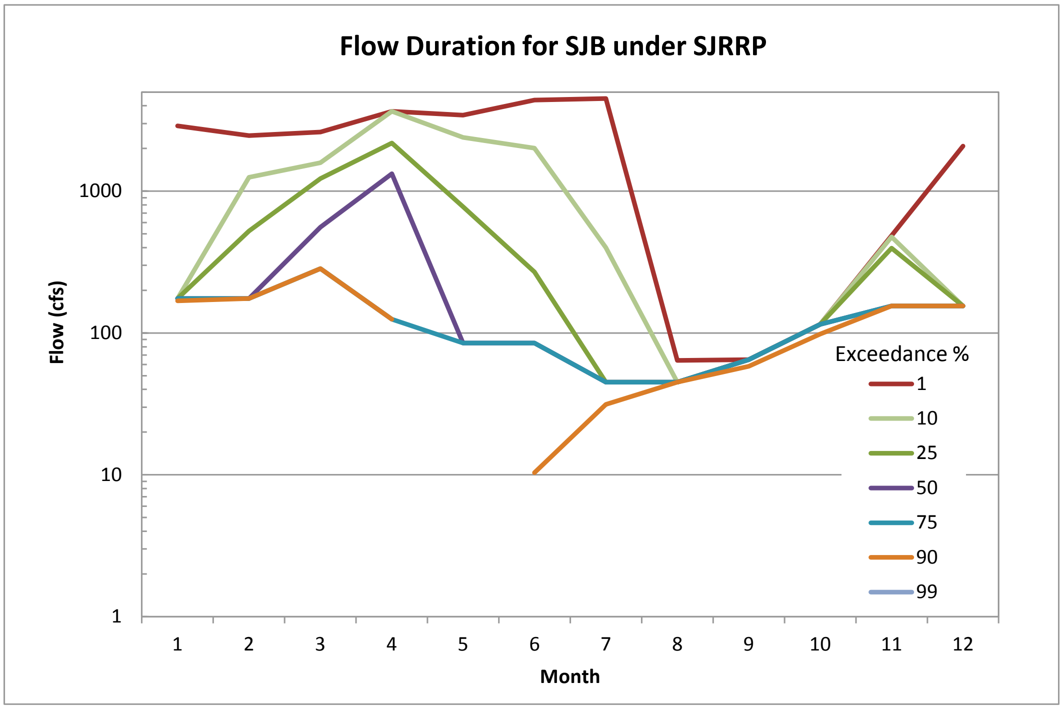


Figure 2-5.—Simulated monthly flow duration at SJR
(stream gage at upstream end of Reach 2B) under the SJRRP.
The 99 percent exceedance is 0 for all months and not shown on log-scale plot.

choose the water year type for the month of May, meaning that in 90 percent of the years the flow volume would be greater than that forecast. The forecast component is necessary to represent the uncertainty water managers will have when releasing water in the early spring. The water year type can be critical-low, critical-high, dry, normal-dry, normal-wet, and wet. Whereas, after May, a more accurate water forecast is available and more flow will generally be available for restoration flows. The 99 percent exceedance flow is zero for all months because in critical-low years there is zero restoration flow available.

There are four basic flow scenarios involving restoration flows, flood flows, and water deliveries that will typically occur in Reach 2B:

1. In critical-low to normal-wet water year types, restoration flows will proceed through Reach 2B and irrigation deliveries and diversions will occur in Mendota Pool with no interaction between the restoration flows in Reach 2B and Mendota Pool.

2. In wet water year types, flood releases from Pine Flat Reservoir may be bypassed to the SJR via Fresno Slough and Mendota Pool. Due to capacity restrictions downstream of Reach 2B, the addition of these flows further restricts the amount of flow that can enter Reach 2B, and more SJR flows will be diverted into the Chowchilla Bypass to compensate. Some portion of the SJR flows is anticipated to perform as restoration flows in

Reach 2B, but the flood management agencies will have ultimate discretion in directing flood flows.

3. In normal-wet to wet water year types, flood releases from Millerton Lake may be diverted from Reach 2B into the Chowchilla Bypass as well as to Mendota Pool where they can be used to fulfill water contracts or by legal water rights holders while alleviating pressure on the flood system. Some portion of these flows is anticipated to perform as restoration flows in Reach 2B, but the flood management agencies will have ultimate discretion in directing flood flows.
4. In all water year types, water can also be released from Millerton Lake to make water deliveries to Mendota Pool where they can be used to fulfill water contracts or used by legal water rights holders.

To meet these flow scenarios, the hydraulic system should be able to achieve the flow conditions shown in table 2-2 while still meeting fish passage criteria to the extent possible. There are three potential water operations conditions: 1) Restoration, 2) Flood, and 3) Delivery, to Mendota Pool (delivery) and then there are two potential combinations of the three operation conditions: 1) Restoration and Delivery and 2) Flood and Delivery. The values shown in table 2-2 are intended to span the range of potential operations and not resolve all potential intermediate operational scenarios. The flow schematic is shown in figure 2-6.

Table 2-2.—Range of Design Conditions for Flow Operations for the Mendota Bypass Project. Values Shown Represent Discharge in CFS

Scenario	Reach 2B	Bypass	Reach 2B Below Bypass	Fresno Slough	Reach 3 Above Bypass	Reach 3 Below Bypass
Restoration	45-4,500	45-4,500	0	0	0-600	45-4,500
Flood	45	45	0	4,455	4,455	4,500
	4,500	4,500	0	0	0	0
Delivery to Mendota	0-2,500	0	0-2,500	0	0-600	0-600
Restoration /Delivery	2,595	45	2,500	0	45-600	45-645
	4,500	2,000	2,500	0	0-600	2,000-2,600
Flood/Delivery to Mendota	4,500	2,000-4,500	0-2,500	0	0	2,000-4,500
	2,500	2,500	2,500	4,500	4,500	4,500

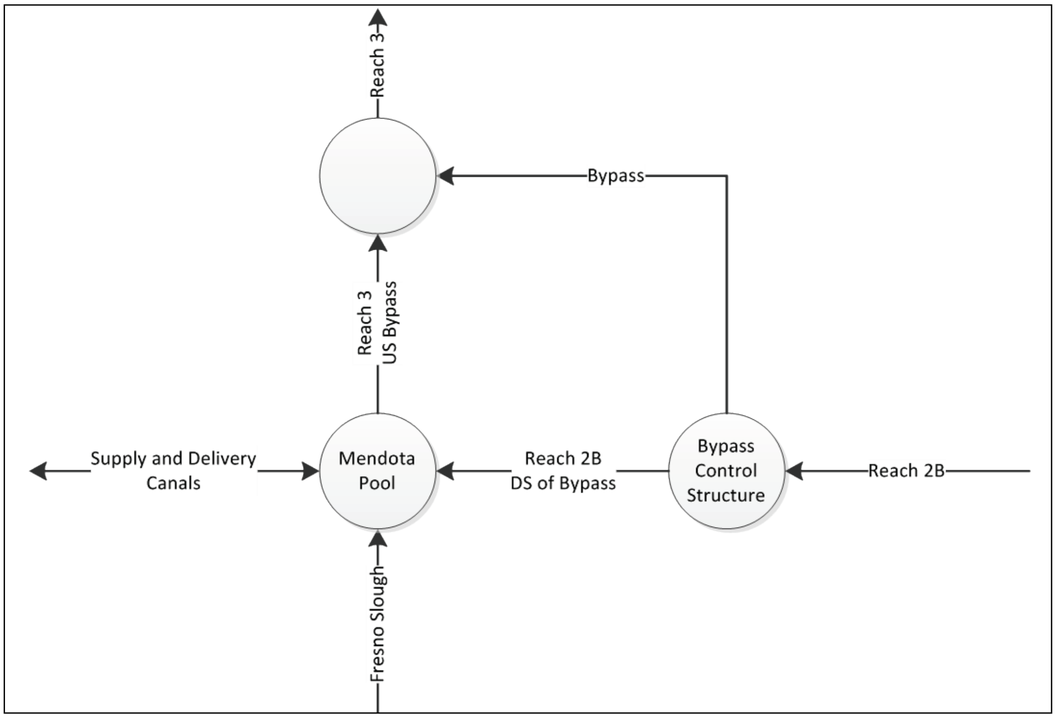


Figure 2-6.—Flow schematic of Bypass Project.

2.4 Sediment Transport

The primary object of the sediment transport conditions is to prevent undesirable bed erosion or deposition in Reach 2B and the adjacent Reaches 2A and 3. This is often described as a sustainable channel or stable channel since the transport of sediment into the Project reach should match the transport of sediment out of the reach. Some immediate erosion and deposition is expected due to the large increase in peak flows within Reach 2B and the construction of the Bypass, but there should be no long-term erosion and deposition within the reach that is undesirable.

To be a sustainable channel, sedimentation at structures should be minimized and there should no longer be dredging required near structures and within the channel. When structures restrain the morphology of the channel, some maintenance at grade control or bank protection locations will be required. The first goal is to develop a sustainable channel design, but if this cannot be done, the selected design should minimize anticipated maintenance.

2.5 Subsidence

There is active subsidence occurring in Reach 2B and in reaches downstream [Reclamation, 2012c]. The design goal is to account for the direct and indirect effects of subsidence in both Option 1 and Option 2 at structures and in the channel profile design. The design goal is to account for the direct and indirect effects of subsidence in both Option 1 and Option 2 so that future channel sustainability or structure stability will not be threatened. The current subsidence rates, along with the potential total subsidence if these rates were to continue for a given period of time, is provided in table 2-3.

Table 2-3.—Current Subsidence Rates Near Reach 2B along the San Joaquin River

River/Bypass Reach: (River Mile(RM)/Mile Post to RM/Mile Post)	Subsidence Rate (feet/year)	Projected Total Subsidence in 25 yrs (feet)
Reach 2B (RM 216.3 to RM 210.0)	0.10	2.50
Reach 2B (RM 210.0 to RM 207.0)	0.15	3.75
Reach 2B (RM 207.0 to RM 204.0)	0.20	5.00
Reach 3 (RM 204 to RM 200.2)	0.20	5.00
Reach 3 (RM 200.2 to RM 196.9)	0.10	2.50
Reach 3 (RM 196.9 to RM 194.9)	0.20	5.00
Reach 3 (RM 194.9 to RM 188)	0.30	7.50
Reach 3 (RM 188 to RM 184.5)	0.20	5.00
Reach 3 (RM 184.5 to RM 182.7)	0.30	7.50
Reach 3 (RM 182.7 to RM 182.0-Sack Dam)	0.40	10.00

2.6 Vegetation

Vegetation objectives were suggested by ESA [ESA 2012], and a modified version of them follows:

- Short-term Goals (Years 1 to 10):
    - Revegetate disturbed channel banks and floodplain/newly created channels to provide stability.
    - Establish widespread beneficial vegetation within the bypass floodplain and channel margins.
    - Manage flows through the bypass to promote beneficial riparian vegetation establishment, as feasible.
    - Remove existing populations of invasive plant species and maintain to limit impacts to habitat.
    - Use LWD to encourage channel and floodplain complexity.

- Long-term Goals (Years 10 to 30):
    - Contiguous expanses of multi-tiered vegetation within the bypass (target acreage to be determined following more detailed revegetation design of the selected alternative).
    - Areas of natural riparian recruitment where sediment is deposited or vegetation removed by natural processes to promote continual habitat succession.

  - Natural recruitment and addition of LWD to the channel and floodplain.
  - Well established and stable ecosystem including a mosaic of herbaceous, shrub, and tree communities.

2.7 Design Objectives Summary

Project design objectives for the Bypass are consistent with the SJRRP goals that are to pass and support Chinook salmon fisheries, and to manage flows in a manner that minimizes impacts to water delivery.

The goal of the Project is to bypass the Mendota Pool with a system that promotes and maintains Chinook salmon migration. Essential design objectives, based on the more detailed goals, objectives, and desired conditions described above, are listed as:

- For the Bypass, accomplish Category B passage for high flows (greater than 1,000 cfs) and Category C passage for low flows (less than 1,000 cfs) during passage of restoration flows.
- During deliveries to Mendota Pool, which happen infrequently only during flood flows or very dry years, a fish passage facility will be constructed around the Bypass control structure and will accomplish Category C passage.
- Promote survival of the species through development of appropriate and sustainable habitat.
- Create a bypass channel around Mendota Pool to ensure conveyance of at least 4,500 cfs through Reach 2B to Reach 3. This improvement requires construction of a structure capable of directing flow down the bypass and allowing the Secretary to make deliveries of SJR water into Mendota Pool when necessary.
- Maintain current flood conveyance capacities in Reach 3.
- Minimize both construction and maintenance cost.
- Create a sustainable stream profile that minimizes long term sediment imbalances within the project area.

Rearing habitat objectives, vegetation habitat, sustainability issues (sediment transport, subsistence and maintenance concerns) are all elements of criteria 2, appropriate and sustainable habitat. Systems with functioning and sustainable river processes provide both desirable habitat and help minimize maintenance costs.

3 Design Development and Analysis

Perhaps the most critical design decision for the Bypass is the sill elevation of the flow control structure that will be placed at the upstream end of the Bypass. The elevation of the structure will define the slope in the Bypass and the slope in Reach 2B, upstream of the Bypass. The slope will then be the dominant variable determining the hydraulic and sediment transport characteristics of those reaches.

To determine the elevation of the flow control structure that best meets project objectives, two options will be analyzed. The two options will be based upon two choices of the Reach 2B design slope. The low slope estimate will be used to define Option 1 and the high slope estimate will be used to define Option 2. The range was defined as the potential range in slope that would met the project objectives. The analysis of the two options will determine which Option best meets the project objectives.

The current slope of the reach upstream, Reach 2A, is 0.00035, and the slope of Reach 3 is 0.00021 [Reclamation, 2009]. The bed slope of Reach 2B is variable, with the portion upstream of the Mendota Pool having a much smaller slope than the upstream portion of Reach 2B. The current profile in Reach 2B is shown in figure 3-1. Mendota Dam was built prior to 1900 so there has been more than 100 years for sediment to deposit behind the dam. The natural stream slope in the lower portion of Reach 2B was likely similar to the slope in the upper portion of Reach 2B prior to the construction of the dam.

3.1 Option 1

The design for Option 1 is analyzed and developed in the following section.

3.1.1 Profile

The low estimate of the design stream slope in Reach 2B corresponds to Option 1 and was computed by fitting a line to the thalweg elevation in Reach 2B in the area not influenced by the Mendota Pool, assuming that Mendota Pool extends approximately 3 miles upstream of the confluence with the Bypass (figure 3-1). Under Option 1, the sediment delta caused by the Mendota Pool was assumed to extend approximately 3 miles upstream of the Bypass confluence. Under Option 1, the sill of the structure will be placed at 145 ft (NAVD88), which corresponds to the low estimate of the average stream slope of 0.00028 in Reach 2B. The slope in the Bypass is 0.0013 for Option 1. A summary of elevations and slopes for each option is given in table 3-1.

It should be noted that these elevations are the intended elevations after the stream profile has stabilized. Therefore, the upstream elevation in Reach 3 is different for Option 1 and 2. Both options remove the hydraulic control that exists due to Mendota Dam and allows some river bed material that was deposited in the pool of Mendota Dam to be eroded and transported into Reach 3. The current bed elevations in Reach 2B near the entrance to the Bypass are approximately 148 to 149 ft. Option 1 allows approximately 3 to 4 ft of incision into Reach 2B. Some of the sediment eroded from Reach 2B will be deposited into Reach 3 and the bed elevations in Reach 3 will increase. The design bed elevations in Reach 3 after deposition of material from Reach 2B is given in table 3-1. The erosion in Reach 2B will decrease water surface elevations in Reach 2B and deposition in Reach 3 will potentially raise water surface elevations in Reach 3. These impacts are analyzed in Appendix C—Hydrologic, Hydraulic, and Sediment Transport Modeling.

Table 3-1.—Design Elevations for Option 1 and 2 in Various Reaches. (Elevations are given to nearest foot except for bypass reach where they are given to nearest 0.5 ft.)

	Upstream Elevation (ft)	Downstream Elevation (ft)	Reach Design Slope (-)
Reach 2A	186	161	0.00035
Option 1			
Reach 2B	161	145	0.00028
Bypass Reach	145	138	0.00130
Reach 3	138	116	0.00022
Option 2			
Reach 2B	161	141.5	0.00035
Bypass Reach	141.5	139	0.00047
Reach 3	139	116	0.00023

There has been physical and chemical sampling of the river bed material in Reach 2B immediately upstream of the Bypass [Reclamation, 2012e]. The average composition of three drill holes (DH-18, -19, and -20) collected within the first mile upstream of the connection with the Bypass was 80 percent sand, 12 percent silt, and 7 percent clay. The material in Reach 3 at the Mendota stream gage is approximately 90 percent sand with the remainder small gravels (table C-5). The material in the lower portion of Reach 2B is slightly finer than Reach 3 because it is located in the backwater of Mendota Dam. However, because the vast majority of the material in lower Reach 2B is sand sized material, it will become integrated into and indistinguishable from the existing bed material in Reach 3.

Because the slope of the Bypass under Option 1 is much larger than the upstream reach, grade stabilization features need to be added to stabilize the Bypass channel. At this stage of design rock ramps are suggested as the grade control mechanism because these will provide grade control and provide fish passage under a wide range of conditions and for a wide range of fish species. An example rock ramp design is shown in figure 3-3. The Passage Memo [SJRRP, 2014] states that rock ramps would be classified as ‘Type A’ fish passage structures, which are the structures with the greatest range of fish passage. It is assumed that each structure should have a downstream slope of no more than 4 percent and have no more than 1 foot (ft) of hydraulic drop between them. There are six rock ramp structures necessary and they are approximately equally spaced through the Bypass. Using the U.S. Army Corps of Engineers' (Corps) Engineering and Design Manual (EM)1601 – Hydraulic Design of Flood Control Channels, rock size method for slopes of between 2 to 20 percent (Eq. 3-5 of the manual), the ramps will be covered with an armor layer of loose rock with a D_{50} of approximately 12 inches. Using the scour prediction methodology of Comiti et al. [2006] gives an expected scour of 5 ft on the downstream side. The rock ramp will span the bankfull channel and be keyed into the bank an additional 15 ft to prevent flanking of the structure. It is estimated that each structure will require 2,500 yd^3 of rock for a total of 15,000 yd^3.

3.1.2 Cross Section

Two types of sections are necessary in the Bypass: riffle sections and pool sections. Riffle sections correspond to the grade stabilization features and the pool sections correspond to the reaches between the grade stabilization features.

The riffle section is designed to be essentially a four-stage channel. The four stages approximately correspond to flows of 75, 200, 1,500, and 4,500 cfs. The four stage channel can also be described as the low flow, base flow, bankfull, and flood flow channels. The pool sections are three stage channels that correspond to flow levels of 200, 1,500, and 4,500 cfs. The stages were designed to decrease the velocities as much as possible to approach the velocity objectives shown in table 2-1 across the full range of flow conditions. In addition, the narrower low flow channel was necessary to meet the depth objectives of table 2-1.

A Hydrologic Engineering Centers River Analysis System (HEC-RAS) was used to simulate the flow conditions within the Bypass channel assuming the conditions are as initially constructed. The details of the modeling are described in Appendix C—Hydrologic, Hydraulic, and Sediment Transport Modeling. The channel geometry and channel roughness are illustrated in the channel cross section in figure 3-4. The channel geometry is based upon initial conditions prior to any channel adjustment and assuming excavation only takes place within the Bypass and that no material is excavated or placed into Reaches 2B or 3.

The water surface profile through the Bypass channel immediately after the construction is shown in figure 3-6. There is only about 1 ft of water surface elevation drop for a flow of 4,500 cfs, similar to the Reach 3 river slope of 0.00022 [Reclamation, 2009]. At a flow of 100 cfs, there is about 7 ft of elevation drop across the bypass.

The low flow section within the rock ramp has a base width of only 8 ft so that the depth of 1.2 ft can be maintained for flows of 100 cfs or greater. The base flow channel contains 200 cfs and is approximately 70 ft wide. The bankfull channel is intended to contain about 1500 cfs and is 190 ft wide. The maximum depth of flow throughout the Bypass is greater than 1.4 ft for all flows above 100 cfs. The depth of flow is greater than 1 ft for flows above 75 cfs.

The average channel velocities are generally less than 4.6 ft/s for all flows (figure 3-7). The maximum channel velocities occur at the upstream end of each ramp and generally decrease as the backwater from the next downstream ramp decreases the flow velocities down the ramp. The highest channel velocities occur at flows below 1,000 cfs because backwater effects from Reach 3 begin to have significant influence throughout the Bypass for larger flows. Because of the high slope for the Bypass reach, it may not be possible to meet the velocity criteria given in table 2-1.

The channel will also be designed to support a dense riparian corridor that will maintain channel stability and benefit aquatic and terrestrial habitat. These flow stages are also roughly consistent with the Habitat Areas identified in Habitat Rearing Objectives [SJRRP, 2014] and shown in figure 2-2 that identified the base flow channel for flows below 300 cfs, the transitional area for flows between 300 and 1,800 cfs, and the seasonally inundated off-channel habitat areas that becomes inundated at flows above 1,800 cfs. The floodplain is intended to inundate significantly at about 2,000 cfs and will be approximately 2.5 to 3.5 ft above the base flow elevation at a flow of 200 cfs, with a width of 155 ft on either side of the bankfull channel. This surface will support a dense mixed riparian forest that will assist with the stabilization of the channel and improve aquatic habitat.

The channel response was analyzed using a sediment transport model SRH-1D [Sedimentation and River Hydraulics – One Dimension, Huang and Greimann, 2012]. The details of the modeling are described in Appendix C—Hydrologic, Hydraulic, and Sediment Transport Modeling. The model was used to predict the erosion in reach 2B and the deposition in Reach 3 that will occur as a result of the project. The model predicted that there would be approximately 3 to 4 ft of incision at the downstream end of Reach 2B where it connects into the Bypass (figure 3-8). The incision gradually decreases until it is approximately zero about 3.5 miles upstream of the Bypass (RM 209.7). There is up to 5 ft of deposition in Reach 3 immediately below the Bypass that gradually decreases to zero deposition approximately 0.7 miles downstream of the Bypass. The majority of the erosion and deposition will occur within the first year, but the channel will continue to slowly adjust for several years into the future. Part of the excavation design could be to excavate river bed material from Reach 2B, prior to the release of water into the Bypass, so that there is not a large release of sediment in the first year, but that option was not simulated here.

The pool sections are generally expected to become deeper and wider because of the high velocities through the reach, with pool depths over 5 ft at base flows of 100 cfs. However, deposition could occur at high flow in the lower Bypass

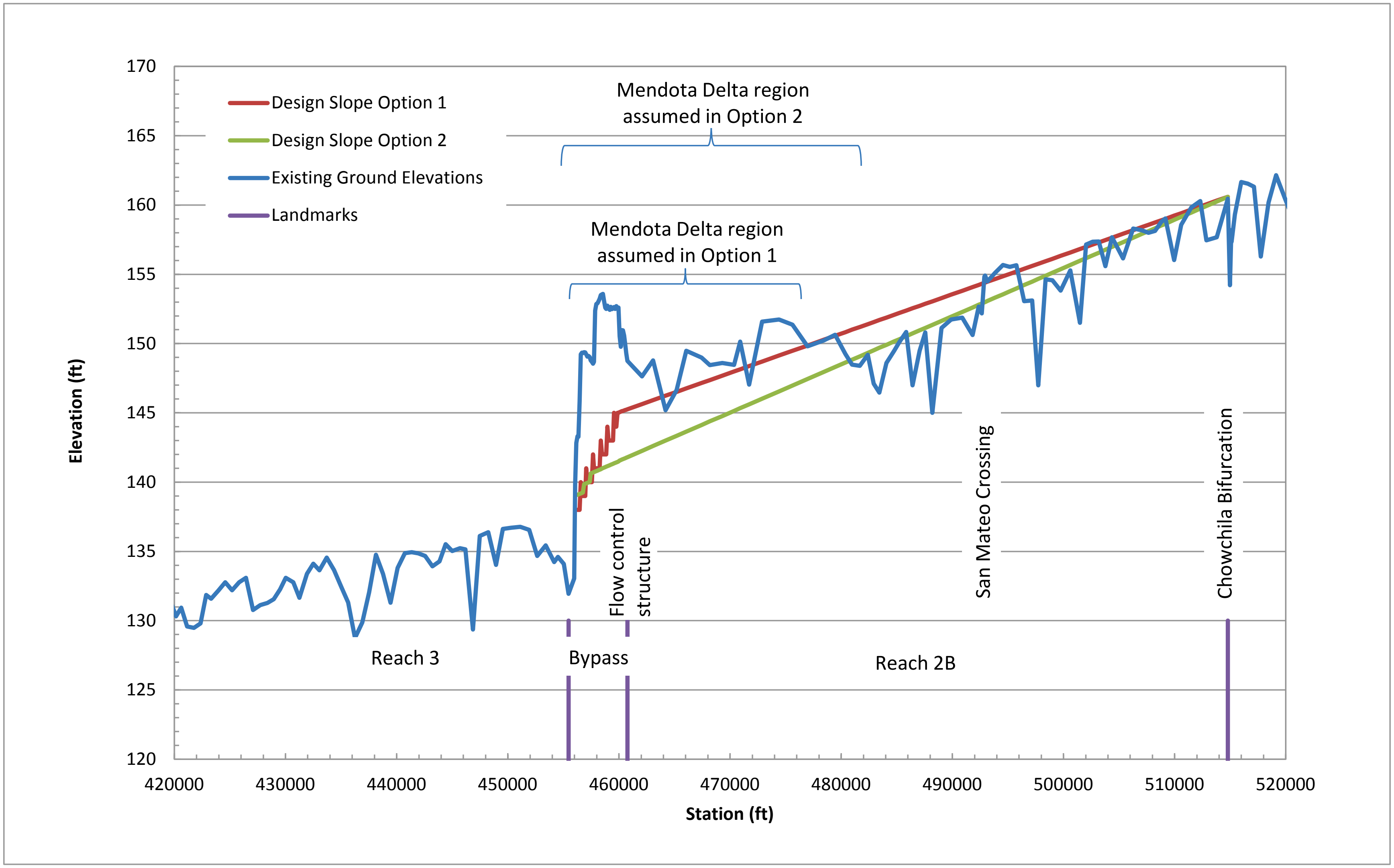


Figure 3-1.—Existing stream profile in Reach 2B and low and high estimates of the design stream slope in Reach 2B. The stationing is relative to the end of the SJRRP project reach.

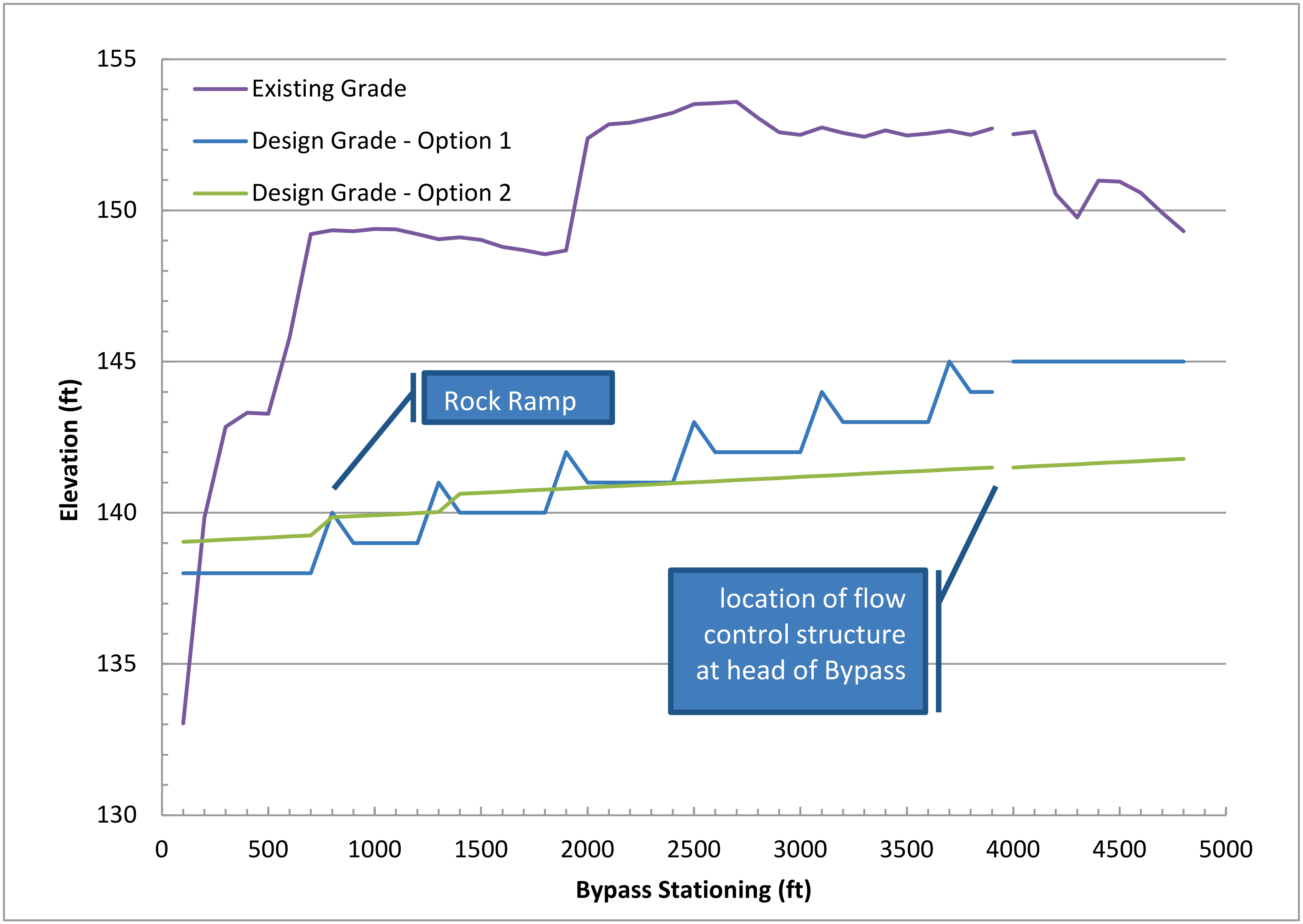


Figure 3-2.—Profile through Bypass for Options 1 and 2.

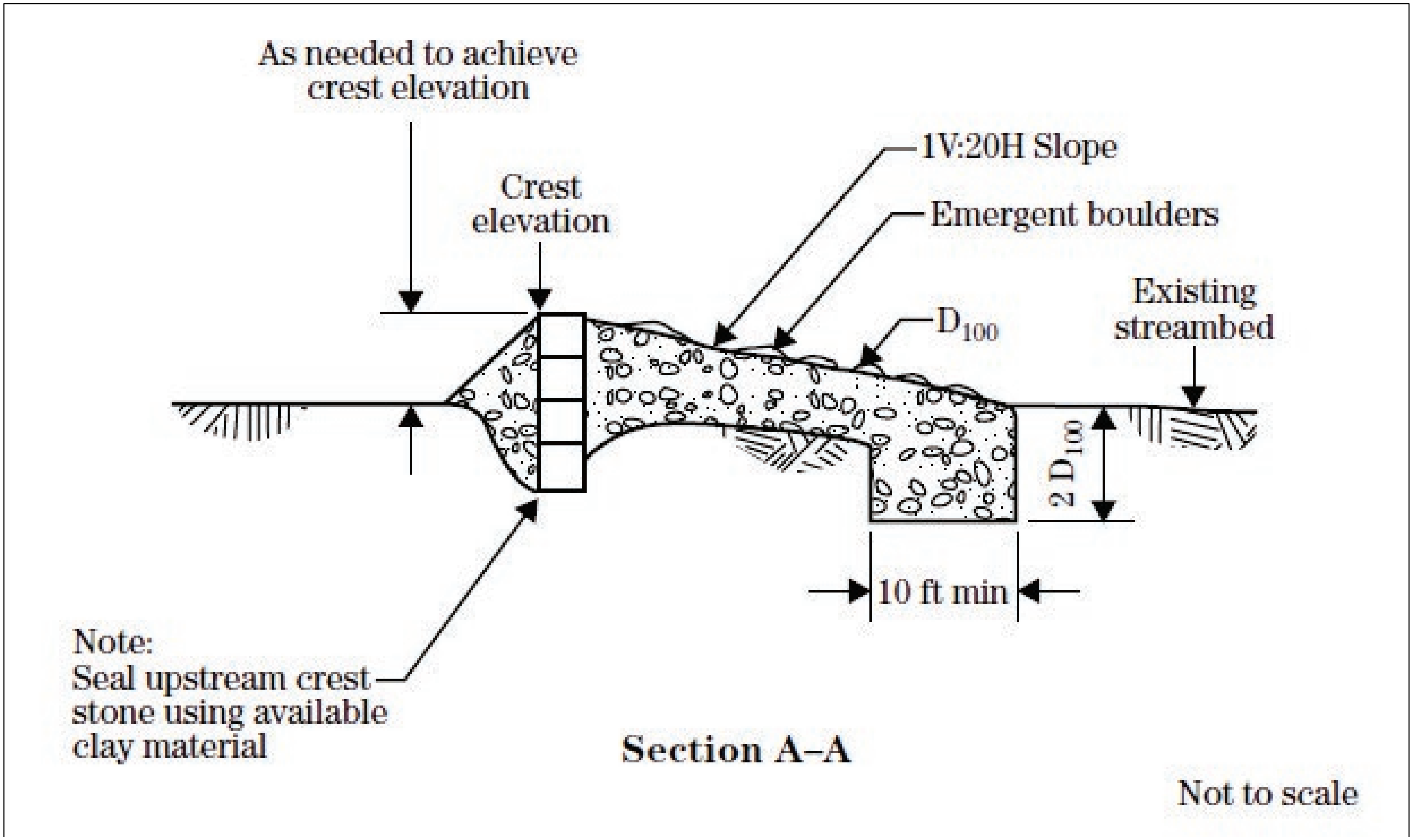


Figure 3-3.—Example rock ramp from NRCS [2007a].
A sheet pile or other impermeable structure may replace the stone cutoff wall in actual design.

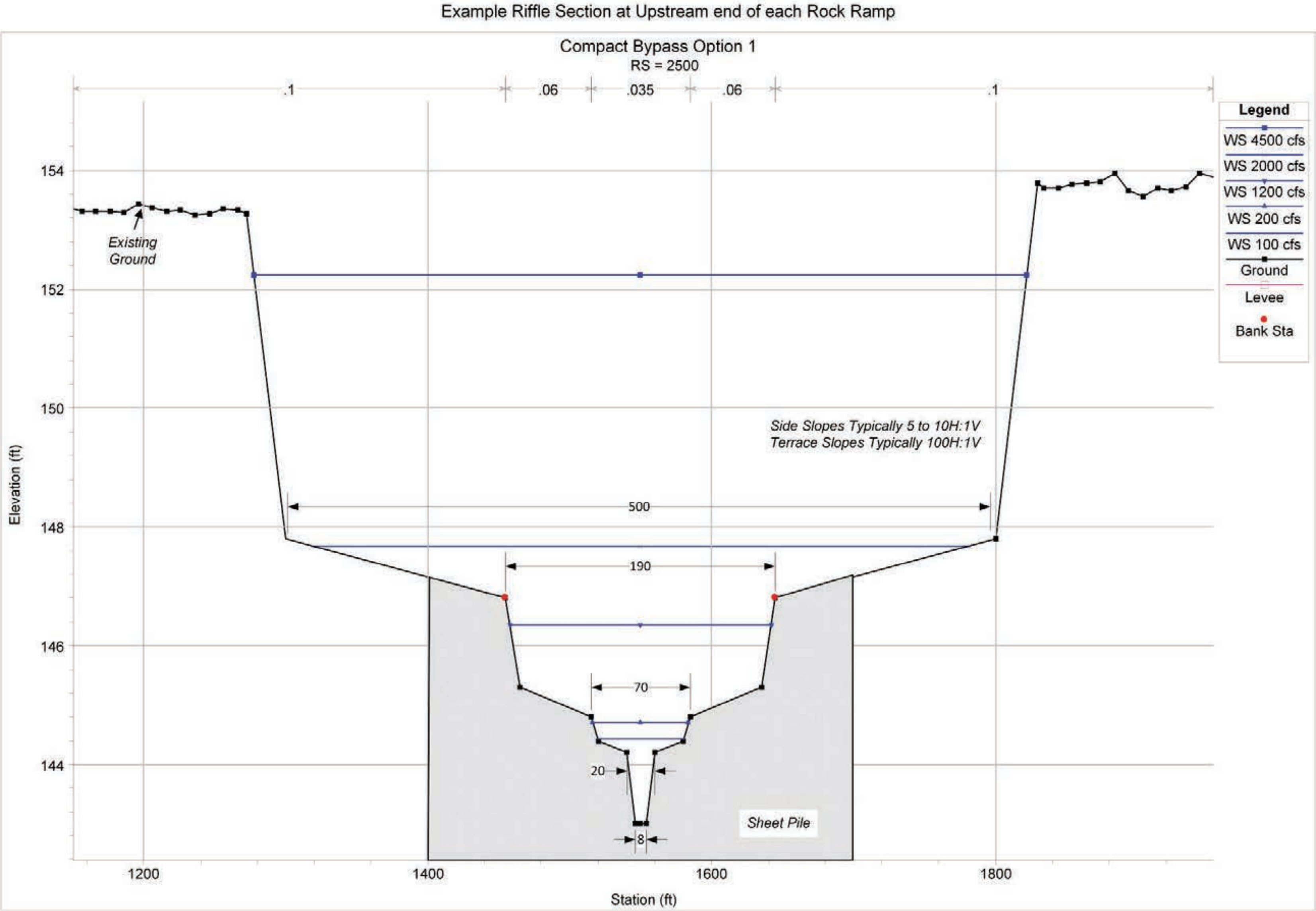


Figure 3-4.—Conceptual riffle section for Option 1.

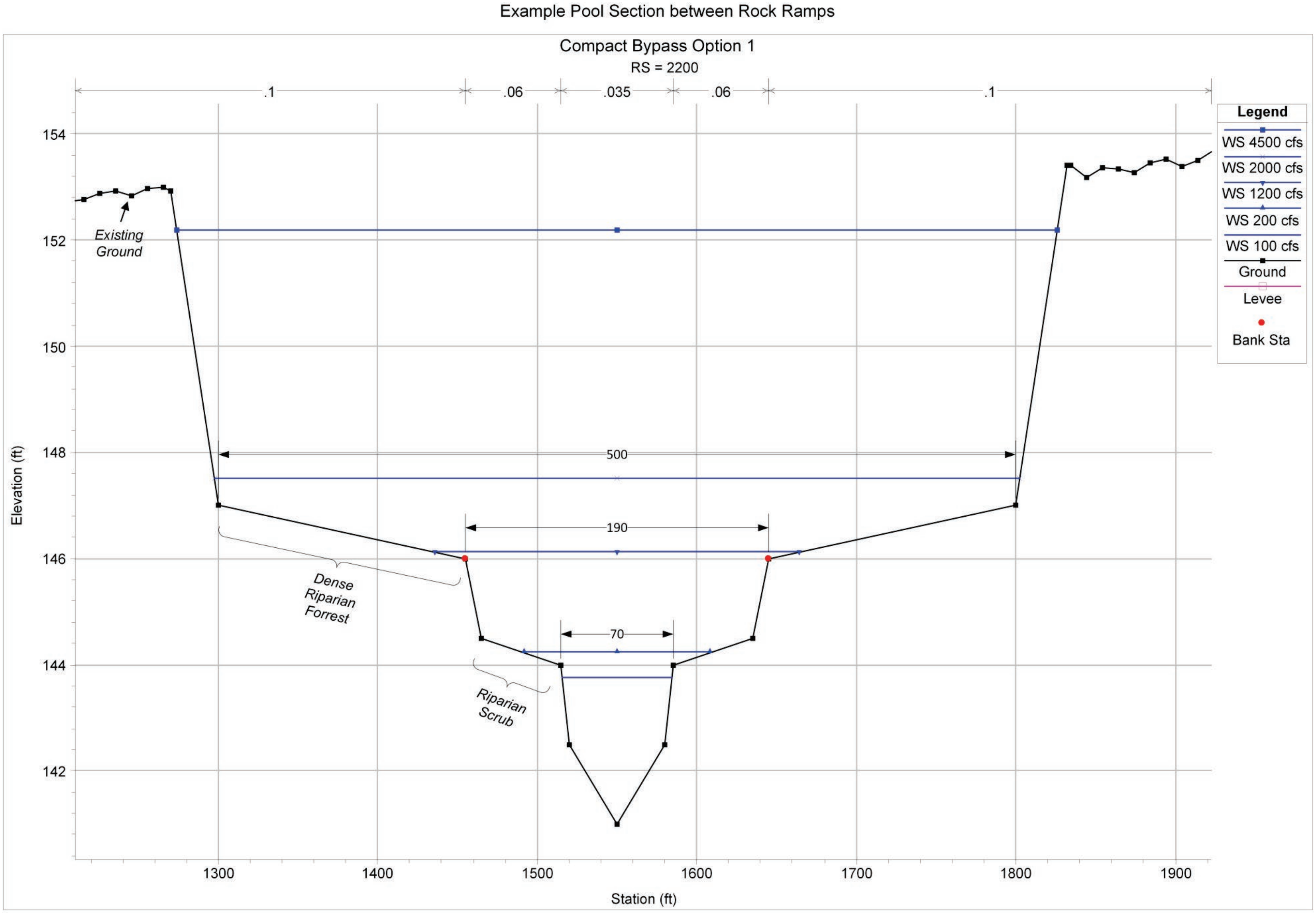


Figure 3-5.—Conceptual pool section for Option 1.

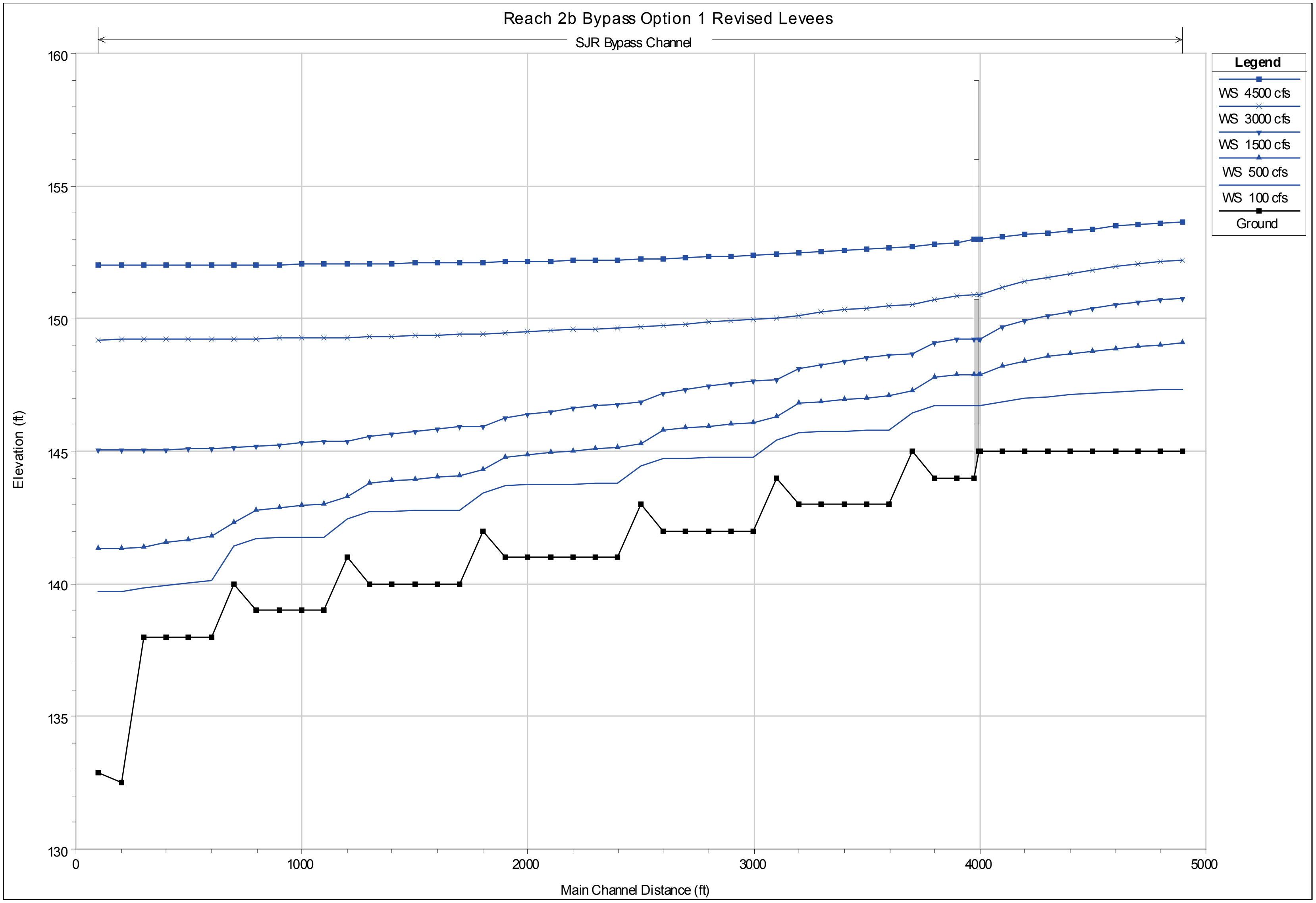


Figure 3-6.—Initial water surface profile in Bypass channel for Option 1.

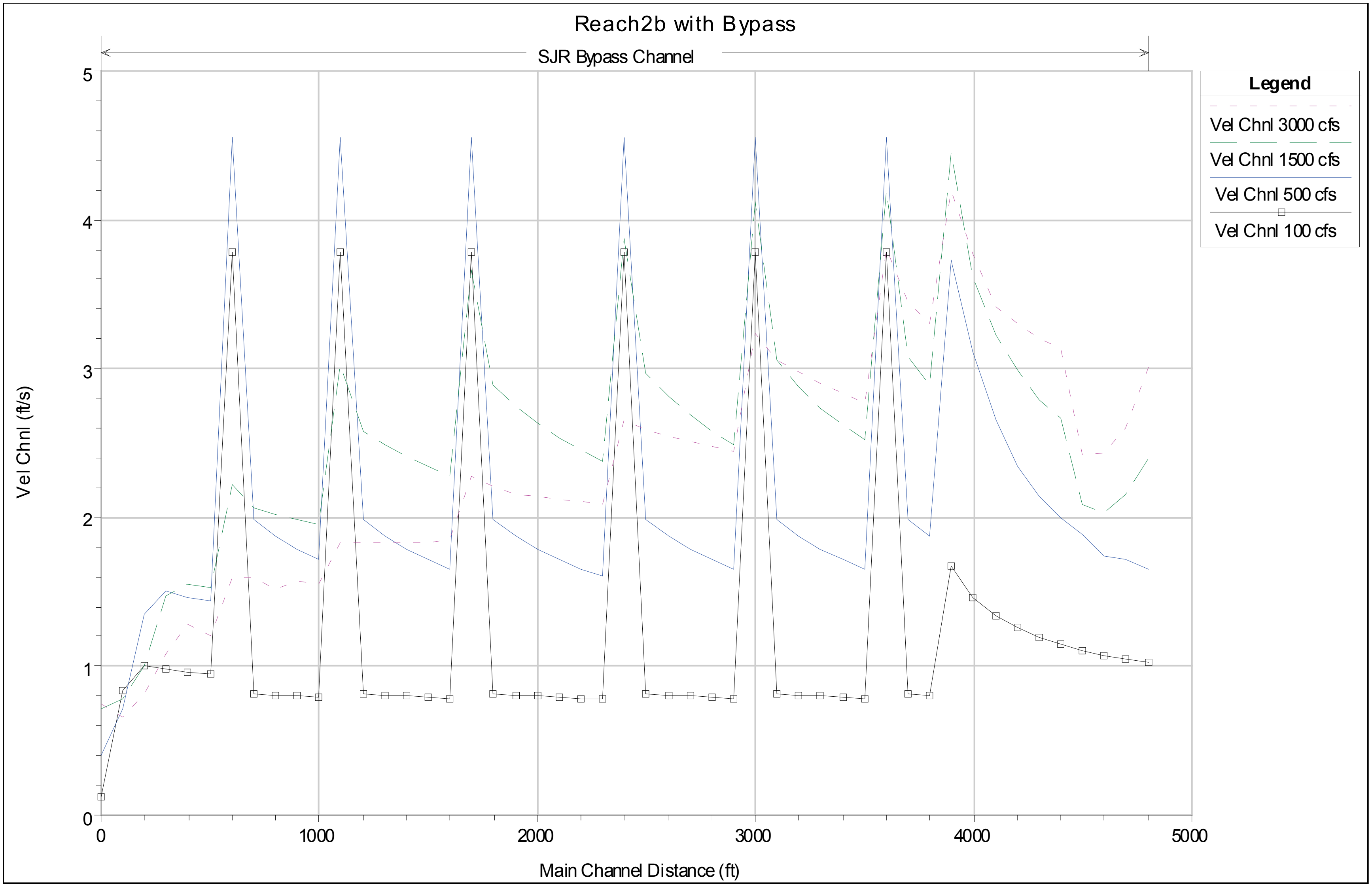


Figure 3-7.—Initial channel velocities in Bypass channel for Option 1.

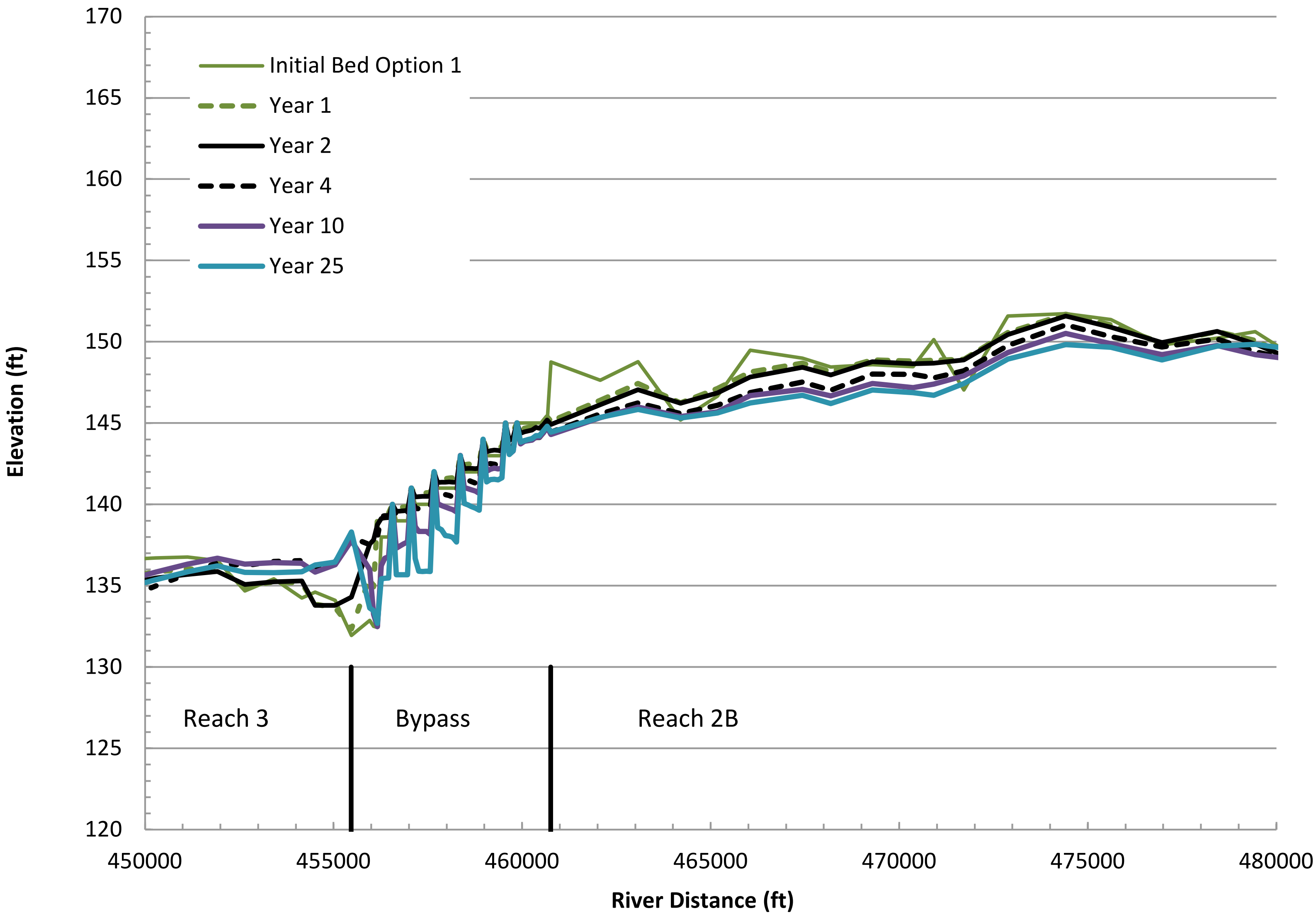


Figure 3-8.—Thalweg elevation for Option 1 for various years after return of flows to Bypass.

because the backwater caused by Reach 3 decreases the flow velocities in the lower Bypass at high flows (greater than 1,500 cfs) and sand will likely deposit in the lower Bypass at high flow and then scour at low flow.

Two major uncertainties in the modeling are the effects of subsidence on the reach and the sediment supply from Fresno Slough. To assess these uncertainties simulations were performed with and without subsidence and with and without flows from Fresno Slough. The main effect of these uncertainties on the Bypass design is that water surface elevations in Reach 3 will be uncertain. Two possibilities exist: one is that deposition in Reach 3 will cause the most downstream rock ramp to be unnecessary, and the other possibility is that the water surface elevations decrease and that the last rock ramp needs to be extended or another needs to be added downstream. The Bypass will need to be monitored after significant flow events to ensure that the rock ramps are performing adequately, particular the most downstream rock ramp that connects the Bypass to Reach 3.

3.1.3 Bank Protection

The Bypass channel will be excavated into unconsolidated silty and sandy material that is highly erodible. This, coupled with the velocities that are higher than in other portions of the San Joaquin, creates a condition in which bank erosion is likely. The velocities in the upper portion of the Bypass are over 3 ft/s, which may require more than natural vegetation to protect [Gray and Sotir, 1996; Reclamation, 2015].

There are basically two banks that potentially require protection: the low flow channel bank and the ‘bankfull’ channel bank. The low flow channel is approximately 70 ft wide and contains the base flows up to 200 cfs. The bankfull channel contains flows up to approximately 1,200 cfs and is 190 ft wide.

Large woody material (LWM) is used to provide stabilization and habitat improvement for the low flow channel and will be designed consistent with guidelines in Natural Resources Conservation Service (NRCS) [NRCS, 2007c]. These structures can provide cover in the scour pools downstream of the grade control structures. The structures will also provide stabilization of the low flow channel until natural woody vegetation becomes established along the low flow channel

The major categories that would be potentially used to stabilize the high flow channel in the Bypass are:

- **Riparian Vegetation.—**If the woody riparian species are given enough time to establish and create root structure, they add sufficient strength to the banks to resist erosion.

- **Rock Vanes.—**These structures are low dikes or sill-like structures that extend from the bank towards the stream in an upstream direction [NRCS, 2007a].

- **Large Woody Material (LWM).—**There are several methods which use LWM to provide bank protection either through flow deflection or through reinforcement of the bank material [NRCS, 2007c]. If LWM is used for bank protection, the most likely method used in the Bypass would be engineered logjams. It may be difficult to anchor these into the sandy bank and additional geotechnical information is necessary before these can be recommended in this case.

- **Rock Revetment.—**Riprap placed along the bank is one of the most commonly employed methods of bank protection. The methods of EM-1110-2-1601 [Corps, 1994] can be used to determine rock size, layer thickness, and filter requirements of the rock revetment. However, a continuous line of rock material may not support riparian species and the habitat value of rock revetments is generally considered low.

At this stage of development, the recommended strategy is to use rock vanes to stabilize the banks and allow vegetation to grow between the structures. The objective is to minimize the use of bank protection because its use will generally increase project costs and maintenance, and permanent bank protection is generally considered to have a negative impact to aquatic species. Bank protection should integrate into the grade stabilization features, so that river flows do not erode material along the edges of the rock ramp grade stabilization and cause them to become flanked.

Rock vanes will be placed on the outer bend between the grade control structures. The rock vane can be placed at grade or only slightly above grade so that it has minimal effect on the hydraulics in the reach. Only if bank erosion occurs will the structure be exposed and start to interact with the flow. It will function to maintain the bankline as constructed and ensure that the riparian vegetation can establish along the bankfull channel. This is different from the typical installation where vanes are placed in actively eroding banks and are intended to immediately interact with the flow.

Bank protection is designed to prevent excessive bank erosion for flows up to 4,500 cfs, but because of backwater effects of Reach 3, flows between 1,000 and 2,000 cfs may create higher bank velocities than occur at 4,500 cfs.

The design procedures as recommended in Reclamation [2015] are used. The effective vane length (L_e) is the length of the vane projected onto a cross section of the channel. The recommended effective vane length is between 25 to 33 percent of the bankfull width. The bankfull width is 190 ft and the effective vane length chosen is 60 ft. The vane spacing was initially chosen by constructing a line from the downstream structure tip, parallel to the bank tangent at the tie-in, to the intersection of the upstream bank. This gives a typical vane spacing of approximately 250 ft. Given that the rock ramps are typically 600 to 700 ft apart, only one or two rock vanes are needed between the rock ramps. Rock vanes will only be placed between the 3rd and 6th rock ramps (counting from downstream to upstream). The vanes are not needed in the lower portion of the Bypass because the velocities are lower in this section and the channel curvature is less.

The top of the vane will be set at the top of the bankfull channel and the vertical angle along the vane is 8 degrees as recommended by [NRCS, 2005; McCullah and Gray, 2005]. The vane horizontal angle is set at 70 degrees as measured from the bankline. The key length adds an additional 10 ft, which gives a total vane length of 95 ft along the vane axis. The median rock size required will be based upon twice the median rock size required for stream bank riprap. A general recommendation of rock size for vanes is for it to be twice the rock size required for riprap along the bank. Based upon the maximum velocities in the channel between the rock ramps, a median rock size of 1 ft is sufficient.

The top width of the vane should not be smaller than 3 times the D_{100}, which if the D_{100} is twice the D_{50}, would be 6 ft, but a minimum width of 8 ft is recommended to provide additional launch-able material if some material is lost from the vane. The side slopes above grade are to be 3H:1V. A scour depth of 9 ft is calculated using the Lacey and Blench scour around nose of guide banks as recommended in Reclamation [1984]. The rock material can be placed with side slopes of 1.5H:1V below grade.

With these dimensions, the approximate volume of each rock vane will be 1,500 yd^3. Four vanes will be necessary to stabilize the bank between the rock ramps, for a total rock volume of 6,000 yd^3 required for the rock vanes. There will also be addition excavation required of up to the vane volume required to bury a portion of the vane.

3.2 Option 2

The design for Option 2 is analyzed and developed in the following section.

3.2.1 Profile

The high estimate of slope in Reach 2B corresponds to Option 2 and was computed by fitting a line to the thalweg elevation in Reach 2B in the area not influenced by the Mendota Pool. For Option 2, the delta caused by Mendota Pool is assumed to extend about 4 miles upstream of the Bypass Confluence. Under Option 2, the elevation of the sill for the low flow gates of the Bypass Gates will be at 141.5 ft instead of 145 ft. This corresponds to the stream slope of 0.00035 in Reach 2B, which is the same slope as Reach 2A.

Based upon sediment transport modeling the bed elevation in the upstream portion of Reach 3 will be approximately 139 ft after the stream equilibrates. Therefore, the average bed slope in the bypass is 0.00047 (table 3-1). Because the slope is slightly steeper in the Bypass than in Reach 2B, two small grade control structures will be necessary. The grade control structures will have approximately 0.6 ft of hydraulic head drop across them, similar to those designed for Option 1, and will be located at approximately the same locations as the lower two grade control structures for Option 1. It is estimated that each structure will require 2,500 yd^3 for a total of 5,000 yd^3.

The goal of Option 2 was to remove all grade control structures within the Bypass downstream of the flow control structure at the head of the bypass. However, it was not possible to eliminate all grade control structures within the Bypass without making Reach 2B steeper than Reach 2A. If Reach 2B is steeper than Reach 2A, then it is possible that incision progresses throughout Reach 2B and potentially creates a need for grade control within Reach 2B.

The erosion in Reach 2B will decrease water surface elevations in Reach 2B and deposition in Reach 3 will potentially raise water surface elevations in Reach 3. These impacts are analyzed in Appendix C—Hydrologic, Hydraulic, and Sediment Transport Modeling.

3.2.2 Cross Section

The same cross section shape is used for the pools and riffles in Option 2 as in Option 1. An example section midway through the Bypass is given in figure 3-9.

The water surface profile through the Bypass is shown in figure 3-10. At a flow of 100 cfs there is just less than 4 ft of drop in water surface elevation across the Bypass. At a flow of 4,500 cfs, there is less than 1 ft of drop in water surface elevation.

There is more than 1.2 ft of depth for all flows above 100 cfs for all cross sections, which satisfies the minimum depth design objective for fish passage (table 2-1). The maximum channel velocities at a flow of 100 cfs are less than 2.5 ft/s, which also satisfies the fish passage criteria in table 2-1 (figure 3-11). At a flow of 500 cfs, the maximum channel velocities increase to approximately 3.5 ft/s in the lower part of the bypass at the head of the rock ramps. At 1,500 cfs, the channel velocities decrease to below 3 ft/s. At 3,000 cfs, the channel velocities are near 2 ft/s.

Reach 3 is expected to aggrade downstream of the Bypass. The deposition will tend to decrease velocities in the Bypass. Figure 3-12 shows the estimated velocities in the Bypass after a 25 year sediment transport simulation that Reach 3 is allowed to aggrade. The velocities are less than 2 ft/s for flows of 500 cfs and less.

3.2.3 Bank Protection

Because the channel velocities are substantially smaller in the upstream portion of the Bypass, no bank protection will be necessary as long as woody riparian vegetation is allowed to establish before the introduction of high flows to the Bypass. The velocities in the vicinity of the channel bend are less than 2.5 ft/s; natural vegetation will be sufficient to stabilize the banks on a long term basis [Gray and Sotir, 1996; Reclamation, 2015].

If flows are introduced before the establishment of natural vegetation, temporary stabilization measures such as degradable large wood structures could be used to stabilize the banks along the outside bend of the Bypass until vegetation is established. These would be intermittent structures built by stacking whole trees and logs in crisscross arrangements as specified in NRCS [2007c]. A conceptual drawing of a large wood structure is shown in figure 3-13.

Tree species that degrade quickly, such as cottonwood, could be used because the maximum time required for their functionality is expected to be 5 to 10 years. A recommended crest length is near 25 ft based upon a typical size of wood available. They would be oriented 75 degrees to the bank pointing upstream as recommended in NRCS [2007c]. The spacing recommended is a maximum of 5 times the crest length with smaller spacing recommended for small ratios of R/W (where R = radius of curvature and W = channel width). The radius of curvature is approximately 1,500 ft in the Bypass, and $R/W = 8$. The ratio of R/W is relatively large and therefore a spacing of 125 ft along the bank is used. The structures will be placed from station 3,500 to 1,500 (using the HEC-RAS stationing in figure 4-2) for a total of approximately 16 structures.

The structures would be anchored into the bank of the bankfull channel. The height of the structure will be similar to the bankfull bank height and gradually taper into the height of the low flow channel bank. The structures would only interact with the flow during flows that exceed the low flow channel capacity. The log pilling would be driven approximately 10 ft below the river bed to stabilize the structure.

To determine the need for bank protection under Option 2, a more detailed construction schedule needs to be developed and the time for riparian establishment needs to be investigated.

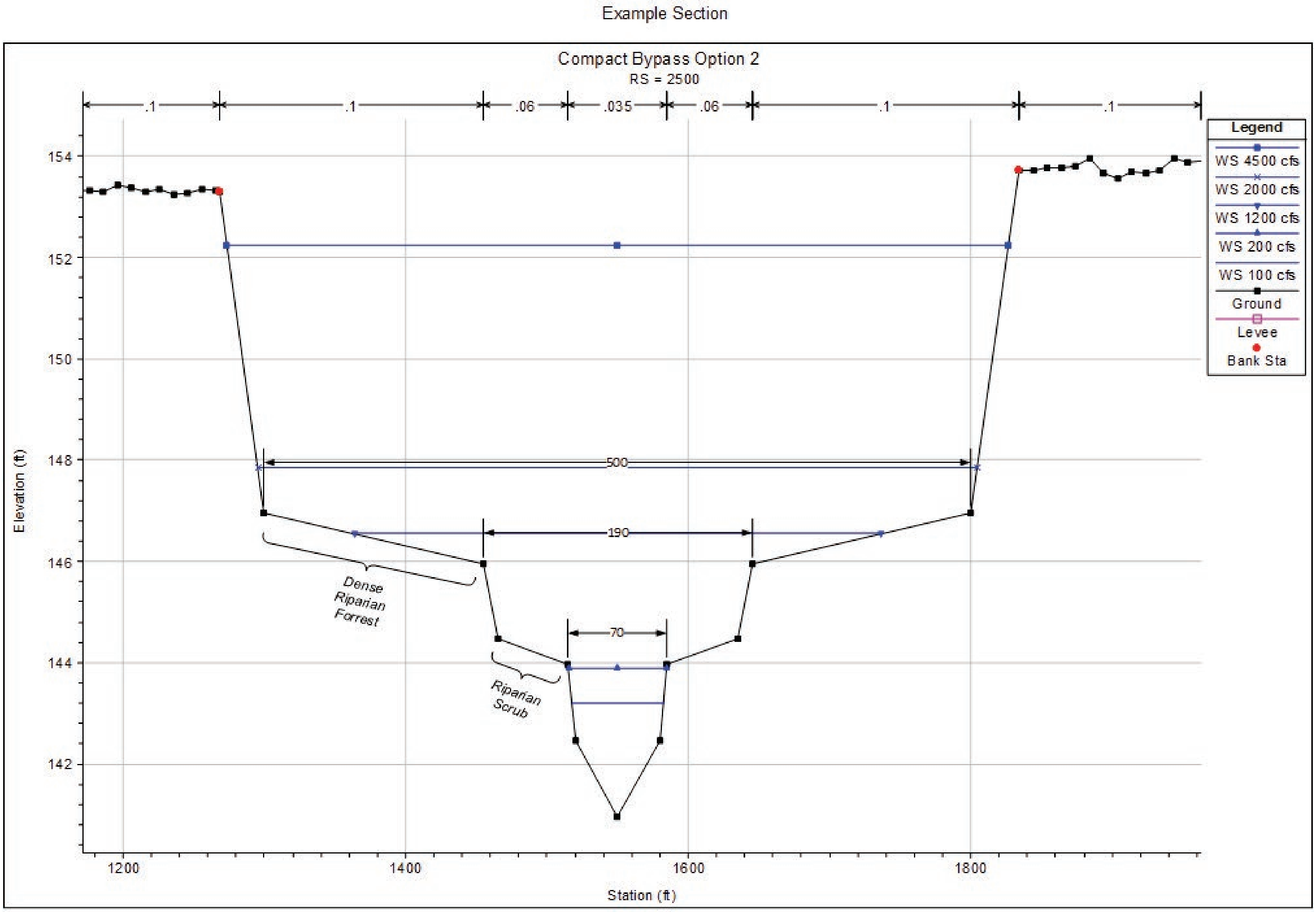


Figure 3-9.—Conceptual cross section for Option 2.

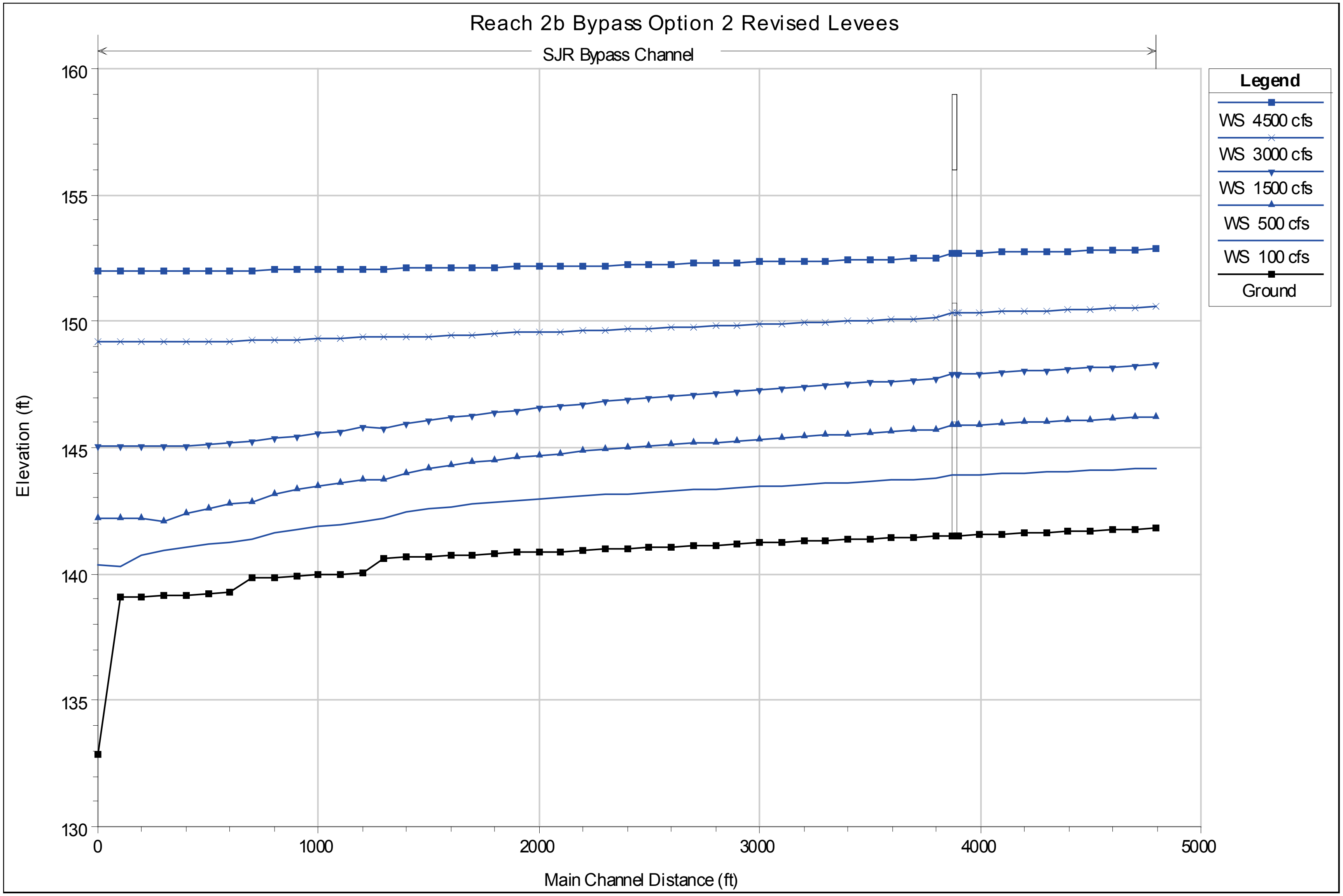


Figure 3-10.—Initial water surface profile in Bypass channel for Option 2.

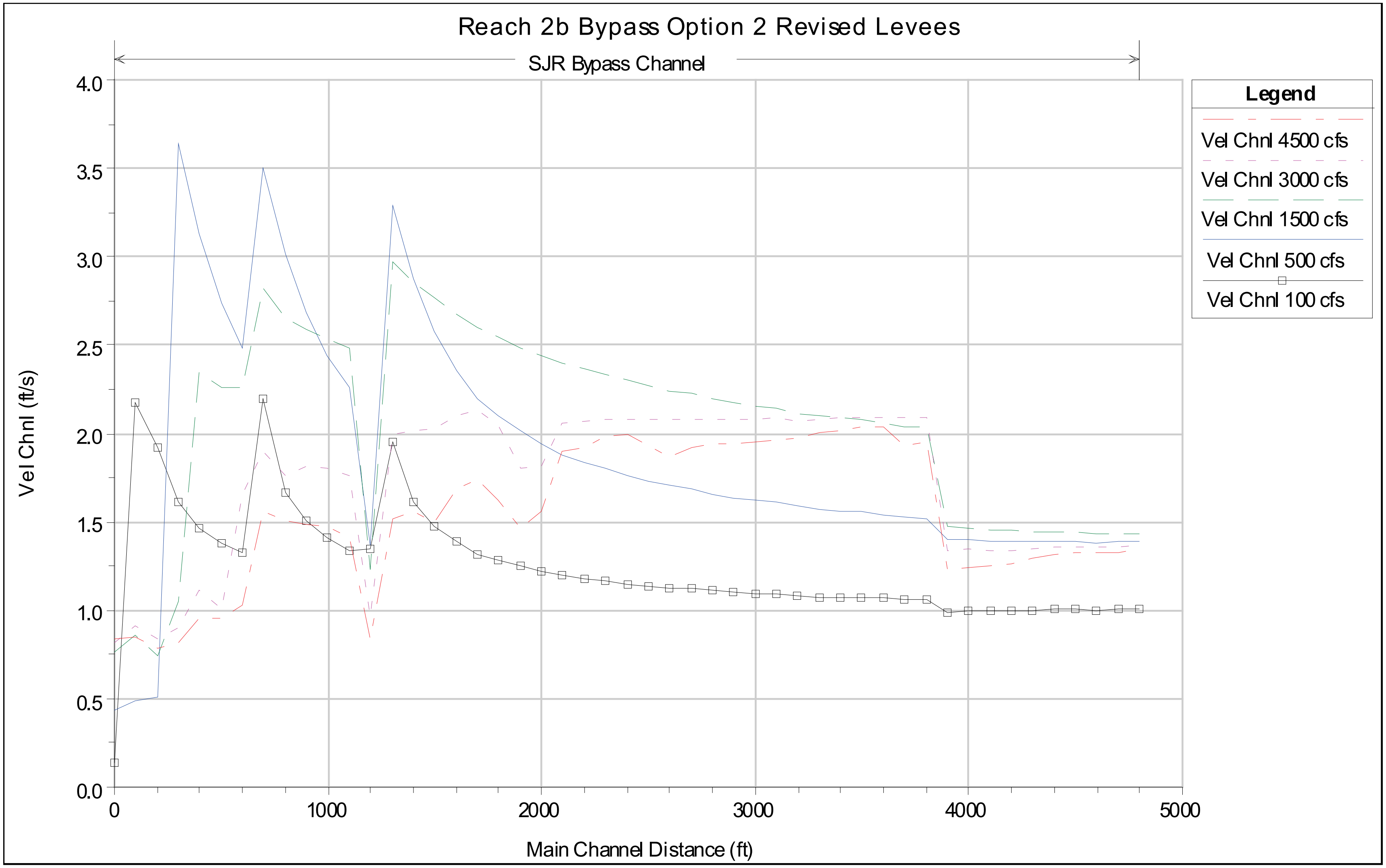


Figure 3-11.—Initial channel velocities in Bypass channel for Option 2.

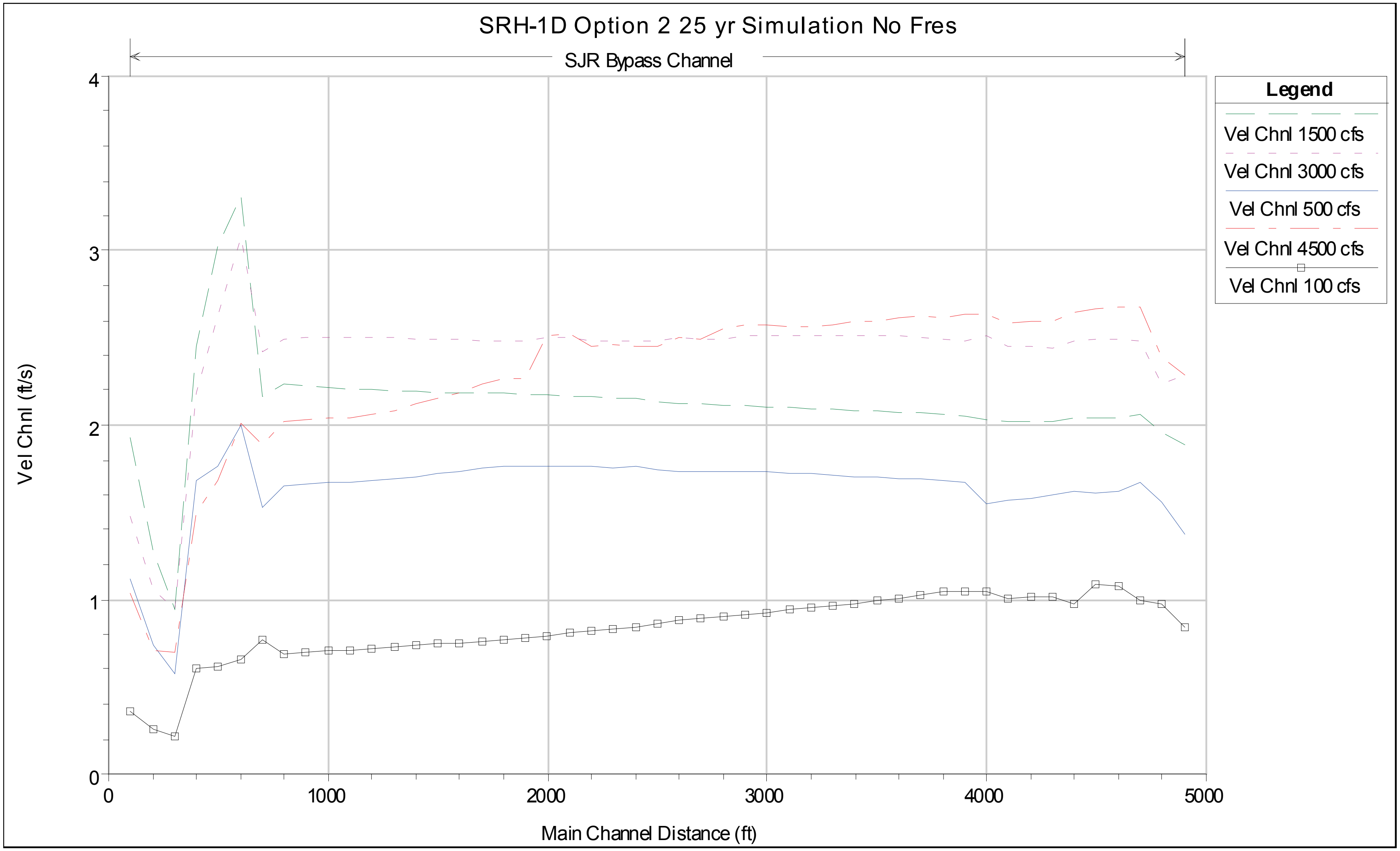
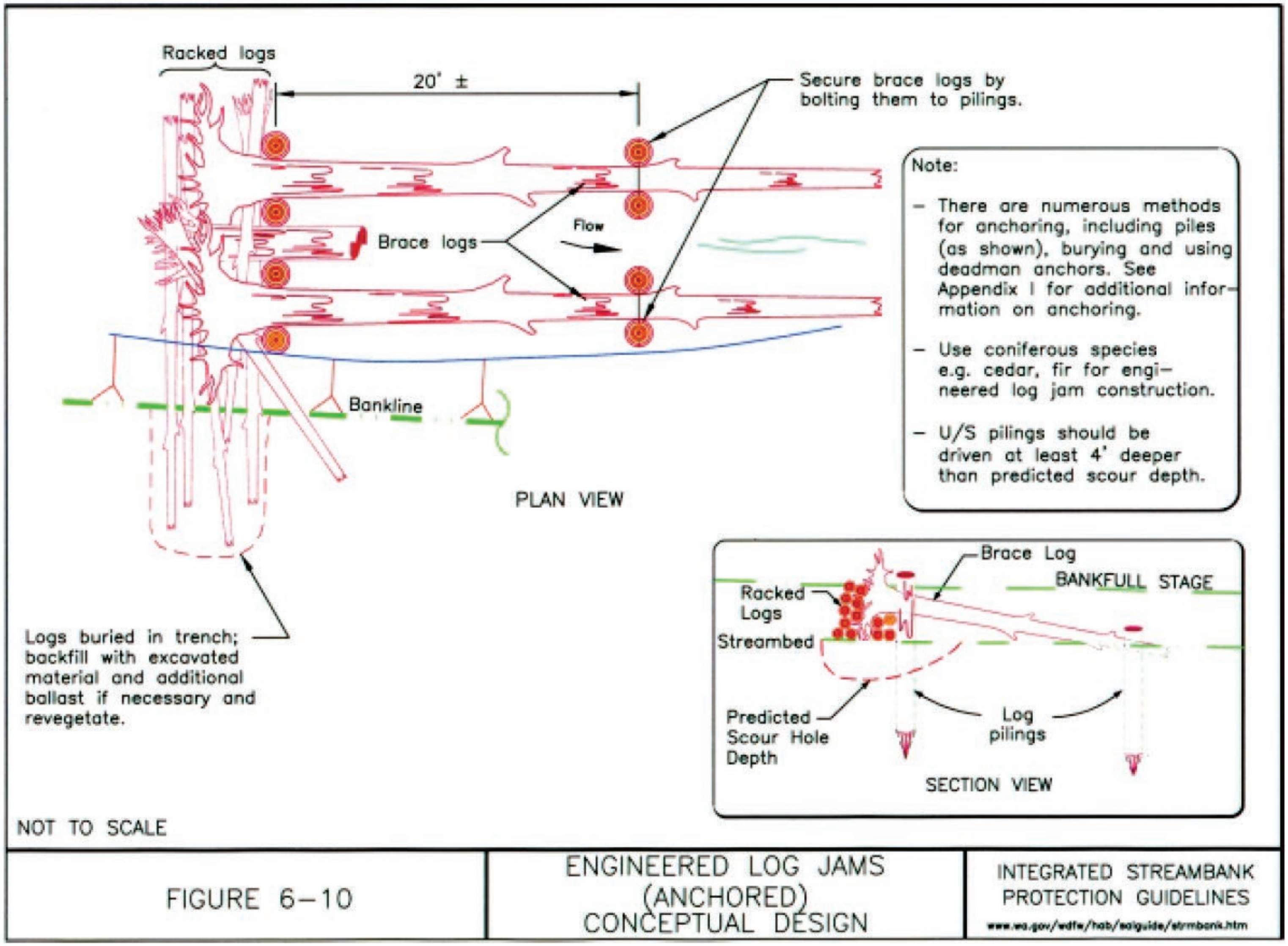


Figure 3-12.—Channel velocities in Bypass channel for Option 2 after a 25 year simulation and Reach 3 aggrades.



Note:

- There are numerous methods for anchoring, including piles (as shown), burying and using deadman anchors. See Appendix I for additional information on anchoring.
- Use coniferous species e.g. cedar, fir for engineered log jam construction.
- U/S pilings should be driven at least 4' deeper than predicted scour depth.

Figure 3-13.—Conceptual log-jam design from Washington State Department of Fish and Wildlife [2003].

4 Design Description

A detailed description of the design is presented here with estimates of excavation and other major quantities to help compare Options.

4.1 Option 1

A conceptual drawing of the channel planform for Option 1 is given in figure 4-1. There are five main features of the design that will be described:

1. Excavation and Fill
2. Flow Control Gates
3. Grade Control
4. Bank Protection
5. Revegetation

4.1.1 Excavation and Fill

A detailed cut and fill analysis has not been performed, but based upon a preliminary analysis using the cross sections for the hydraulic analysis, the volume of excavation within the Bypass will be between 400,000 and 500,000 yd^3. The extent of excavation is shown as the ‘Cut Extent’ in figure 4-1. Some of this material may be used for the levees and some of the material could be placed as fill within the Bypass area. A potential fill location is shown in figure 4-1, where the fill will also be beneficial to preventing flanking of the grade control structures. The area of the fill location is approximately 17 acres and if the entire 500,000 yd^3 is deposited in this area it would equate to approximately 18 ft of fill. Some of this material could also be used to supplement levee material and decrease the fill required.

Additional excavation into Reach 2B will likely be necessary to limit the overloading of the channel and flow control structure with sediment. It is suggested that a pilot channel 3-ft-deep at the Bypass channel inlet, 70 ft wide and 5,000 ft long will be excavated into Reach 2B. This equates to an additional 19,000 yd^3 of excavation into Reach 2B. Given the uncertainties at this stage of design, it is suggested that the potential excavation into Reach 2B be considered 20,000 to 30,000 yd^3. This material excavated in Reach 2B will be primarily medium sized sand and should be placed on top of the excavated pool sections in the Bypass because the base material in the Bypass within the pools may be primarily highly erodible silt. Additional sand-sized material could be placed in the deep pools of Reach 3 immediately downstream of the Bypass.

Two high flow channels will also be excavated into the terrace as shown in figure 4-1. The high flow channels will provide a drainage path for water that is

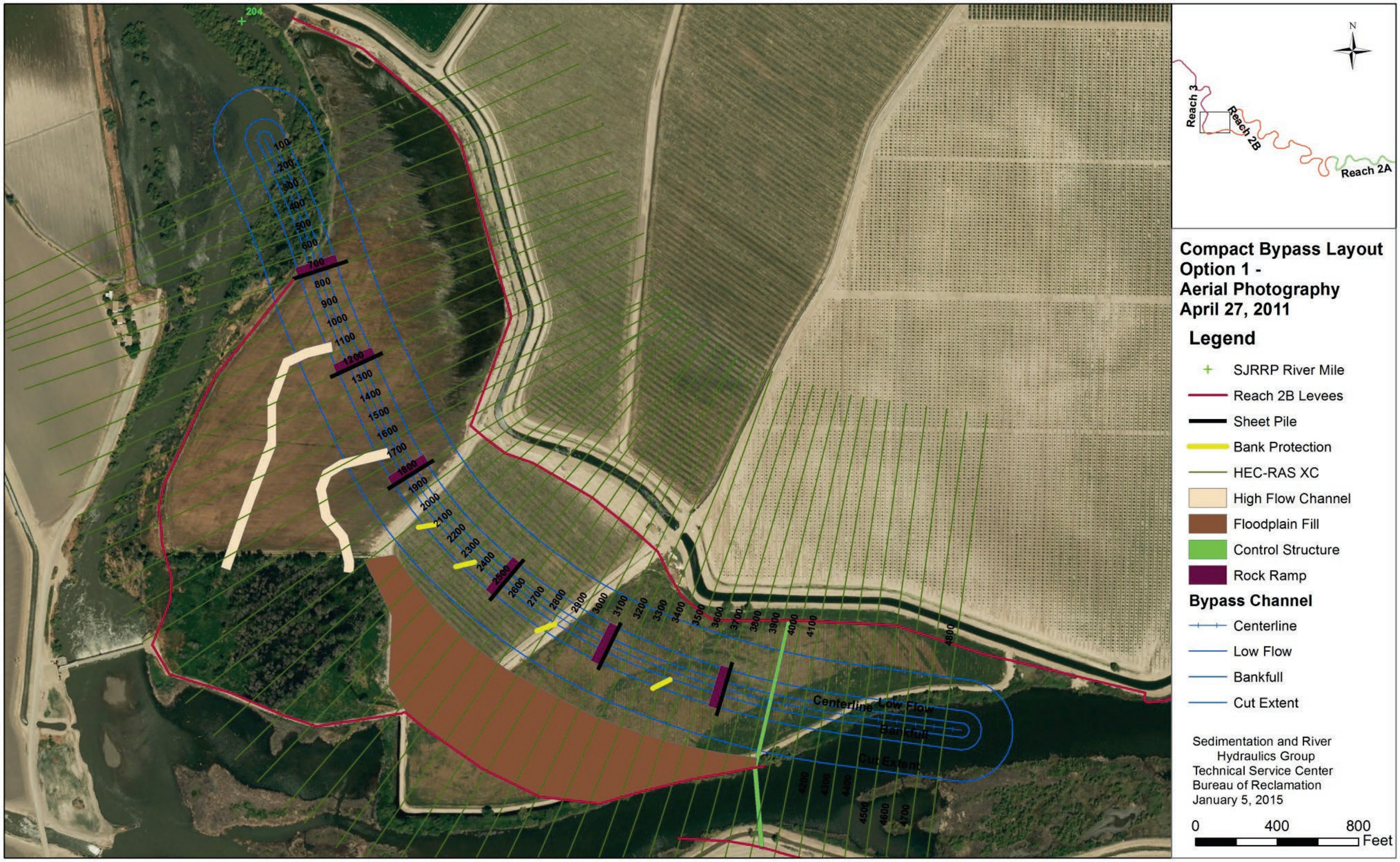


Figure 4-1.—Plan view of Bypass Option 1.

on the floodplain and in the low areas of the undeveloped land in the southwest corner of the Bypass area. They will be graded so that the invert elevation of the high flow channel meets with the top of the bank of the low flow channel.

4.1.2 Flow Control Gates

A gated flow control structure will be placed at the upstream end of the Bypass (Bypass Gates) and another at the upstream end of the Mendota Pool to divert flow from Reach 2B into the Mendota Pool. Figure 4-1 shows in plan view the proposed location of the structures across the head of the bypass and Mendota Pool. The gates at the structure at the head of the Bypass during restoration flows would generally be fully open and be large enough to ensure fish passage through the structure. As a first estimate, there would be two sets of gates. The low flow set would have a sill elevation of 145 ft and be open during all restoration flow releases. A second set would be open when flows are above the low flow channel and have a sill elevation of 148 ft. The detailed design will be performed after selection of channel design Option 1 or Option 2.

The gates of the structure at the upstream end of the Mendota Pool would generally be closed during restoration flows to maintain the water surface elevation in the Mendota Pool similar to existing conditions, which is generally above 152 ft. The water surface on the upstream side of the gates in Reach 2B will generally be at approximately 147 to 148 ft during period of flows of 100 to 200 cfs in Reach 2B. There will therefore be approximately 5 to 6 feet of water surface differential on the gates at the head of the Mendota Pool for the majority of the year.

During deliveries to Mendota Pool under critical water years, all gates on the structure at the head of the bypass would likely be closed and the gates at the upstream end of the Mendota Pool would be open so that SJR flow can be diverted into the Mendota Pool.

When there are deliveries to the Bypass there will be fish passage structures necessary at the head of the bypass to route fish into the bypass. The design of the fish passage structure will be detailed in a separate report.

4.1.3 Grade Control

Two types of sections are designed in the Bypass: riffle sections and pool sections. Riffle sections correspond to the grade stabilization features and the pool sections correspond to the reaches between the grade stabilization features. An example riffle cross section and a pool section is shown in figure 3-4 and figure 3-5, respectively.

The grade stabilization features will be rock ramps and will provide grade control and provide fish passage under a wide range of conditions and for a wide range of fish species. The Passage Memo [SJRRP, 2014] states that rock ramps would be classified as Type A fish passage structures.

There are six grade control structures approximately equally spaced through the Bypass. Each span the bankfull channel and have about 1 ft of hydraulic drop across them at low flow. They will have a maximum downstream slope of 0.04 and be between 25 and 50 ft in length in the streamwise direction. The ramps will consist of loose rock with a D_{50} of 12 inches. No filter fabric will be used, but a granular filter should be included beneath the material in the rock ramp. The rock will be placed with a minimum thickness of 5 ft excavated into the bed to account for the scour on the downstream side. The rock ramp will span the bankfull channel and be keyed into the bank an additional 15 ft.

To prevent destabilization of the loose rock structures and excessive maintenance costs, a sheet pile wall will be constructed at the head of each riffle. Because the rock will be sitting on a base of unconsolidated silty and sandy material, a sheet pile cutoff wall on the upstream end of the rock ramp is recommended (*see* section typical, figure 3-4). Without a sheet pile cutoff wall, the rock may shift and lose its ability to maintain grade control. The sheet pile can be covered with a cap to prevent the unsightly and potentially harmful exposure of the steel sheet. The sheet pile depths and details will be designed in the next phase of design. Rock will be placed at a 3H:1V slope on the upstream side of the sheet pile to prevent exposure of the wall.

There is expected to be some loss of rock material after each high flow, and additional rock material may need to be placed every few years so the sheet pile wall remains covered.

4.1.4 Bank Protection

Rock vanes will be placed on the outer bend between the grade control structures 3 to 6 (counting from downstream to upstream). The rock vane will begin at the bankfull channel and end before the bank of the low flow channel. It will only interact significantly with the flow if bank erosion begins to occur. It will function to maintain the bankline as constructed and ensure that the riparian vegetation can establish along the bankfull channel. This is different from the typical installation where vanes are placed in actively eroding banks and are intended to immediately interact with the flow.

There will be two rock vanes placed between rock ramps 3 and 4, and then one rock vane placed between rock ramps 4 and 5 and then 5 and 6. The rock vanes will be 95 ft long oriented upstream approximately 45 degrees from the bank. They will be composed of rock 12 inches in diameter. The top of the vane will intersect the top of the bankfull channel and have a longitudinal slope of 8 to 20 degrees and side slopes of 3H:1V. The recommended top width of the vane should be a minimum of 4 ft. The rock will need to be placed 9 ft below grade at the tip of the structure to provide scour protection.

4.1.5 Revegetation

Active revegetation in the bypass will be intensive as there will be no existing vegetation within the excavated channel. Revegetation categories and species selection will be similar between both options:

- **Riparian Scrub and Wetland.—**Areas with elevations in the range of 0 to 2 ft above summer base flow elevations will likely support emergent wetlands and water tolerant woody species (table 4-1). This includes a relatively narrow shelf along the low flow channel that will remain wet throughout most of the year, and may be inundated for extended periods during wet years or high summer flow events.

- **Dense Riparian.—**All floodplain areas with potentially suitable soils and elevations within a range of 2 to 8 ft above summer base flow elevations were selected as potentially suitable for riparian recruitment. Vegetation for this category includes primarily woody shrubs and trees with herbaceous understory (table 4-2).

- **Upland.—A**reas with elevations greater than 8 ft above summer base flow will not likely be able to support riparian vegetation development and recruitment. These areas will be seeded primarily with grasses, adding a minor component of shrubs and other upland vegetation. The purpose of revegetating the upland areas is primarily to stabilize soils and prevent invasive species colonization, and may provide a minor habitat component (table 4-3).

Table 4-1.—Potential Species for Revegetation: Category 1 Riparian Shrub and Wetland

Common Name	Scientific Name	Veg Type
Gooding's willow	*Salix gooddingii*	tree
common buttonbrush	*Cephalanthus occidentalis*	shrub
narrowleaf willow	*Salix exigua*	shrub
redroot flatsedge	*Cyperus erythrorhizos*	annual sedge
baltic rush	*Juncus balticus*	perennial rush
dwarf barley	*Hordeum depressum*	annual grass
spike bentgrass	*Agrostis exarata*	perennial grass
meadow barley	*Hordeum brachyantherum*	perennial grass
distant phacelia	*Phacelia distans*	annual forb
seep monkeyflower	*Mimulus guttatus*	annual/perennial forb
yerba mansa	*Anemopsis californica*	perennial forb
Douglas' sagewort	*Artemisia douglasiana*	perennial forb

Table 4-2.—Potential Species for Revegetation: Category 2 Dense Riparian

Common Name	Scientific Name	Veg Type
white alder	*Alnus rhombifolia*	tree
Oregon ash	*Fraxinus latifolia*	tree
California sycamore	*Platanus racemosa*	tree
Fremont cottonwood	*Populus fremontii*	tree
Gooding's willow	*Salix gooddingii*	tree
mule-fat	*Baccharis salicifolia*	shrub
California wildrose	*Rosa californica*	shrub
narrowleaf willow	*Salix exigua*	shrub
dwarf barley	*Hordeum depressum*	annual grass
spike bentgrass	*Agrostis exarata*	perennial grass
meadow barley	*Hordeum brachyantherum*	perennial grass
Douglas' sagewort	*Artemisia douglasiana*	perennial forb

Table 4-3.—Potential Species for Revegetation: Category 3 Upland

Common Name	Scientific Name	Veg Type
cattle saltbush	*Atriplex polycarpa*	shrub
California wildrose	*Rosa californica*	shrub
Saltgrass	*Distichlis spicata*	perennial grass
blue wildrye	*Elymus glaucus*	perennial grass
beardless wildrye	*Leymus triticodes*	perennial grass
California goldfields	*Lasthenia californica*	annual forb
bull clover	*Trifolium fucatum*	annual forb

Criteria for potential species selection were based on:

- Species which are native to the SJR
- Have been detected in reach 2B existing vegetation surveys
- Suitable to the particular site (primarily hydrology)
- Commercial available as seed and/or transplants or rootstock

Commercially available planting materials may be necessary due to constraints in budget, time, or other logistics. However, local sources of plant material are generally preferred due to adaptations to local conditions, providing the best possible establishment success. It should be noted that intra-specific genetic diversity of planting sources is also an important component of successful revegetation, and commercial seed and stock may have better long term success if locally available genetic diversity is low (i.e. few parent sources).

Planting design will generally be clusters of trees and shrubs with larger areas of seeded grasses and forbs. Further refinements of soil characteristics, topography, and hydrology will dictate where the most suitable spots for establishing parent clusters of vegetation are located and arranged. Mixed species implementation will provide a buffer for uncertainty in species survival and adaptation as well as serve to establish a diverse vegetation community. Spacing and alignment of plantings should take into account species growth patterns, potential equipment access needs for monitoring and maintenance, and desired future stand development.

Revegetation will likely require a combination of seeding, transplanting, and pole plantings. Woody species will need to be planted by hand, and holes or pits in which the poles/transplants are placed will need to be created by hand or mechanically. Pole plantings can be installed relatively easily with a hydrodrill, such as a Waterjet Stinger. Transplants will likely need bigger openings (6 to 12 inches) dug by hand or with a mechanized auger. Several options exist, but they will be limited by access, site conditions, and the time window when plantings need to occur.

Seeded sites require site preparation (prep) before seeding and potentially incorporation after seeding depending on the existing conditions and method of seeding. Site prep can include grading for equipment access, clearing of existing vegetation and other debris, and seedbed preparation. Alternatively, seeding methods may be modified to some extent in order to produce sufficient establishment with little or no site prep in order to maintain existing vegetation.

Monitoring and maintenance will be conducted for ten years following revegetation: Yearly for the first six years, then every other year up until year ten (total of eight monitoring years). This may ultimately be included as part of a larger overall program. Development of specific monitoring protocols will be based on the goals of the project. Per the currently stated goals, these would include a field survey of successful plant establishment, vigor, and coverage for both desired and invasive species per site specific condition, as well as aerial or satellite imagery analysis, geographic information system (GIS) integration, and potentially other tasks. Monitoring reports should include recommendations for adaptive management strategies to be applied as data becomes available.

Maintenance activities include controlling invasive plant species, mitigating animal damage, and irrigation. Management of invasive species will be critical, especially during the short term (minimum of three years) to ensure that the desirable vegetation dominates the landscape and provides habitat diversity, productivity, and sustainability. Animal damage to newly planted or germinated vegetation can be alleviated with screens, chemical deterrents, or other exclusion methods.

The dense riparian and riparian shrub/wetland zones will likely require irrigation during establishment, especially if precipitation is below normal, in order to ensure root systems develop into the reestablished alluvium groundwater. Irrigation infrastructure will need to be installed and remain in place for at least three years. Upland areas will be seeded in the fall before the winter precipitation season, and it is assumed these areas will become established to an acceptable level after one season of normal precipitation.

4.2 Option 2

4.2.1 Excavation and Fill

A conceptual drawing of the channel planform is given in figure 4-2. The same channel alignment will be used as in Option 1. At this phase of design, it is assumed that a similar cross section to pool and riffle sections of Option 1 will be excavated through the Bypass at the assumed equilibrium grade. The thalweg elevation at the upper end of the Bypass will be 141.5 ft, and the elevation at the downstream end will be 140 ft.

A detailed cut and fill analysis has not been performed, but based upon a preliminary analysis using the cross sections for the hydraulic analysis, the volume of excavation within the Bypass will be between 500,000 and 600,000 yd^3. The suggested location of the fill and the high flow channels are identical to Option 1. The area of the fill location is approximately 17 acres and if the entire 600,000 yd^3 is deposited in this area it would equate to approximately 22 ft of fill. Some of this material could also be used to supplement levee material and decrease the fill required.

Additional excavation into Reach 2B will likely be necessary to limit the overloading of the channel and flow control structure with sediment. It is suggested that a pilot channel 7-ft-deep at the downstream end, 70–ft-wide and 5,000–ft-long will be excavated into Reach 2B. This equates to an additional 45,000 yd^3 of excavation into Reach 2B that will be necessary. Given the uncertainties at this stage of design, it is suggested that the potential excavation into Reach 2B be considered 45,000 to 70,000 yd^3. This material excavated in Reach 2B will be primarily medium sized sand and should be placed on top of the excavated channel in the Bypass because the base material in the Bypass may be primarily highly erodible silt. Additional sand-sized material could be placed in the deep pools of Reach 3 immediately downstream of the Bypass or in the fill location specified in figure 4-2.

4.2.2 Flow Control Structure

The flow control structure will be similar to that used in Option 1, but the elevation of the sill for the low flow gates of the Bypass Gates will be at 141.5 ft instead of 145 ft. Therefore, during restoration base flows between 100 and 200 cfs in Reach 2B, there will be approximately 8 to 9 ft of water surface differential between the Mendota Pool elevation and the water surface elevation on the upstream side of the flow control structure.

Figure 4-2.—Plan view of bypass Option 2.

4.2.3 Grade Control

Because the slope is slightly steeper in the Bypass than in Reach 2B, two small grade control structures will be necessary. Each grade control structure will have approximately 0.6 ft of hydraulic head drop across it and be similar in composition and geometry to those designed for Option 1. The two structures will be located at approximately the same locations as the lower two grade control structures for Option 1.

4.2.4 Bank Protection

After riparian vegetation is established, no additional bank protection will be necessary. If flows are introduced before the establishment of natural vegetation, however, temporary stabilization measures such as degradable large wood structures could be used to stabilize the banks until vegetation is established. A recommended crest length is 25 ft and oriented 75 degrees to the bank, pointing upstream, with a spacing of 125 ft along the bank from station 3,500 to 1,500 (using the HEC-RAS stationing in figure 4-2) for a total of 16 structures.

To determine the need for bank protection under Option 2, a more detailed construction schedule needs to be developed and the time for riparian establishment needs to be investigated.

4.2.5 Revegetation

The revegetation strategy will be similar to that used in Option 1, but the channel will be less stable than Option 2 because it has fewer bank stabilization and grade stabilization measures and therefore, there may be a significant portion of the initial plantings lost to erosion and deposition processes. There will likely be more than one active revegetation effort required to establish a dense riparian corridor necessary to naturally stabilize the channel planform.

Installation may be more heavily reliant on seed introductions in order to keep costs to a minimum while still pushing native beneficial species into the system as the streambed moves towards equilibrium. Alternatively, aggressive revegetation combined with some erosion mitigation may be used to anchor stream banks and create islands of parent material for recruitment during the stabilization period. Suppression of invasive species to keep niches open for establishing native species as sediments migrate will be a critical component for revegetation with Option 2.

5 Summary and Recommendations

Two conceptual channel designs were developed for the Bypass that includes a bypass around Mendota Pool. The options were based on project goals and objectives that are summarized as design criteria. Options were designed from hydrologic, geomorphic, and sediment transport data. The design was also developed using a sediment transport model that was used as the profile design tool and HEC-RAS was used as the cross section and channel protection design tool. General excavation volumes and quantities were developed to help in a comparison of options and a discussion of the benefits and shortcomings of each option are presented below.

Two design options are proposed in this report:

1. **Option 1.—**This option has the goal of limiting incision into Reach 2B by stabilization of the Bypass with grade control structures. It also has the goal of allowing for adult upstream fish passage at all flows, but juvenile upstream passage may be limited at some flows.

2. **Option 2.—**This option has the goal of minimizing the use of channel stabilization features and allowing both upstream and downstream passage of adults and juvenile fish within the channel at restoration flows.

A summary of the quantitative differences between the Options is given in table 5-1 and the differences between each option are discussed below.

5.1 Channel Stability

Option 1 has the advantage of creating a reasonably stable channel within the Bypass immediately upon construction, which decreases uncertainty in the design. However, more permanent structures are required to accomplish this channel stability. Option 2 has the advantage of minimizing the use of grade control and bank stabilization features. However, the option will require a greater time to create a stable channel because it relies upon vegetation to stabilize the channel.

Approximately 21,000 yd^3 of rock would be required to stabilize the channel under Option 1, while only about 5,000 yd^3 of rock would be required under Option 2.

5.2 Excavation

Option 1 requires between 400,000 and 500,000 yd^3 of excavation within the Bypass and between 20,000 and 30,000 yd^3 in Reach 2B. The excavation quantity required for Option 2 is between 500,000 and 600,000 yd^3 within the Bypass and an additional 45,000 to 70,000 yd^3 within Reach 2B.

There will be additional excavation required in Reach 2B to meet floodplain habitat objectives. The volume of floodplain excavation estimated for Option 2 is 1.65 million cubic yards. The volume for Option 1 has not been estimated, but will be less than that required for Option 2.

5.3 Channel Velocities

Because of the steep slope of the Bypass in Option 1 versus Option 2, the velocities are significantly higher in the Bypass under Option 1 than Option 2. In particular, upstream passage of juvenile salmon could be limited in the Bypass under Option 1. Option 1 also requires the maintenance of more and larger grade control structures and has bank stabilization features. Because of the lower slope of the Bypass under Option 2, it has much lower velocities in the Bypass and could allow for upstream passage of juvenile salmon. However, it does not guarantee that juvenile passage will be possible at the flow control structures at the head of the Bypass. These structures will be designed in a subsequent phase.

5.4 Flood Water Surface Elevations in Reach 3

Under both Option 1 and 2, some of the sediment eroded from Reach 2B will deposit in Reach 3. The deposition will potentially increase the elevation of flood flows in Reach 3 for the first mile downstream of the Bypass; however, the rise in water surface at a flow of 4,500 cfs is expected to be less than 0.25 ft.

5.5 Floodplain Inundation in Reach 2B

Under Option 1, there is incision in the bed of Reach 2B of approximately 3 to 4 ft and the flood inundation is significantly decreased in the lower portion of Reach 2B. Under Option 2, there is up to 7 ft of bed incision in Reach 2B and it will further decrease floodplain inundation. However, the return to a more natural stream slope in Reach 2B will improve bend pool channel conditions and will likely result in a more diverse habitat within the main channel of Reach 2B.

To estimate the floodplain inundation under Option 2, the terrain of Reach 2B was modified to reflect the incision into Reach 2B and a preliminary design of floodplain grading in Reach 2B was accomplished. An estimate of potential inundation is given in table 5-1 and described in Appendix C—Hydrologic, Hydraulic and Sediment Transport Modeling.

No floodplain inundation estimate is given for Option 1 because Option 2 was selected as the preferred option. The floodplain inundation would be significantly higher under Option 1, but it was not considered to warrant further analysis. To estimate floodplain inundation under Option 1, a new terrain of Reach 2B would need to be developed that reflects the incision of Option 1.

Table 5-1.—Overview of Differences between Conceptual Design Options 1 and 2

Criteria	Option 1	Option 2
Sill Elevation of flow control structure	145 ft	141.5 ft
Number of grade control structures	6	2
Bank protection	4 rock vanes	No permanent bank protection required but temporary stabilization may be necessary such as 16 large wood structures
Rock required for stabilization	21,000 yd^3	5,000 yd^3
Excavation of Bypass	400,000 to 500,000 yd^3	500,000 to 600,000 yd^3
Excavation in Reach 2B	20,000 to 30,000 yd^3	45,000 to 70,000 yd^3
Velocity in Bypass relevant to fish passage criteria	Maximum velocities of 4.5 ft/s at grade control structures	Initial maximum velocities near 3.5 ft/s, with the potential for maximum velocities less than 2 ft/s after channel adjustment occurs
Maximum increase in Reach 3 flood elevations	0.23 ft	0.25 ft
Reach 2B Inundated Area (acres)		
1,200 cfs	*	562
1,500 cfs	*	624
2,000 cfs	*	725
3,000 cfs	*	1,194
4,500 cfs	*	1,532

* = Not Estimated

5.6 Project Objectives

To assess the relative ability of each option to meet the project objectives listed in section 2.7, a simple scoring system was applied to each option. For each objective, the option received a 3 if the option is expected to fully accomplish the objective, a 2 if it will partially accomplish the objective, and a 1 if it is not expected to meet the objective.

Option 1 is expected to only partially accomplish objectives 1, 2, 5, and 6 because the channel requires significant maintenance of grade control structures and the high velocities will likely necessitate bank stabilization. The hard structures will decrease the habitat value of the reach and also decrease the likelihood that Category A fish passage is accomplished.

Table 5-2.—Option Scoring for Each Project Objective
(3 if the option is expected to fully accomplish the objective, 2 if it will partially accomplish the objective, and 1 if it is not expected to meet the objective).

#	Design Objective	Option Score	
		Option 1	Option 2
1	Achieve Category A fish passage as stated in table 2-1	2	3
2	Promote survival of the species through development of appropriate and sustainable habitat	2	3
3	Create a bypass channel around Mendota Pool to ensure conveyance of at least 4,500 cfs through Reach 2B to Reach 3. This improvement requires construction of a structure capable of directing flow down the bypass and allowing the Secretary to make deliveries of SJR water into Mendota Pool when necessary	3	3
4	Maintain current flood conveyance capacities in Reach 3	3	3
5	Minimize both construction and maintenance cost	2	3
6	Create a sustainable stream profile that minimizes long term sediment imbalances within the project area	2	3

5.7 Recommendations

Option 2 most likely accomplishes the project objectives listed in section 2.7–Design Objectives Summary, and is the recommended option to move forward in the design process. With input from agencies on February 10, 2015, and from stakeholders including local water districts and landowners on February 12, 2015, Option 2 was selected to move forwards with design.

As part of the next stage in design, several additional analyses are recommended.

- Development of an approximate schedule of revegetation and excavation activities. The revegetation strategy is dependent upon the expected excavation schedule and the expected timing of flow release into the Bypass channel. Further detail on the schedule will allow additional detail in the revegetation strategy.

- Further sediment model uncertainty analysis is necessary to verify the elevation of the levees, control structures, and grade control structures. The following issues will be analyzed:
  - **Hydraulic Roughness.—**The hydraulic roughness is due to plan form, bed form, and vegetation effects. All these factors are uncertain and vegetation is expected to evolve in time. Therefore, the hydraulic roughness in the Bypass is uncertain.
  - **Sediment Boundary Conditions.—**This includes the boundary conditions in the upstream portion of Reach 2A as well as the fraction of sediment being transported through Chowchilla Bifurcation Structure.

- Two dimensional (2D) hydraulic analysis and sediment transport will be performed to analyze the detailed hydraulics through the Bypass. The 2D analysis will aid in fish passage assessment and in the design of grade control and bank stabilization structures.

References

Aceituno, M.E. 1990. Habitat Preference Criteria for Chinook Salmon of the Stanislaus River, California. U.S. Fish and Wildlife Service, Sacramento, CA.

Biendenharn, D.S., Watson, C.C., and Thorne, C.R. 2008. Fundamentals of Fluvial Morphology, Ch 6 of Sedimentation Engineering. American Society of Civil Engineers (ASCE) Manual and Reports on Engineering Practice No. 110.

Brandt, S. Anders. 2000 draft. Classification of Geomorphological Effects Downstream of Dams," *Catena 40*:375-401.

Buffington, J.M, and Montgomery, D.R. 1997. A Systematic Analysis of Eight Decades of Incipient Motion Studies, with special Reference to Gravel-Bedded Rivers. *Water Resources Research*, Vol. 33, No. 8:1993-2029.

Bunte, Kristin; Abt, Steven R. 2001. Sampling Surface and Subsurface Particle-Size Distributions in Wadable Gravel and Cobble-Bed Streams for Analyses in Sediment Transport, Hydraulics, and Streambed Monitoring. General Technical Report No. RMRS-GTR-74. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fort Collins, CO. 428 p.

Burchsted, D., Daniels, M.,Wohl, E. 2013. Introduction to the Special Issue on Discontinuity of Fluvial Systems. *Geomorphology*. doi:10.1016/j. geomorph.2013.04.004.

Caamaño, D., Goodwin, P., and Buffington, J.M. 2012. Flow Structure through Pool-Riffle Sequences and a Conceptual Model for Their Sustainability in Gravel-Bed Rivers. *River Research and Applications*, 28:377-390.

Cain, J.R. 1997. Hydrologic and Geomorphic Changes to the San Joaquin River between Friant Dam and Gravelly Ford and Implications for Restoration of Chinook Salmon (*Oncorhynchus Tshawytscha*). M.A. Thesis, University of California, Berkely, CA. 143 p.

Camenen, B. 2012. Discussion of Understanding the Influence of Slope on the Threshold Of Coarse Grain Motion: Revisiting Critical Stream Power. C. Parker, N.J. Clifford, and C.R. Thorne. *Geomorphology* 139-140:34–38. doi:10.1016/j.geomorph.2011.10.033.

Childers, D. 1999. Field Comparisons of Six Pressure-Difference Bedload Samplers in High Energy Flow. U.S. Geological Survey Water Resources Investigations Report No. 92-4068:59.

Comiti F., V. D'Agostino, V. Ferro, M.A. Lenzi. 2006. Fenomeni di Erosione Localizzata a Valle di Opere Trasversali: Integrazioni tra Indagini di Campo e di Laboratorio, Quaderni di Idronomia, MT, 25:217-225.

Davis, B.E. 2005. A Guide to the Proper Selection and Use of Federally Approved Sediment and Water-Quality Samplers. Report No. QQ, Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, MS.

DeFlitch, Douglas 2010. *Measurements and Monitoring of Bedload Sediment Transport Along the Upper San Joaquin River from Gravelly Ford to the Chowchilla Bypass Bifurcation Structure, California*, A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Geology in the College of Science and Mathematics California State University, Fresno.

Dust, D., and Wohl, E. 2012. Conceptual Model for Complex River Responses Using an Expanded Lane's Relation. *Geomorphology*. p. 139-140 and 109–121.

Edwards, T.K., and Glysson, G.D. 1999. Field Methods for Measurement of Fluvial Sediment. U.S. Geological Survey. *Techniques of Water Resources Investigation*, Book 3, Ch C2:89.

Engelund, F., and Hansen, E. 1972. A Monograph on Sediment Transport in Alluvial Streams. Teknish Forlag, Technical Press, Copenhagen, Denmark.

ESA. 2012. Conceptual Riparian Revegetation Approach, San Joaquin River Restoration Program, Reach 4B. Prepared for Bureau of Reclamation, Denver, CO, June 2012.

García, M. 2011. Sediment Transport and Morphodynamics. Ch 2 – Sedimentation Engineering, American Society of Civil Engineers (ASCE) Manual and Reports on Engineering Practice No. 110, edited by M. Garcia. *Geomorphology*, Volume 126, p. 51-65.

Graham Matthews & Associates (2004-2011). Annual Flow Release Sediment Transport Monitoring Reports. Reports for Trinity River Restoration Program, Bureau of Reclamation, Weaverville, CA.

Graham Matthews and Associates (2011). *San Joaquin near Ledger Island Water Year 2011 Bedload Sampling*, Technical Memorandum dated June 13,2011. In Appendix D Sediment of 2011 Final Annual Technical Report. San Joaquin River Restoration Program.

Gray, D.H., and Sotir, R.B. 1996. Biotechnical and Soil Bioengineering Slope Stabilization. John Wiley and Sons, New York, NY.

Greimann, B., Lai, L., and Huang, J. 2008. Two-Dimensional Total Sediment Load Model Equations. American Society of Civil Engineers (ASCE), *Journal of Hydraulic Engineering*, Vol. 134, No. 8:1142-1146.

Gurnell, A.M., Petts, G.E. 2002. Island-Dominated Landscapes of Large Floodplain Rivers, A European Perspective. Biol. 47:581–600.

Huang, J. and Greimann, B. 2012. User's Manual for SRH-1D, Sedimentation and River Hydraulics – One Dimension Version 3.0, Technical Report SRH-2013-11. Bureau of Reclamation, Technical Service Center, Denver, CO.

Jones and Stokes Associates, Inc. (JSA) and Mussetter Engineering Inc. (MEI). 1998. Analysis of Physical Processes and Riparian Habitat Potential of the San Joaquin River – Friant Dam to the Merced River. Sacramento, CA. Technical assistance from Ayers Associates. Prepared for Bureau of Reclamation, Fresno, CA.

Kottegoda, N., and Rosso, R. 1997. Statistics, Probability, and Reliability for Civil and Environmental Engineers, McGraw-Hill.

Lai, Y. 2008. SRH-2D Version 2: Theory and User's Manual, Sedimentation and River Hydraulics – Two-Dimensional River Flow Modeling. Bureau of Reclamation, Technical Service Center, Denver, CO.

Lamb, M.P, Dietrich, W.E., and Venditti, J.G. 2008. Is the Critical ShieldsS for Incipient Sediment Motion Dependent on Channel-Bed Slope? *Journal of Geophysical Research*, Vol. 113, F02008, doi:10.1029/2007JF000831.

Laursen, E.M. 1958. The Total Sediment Load of Streams. American Society of Civil Engineers (ASCE) *Journal of Hydraulic Division*, Vol. 84(1):1531-1536.

Madden, E.B. 1993. Modified Laursen Method for Estimating Bed-Material Sediment Load. U.S. Army Corps of Engineers, U.S. Army Engineer Waterways Experiment Station Contract Report No. HL-93-3.

McBain and Trush, Inc. (eds.). 2002. San Joaquin River Restoration Study Background Report. Prepared for Friant Water Users Authority, Lindsay, CA, and Natural Resources Defense, Council, San Francisco, CA.

Mueller, E.R., Pitlick, J., and Nelson, J. 2005. Variation in the Reference Shields Stress for Bed Load Transport in Gravel-Bed Streams and Rivers. *Water Resources Research,* Vol 41, W04006, doi:10.1029/2004WR003692.

NAVD88. 1988. North American Vertical Datum of 1988.

NRCS. 2007a. Grade Stabilization Techniques. *Technical Supplement 14G to Stream Restoration Design, National Engineering Handbook,* Part 654. Natural Resources Conservation Service.

NRCS. 2007b. Flow Changing *Techniques Technical Supplement 14H to Stream Restoration Design, National Engineering Handbook,* Part 654. Natural Resources Conservation Service.

NRCS. 2007c. Use of Large Woody Material for Habitat and Bank Protection. *Technical Supplement 14J to Stream Restoration Design, National Engineering Handbook,* Part 654. Natural Resources Conservation Service.

NRCS. 2007d. Streambank Armor Protection with Stone Structures. *Technical Supplement 14K to Stream Restoration Design, National Engineering Handbook*, Part 654. Natural Resources Conservation Service.

NRCS. 2007e. Streambank Soil Bioengineering. *Technical Supplement 14I to Stream Restoration Design, National Engineering Handbook,* Part 654. Natural Resources Conservation Service.

Parker, C., Clifford, N.J., and Thorne, C.R. 2011. Understanding the Influence of Slope on the Threshold of Coarse Grain Motion: Revisiting Critical Stream Power. *Geomorphology*, p 126:51-65, doi:10.1016/j.geomorph. 2010.10.027.

Parker, G. 1990. Surface Based Bedload Transport Relationship for Gravel Rivers. *Journal of Hydraulic Research*, Vol 28(4):417–436.

Pettsa, G.E., and Gurnell, A.M. 2005. Dams and Geomorphology: Research Progress and Future Directions, *Geomorphology*, Vol. 71, Issues 1-2:27–47.

Pittman, S.A. 2005. Toutle River-2 Bedload Sampler. Prepared for Trinity River Restoration Program: WY 2005, Technical Memo #1. Bureau of Reclamation, Weaverville, CA.

Recking, A. 2009. Theoretical Development on the Effects of Changing Flow Hydraulics on Incipient Bed Load Motion. *Water Resources Research,* Vol 45, W04401, doi:10.1029/2008WR006826.

Reclamation. 2008. San Joaquin Data Collection Report Sediment Sampling February 4-6, 2008. San Joaquin River Restoration Project. Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation. 2009. Geomorphology, Sediment, and Vegetation Impacts of the San Joaquin River Restoration Program, Technical Report No. SRH-2009-27. Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation. 2012a. Hydrology, Hydraulic, and Sediment Studies for Reach 4B, Eastside Bypass, and Mariposa Bypass Channel and Structural Improvements Project, Technical Report No. SRH-2012-16. Prepared for San Joaquin River Restoration Project, Mid-Pacific Region by Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation. 2012b. San Joaquin River Restoration Daily Flow Model, documentation for Reach 4B Study, Technical Report No. 86-68210-2012-04. Bureau of Reclamation, Technical Service Center, Denver, CO.

Reclamation. 2012c. Central Valley Subsidence Investigation – Data Update, (Memorandum dated Aug 21, 2012) to San Joaquin River Restoration Project from Ani Bhattacharyya, Bureau of Reclamation.

Reclamation. 2012d. Hydraulic Studies for Fish Habitat Analysis, San Joaquin River Restoration Project, Mid-Pacific Region, Technical Report No. SRH-2012-15. Bureau of Reclamation.

Reclamation. 2012e. Mendota Pool Sediment Quality Investigation – Analytical Results, Data Assessment, and Quality Assurance Summary, In Support of the Mendota Pool Bypass and Reach 2B Improvements Project, San Joaquin River Restoration Program. Bureau of Reclamation, Mid-Pacific Region, Division of Environmental Affairs, Sacramento, CA.

Reclamation. 2014a draft. Large Wood National Manual, Technical Review. Bureau of Reclamation.

Reclamation. 2014b. Sediment Budget Analysis of the San Joaquin River WY 2010 to 2012, prepared for the San Joaquin River Restoration Project, Mid-Pacific Region.

Reclamation. 2015 draft. Bank Stabilization Design Guideline, Report No. SRH-2014-XX. Bureau of Reclamation.

Schumm S.A., Harvey, M.D., and Watson, C.C. 1984. Incised Channels: Morphology, Dynamics, and Control. *Water Resources Publications*. Littleton, CO.

Simon A., and Hupp,C.R. 1986. Geomorphic and Vegetative Recovery Processes along Modified Tennessee Streams: an Interdisciplinary Approach to Disturbed Fluvial Systems. *Forest Hydrology and Watershed Management.* IAHS-AISH Publ.167.

SJRRP. 2012a. Appendix D Sediment, Final Annual Technical Report. San Joaquin River Restoration Program.

SJRRP. 2012b draft. Mendota Pool Bypass and Reach 2B Improvements Project, Project Description Technical Memorandum. San Joaquin River Restoration Program.

SJRRP. 2012c. Minimum Floodplain Habitat Area for Spring and Fall-Run Chinook Salmon. San Joaquin River Restoration Program.

SJRRP. 2014. Fish Passage Design Criteria. San Joaquin River Restoration Program.

SJRRP. 2015. Channel Capacity Report 2015 Restoration Year Technical Memorandum. San Joaquin River Restoration Program.

Stillwater Sciences. 2003 draft. Restoration Strategies for the San Joaquin River, Appendices. prepared for Friant Water Users Authority and Natural Resources Defense Council.

Tetra Tech. 2011 draft. San Joaquin River Reach 1A HEC-RAS Steady-State Hydraulic Model Geometry Updates.

Tetra Tech. 2012a draft. 2011 San Joaquin River Sand Storage Evaluation.

Tetra Tech. 2012b draft. San Joaquin River: Evaluation of Sand Supply Storage and Transport in Reaches 1A and 1B.

Tetra Tech. 2012c. 2011 Reach 2A Sedimentation Evaluation.

Tetra Tech. 2013. San Joaquin River and Bypass System 1-D Steady State HEC-RAS Model Documentation.

Washington State Department of Fish and Wildlife. 2002. Integrated Stream Protection Guidelines. Washington State Aquatic Habitat Guidelines Program.

Wilcock, P.R., and Crowe, J.C. 2003. Surface-Based Transport Model for Mixed-Size Sediment. American Society of Civil Engineers (ASCE) *Journal of Hydraulic Engineering*. 129(2). p 120-128.

Wu, W., Wang, S.S.Y., and Jia, Y. 2000. Nonuniform Sediment Transport In Alluvial Rivers. *Journal of Hydraulic Research,* Vol. 38(6):427-434.

U.S. Army Corp of Engineer. 1994. Hydraulic Design of Flood Control Channels, EM-1110-2-1601. Department of the Army, U.S. Army Corp of Engineers, Washington, D.C.