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Managing Water in the West

Technical Report No. SRH-2017-04

DRAFT Hydraulic and Revegetation Design of the Mendota Bypass – 60% Design

San Joaquin River Restoration Project
Mid-Pacific Region

U.S. Department of the Interior
Bureau of Reclamation

November 2016

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San Joaquin River Restoration Project
Mid-Pacific Region

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Acronyms and Abbreviations

1D	one dimension
2D	two dimensional
ArcGIS	a Geographic Information System
ASCE	American Society of Civil Engineers
Bypass	Mendota Pool Bypass
cfs	cubic feet per second
Ch	chapter
Corps	U.S. Army Corp of Engineers
DH	drill holes
EM	Engineering Manual
Eq.	equation
ft	foot/feet
GRF	Gravelly Ford gage
HEC-GeoRAS	Hydrologic Engineering Center's 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.
MEN	San Joaquin River near Mendota CA
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
PLS	Pure Live Seed
prep	preparation
Project	Mendota Pool Bypass and Reach 2B Improvements Project
Reclamation	Bureau of Reclamation
RM	river mile
R/W	where R = radius of curvature and W = channel width
SJB	San Joaquin River below Bifurcation
SJN	San Joaquin River at San Mateo Road near Mendota
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
Settlement	Stipulation of Settlement
TSC	Technical Service Center
U.S.	United States
USGS	U.S. Geological Survey
WY	water year
yd	yard

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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) 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. 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 Interior 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 document the hydraulic modeling results and present the 60% Design of the following features:

- Excavation of the Channel,
- Bed and Bank Erosion Protection,
- Revegetation, Irrigation, and
- Flow Reintroduction.

Appurtenant features, including fish ladders, fish barriers, control gates, and levees will be described in separate documentation and are integrated here by location and water surface elevations.

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

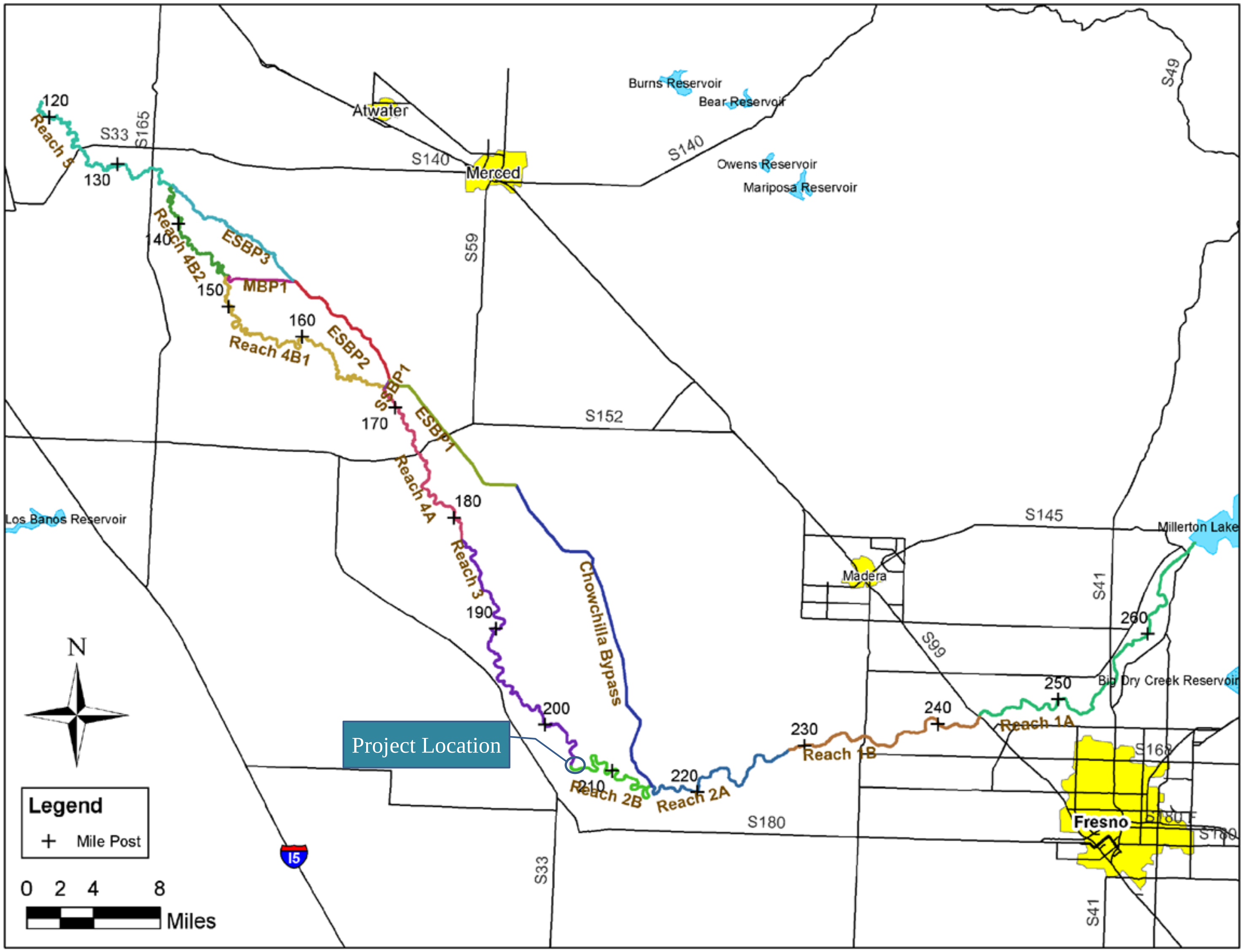


Figure 1-1. Overview of reaches associated with the SJRRP.

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 objectives for the Reach 2B project were originally identified in SJRRP (2012b) during the EIS process and are given in Figure 2-1. 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 at this location. The final recommended minimum depths and maximum velocities for the Compact Bypass project are given in Table 2-1. Note that upstream juvenile passage 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.

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].

Table 2-1.—Recommended fish passage design objectives.

Minimum Depth (ft)	Maximum Hydraulic Jump Height (ft)	Maximum Recommended Cross Sectional Average Design Velocity (ft/s)
1.2	1.0	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 target 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 addressed 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 long-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.

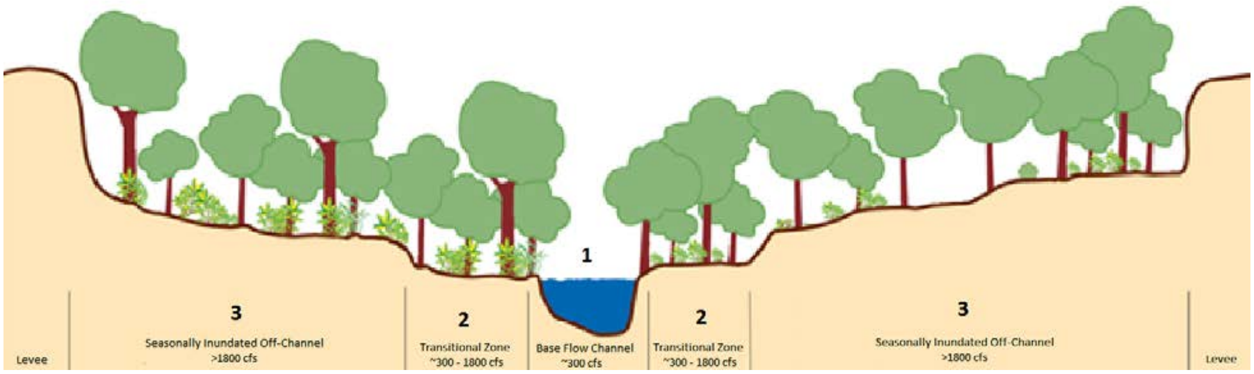


Figure 2-2.—Habitat areas identified in Habitat Rearing Objectives [SJRRP, 2014].

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 in the main channel that inundates 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, thereby 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 shelves and narrow low flow channels
    - Multiple low flow channels
    - Perennial marsh

2. Transition Zone

    - Low floodplain surfaces adjacent to base flow channel
    - Split flow channel inundated just above base flow

3. Seasonally Inundated Off-Channel Habitat

    - Seasonally inundated floodplain
    - Seasonally inundated side channels
    - 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.

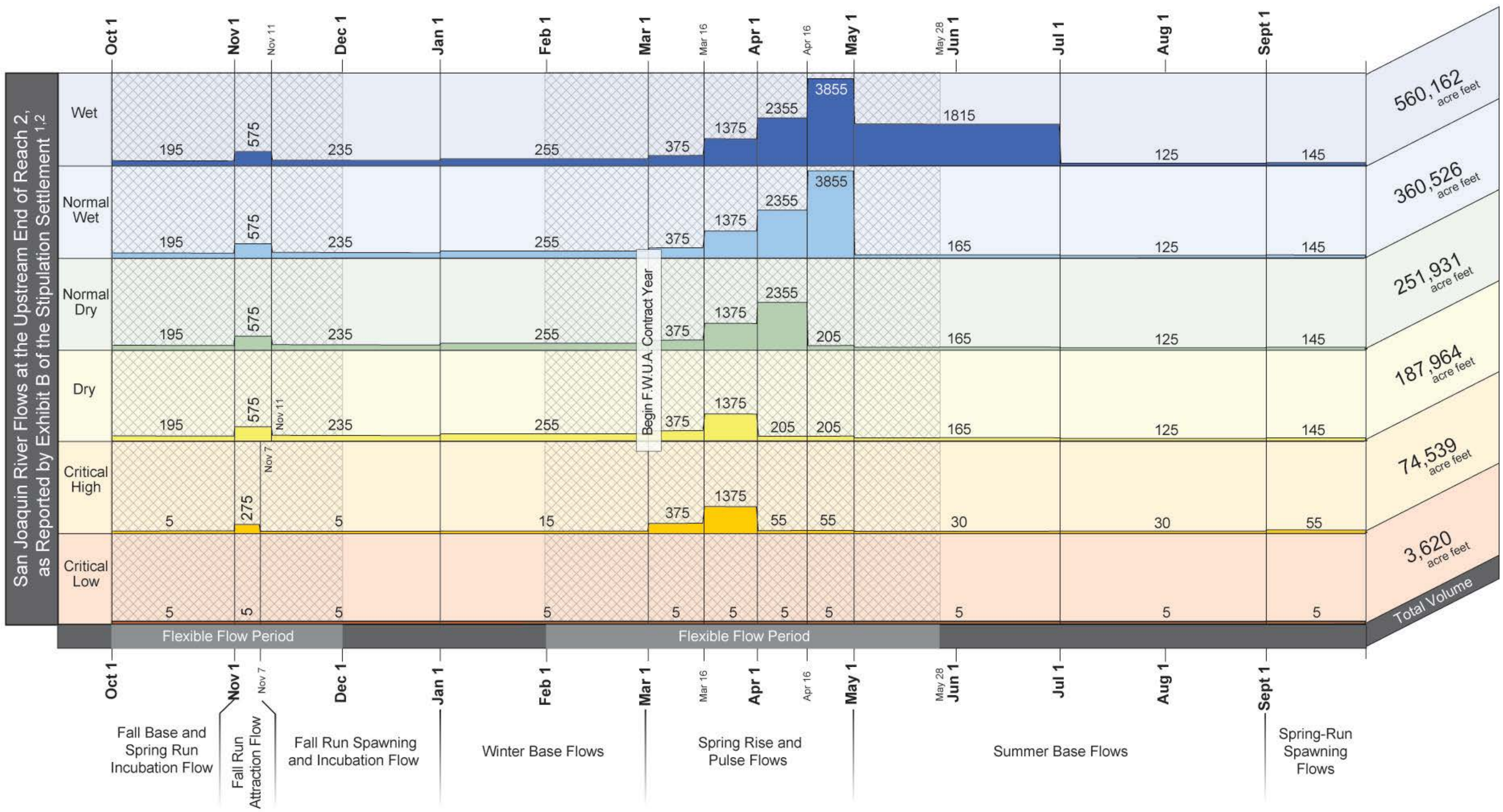
The RiverWare simulated flows under SJRRP for the period using the historical inflows from 1923 to 2003 is shown in Figure 2-5 for the stream gage SJR, which is located at the upstream end of Reach 2B. The highest flows are limited to 4,500 cfs in Reach 2B. The flow is zero more than 10 percent of the 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 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. 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:

- 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.
- 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.

San Joaquin River Flows at the Upstream End of Reach 2, 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 2-3.—San Joaquin River flows at upstream end of Reach 2 as reported in Exhibit B of Stipulation of Settlement.

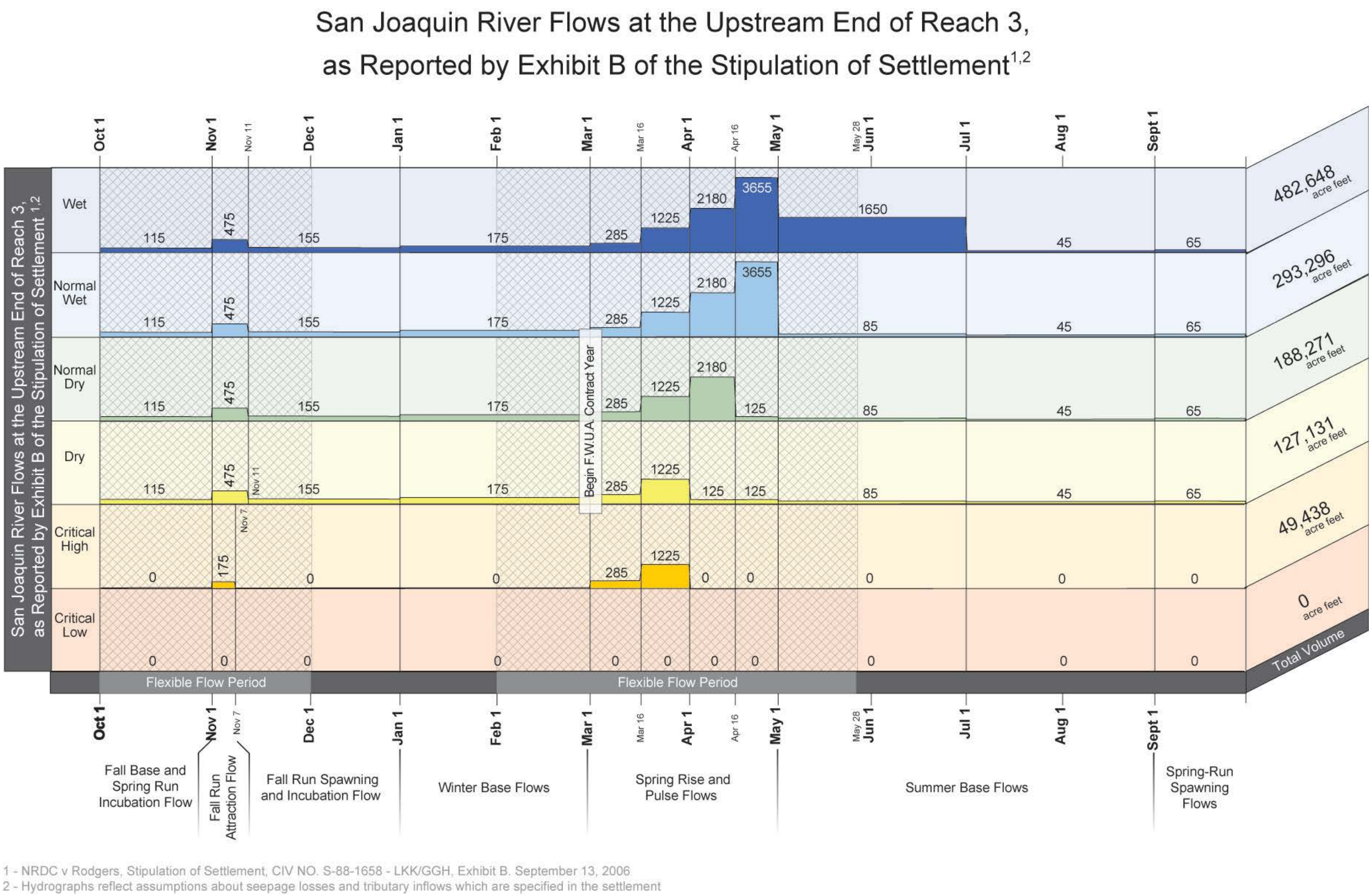


Figure 2-4.—San Joaquin River flows at upstream end of Reach 3 as reported in Exhibit B of Stipulation of Settlement.

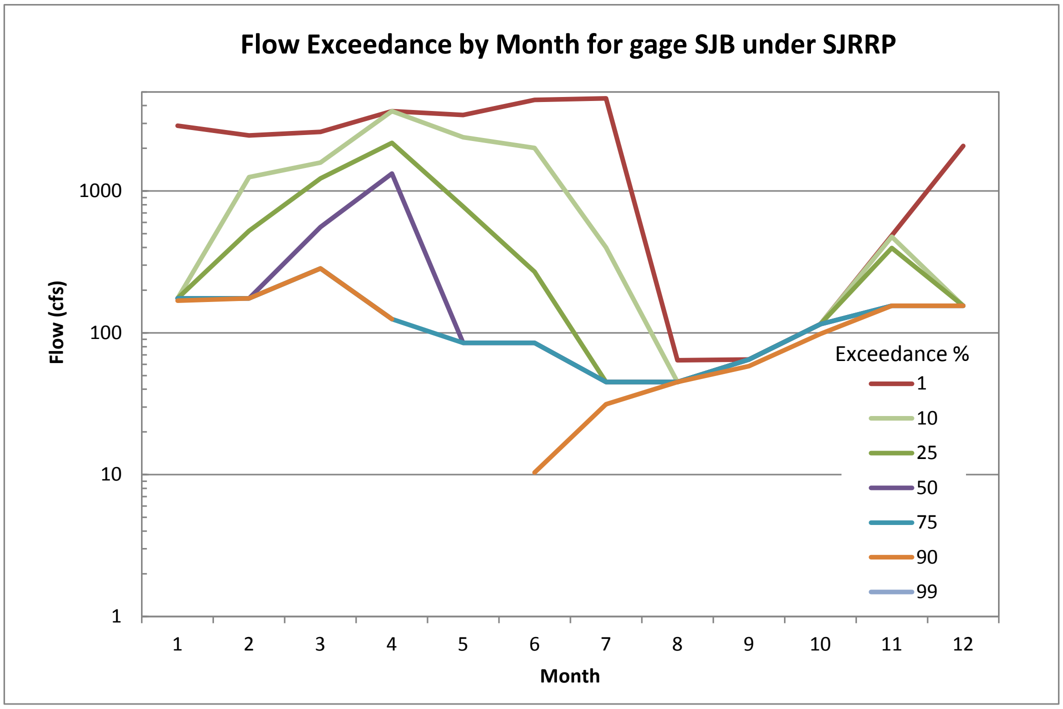


Figure 2-5.—Simulated monthly flow duration at SJB
(stream gage at upstream end of Reach 2B) under the SJRRP.
The 99 percent exceedance is 0 for all months and not shown on log-scale plot.

- 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.

- In all water year types, water can also be released from Millerton 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	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

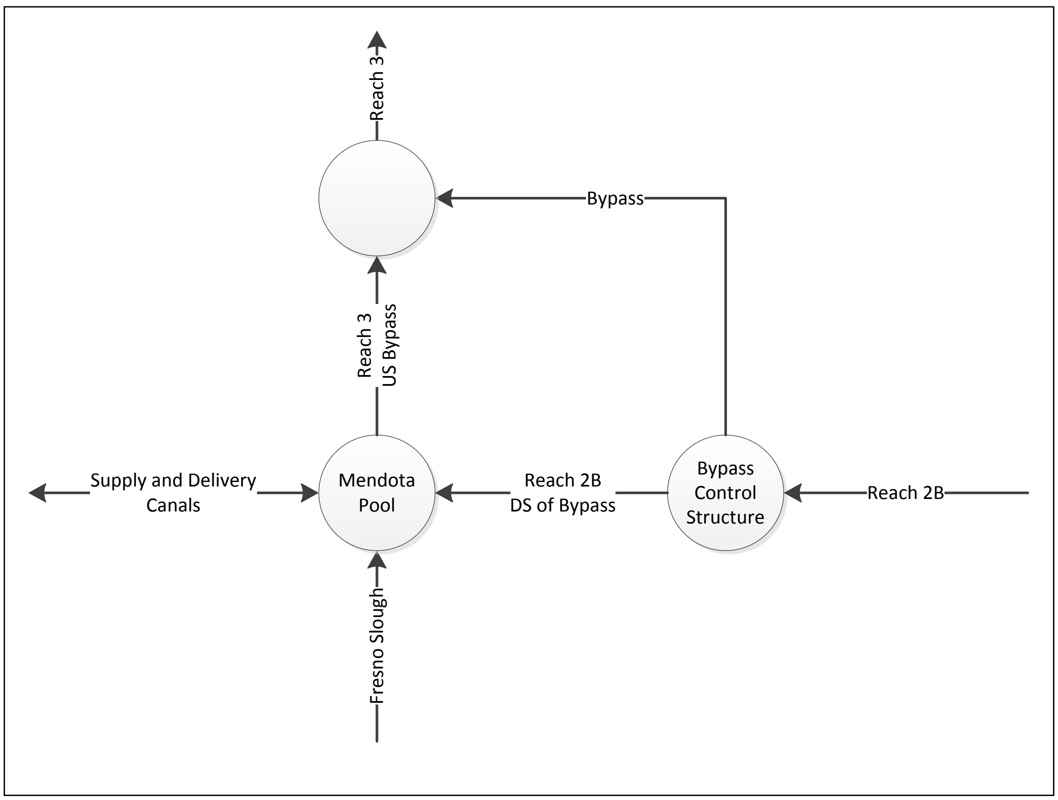


Figure 2-6.—Flow schematic of Bypass Project.

2.4 Sediment Transport

The primary objective 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 be no longer term 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 at structures and in the channel profile design. Also, part of the design goal is that future subsidence will not threaten channel sustainability or structure stability. The current subsidence rates, along with the potential total subsidence if these rates were to continue for a given period of time, are 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 (ft/yr)	Projected Total Subsidence in 25 yrs (ft)
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 goals were suggested by ESA [ESA 2012], and a modified version of them follows:

- Short-term Goals (Years 1 to 10):
    - Maintain suppression of invasive plants to limit impacts to habitat and competition with native species
    - Revegetate newly created channel to provide sediment stability
    - Establish widespread beneficial vegetation within the bypass floodplain, uplands, and channel margins to enhance habitat diversity and inhibit invasive weed colonization
    - Manage flows through the Bypass to promote establishment and growth of native riparian vegetation
    - Use woody species to encourage channel and floodplain complexity

- Long-term Goals (Years 10 to 30):
    - Contiguous expanses of multi-tiered native vegetation within the Bypass
    - 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 sustainable 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 restoration flows.

- During deliveries to Mendota Pool, a fish passage facility will convey fish around the Bypass control structure and will accomplish Category C passage.

- Promote survival of the species through development of appropriate and sustainable habitat.

- The Bypass should convey at least 4,500 cfs. This improvement requires construction of a structure capable of directing flow down the Bypass and allowing the Secretary of Interior 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.

3 Hydrology and Hydraulic Studies

3.1 Hydrology

The future hydrology in the Project Reach is largely determined by the Settlement and flood flows. These are the defined "restoration flows," however, they may not define the actual flows because these restoration flows do not consider the daily operations of the system and the flood releases from Friant Dam and other tributaries to the San Joaquin below Friant.

A daily operations model for the San Joaquin River Restoration Program was developed in RiverWare, a versatile hydrologic modeling software package (Reclamation, 2012). The model simulates hydrology along the San Joaquin restoration reaches from Millerton Lake to the Merced River, and along the Chowchilla and Eastside Bypasses. Daily Friant Dam operations are modeled as well as downstream routing, losses, and operations (bifurcations, diversions, etc.). Daily inflows sum to match monthly CalSim II volumes. Monthly diversions and some downstream inflows are taken from CalSim II results, with monthly to daily flow patterning applied where appropriate. Daily Friant releases are modeled independently from the CalSim II restoration runs used for the Program Environmental Impact Statement/Environmental Impact Report (PEIS/R), including restoration release flow schedules and flood control releases. The model has the ability to schedule restoration releases in differing patterns, following the constraints defined in the Settlement (NRCD, 2006). The model simulates the operational challenges associated with forecast error and its effects on restoration allocations and scheduling and flood control operations. Model results include Millerton parameters such as storage, pool elevation, and releases, and downstream river flows on a daily timescale.

The daily flow model incorporates both restoration flows and flood operations. It also includes the contributions of tributaries to and diversions from the San Joaquin. The daily flow model uses the historical period of record for Water Years (WY) 1922 to 2003. A water supply forecast is used to define the Restoration Water Year Type within the model, and the resulting number of each year type for the 82-yr period of record is shown in Table 3-1.

It is important to recognize that delivery of irrigation water from Friant Dam to the Mendota Pool is not incorporated into the hydrologic simulations. This is because delivery of water to the Mendota Pool is not included into the CALSIM model upon which the model is dependent.

The estimated daily flow exceedances in Reach 2B by month are given in Appendix A and Figure 3-1.

Table 3-1. Number of Restoration Year Types within 82-yr Period of Record (1922 to 2003).

Year Type	Number within 82-yr period of record
Critical Low	1
Critical High	4
Dry	12
Normal-Dry	25
Normal-Wet	24
Wet	16

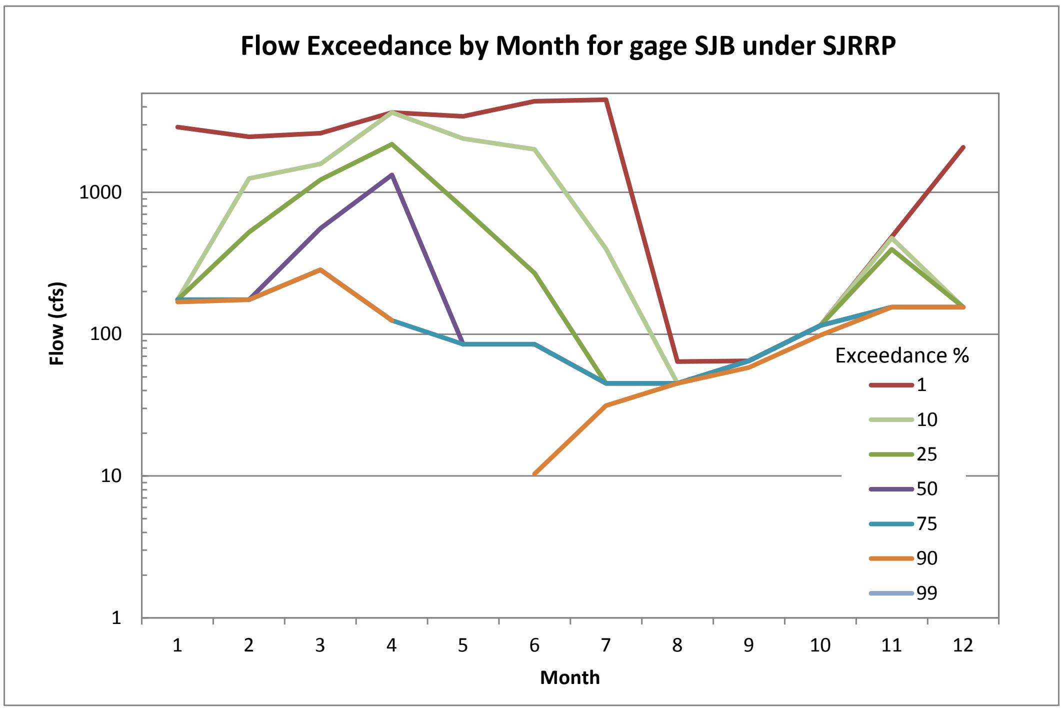


Figure 3-1.— Flow Exceedance by Month for gage SJB (in Reach 2B) under the SJRRP.

3.2 Description of Hydraulic Model

The hydraulic data and analysis used to support the hydraulic design is described in this section.

3.2.1 Topography and Bathymetry

The above water topography used in the hydraulic model is based upon 2015 LiDAR mapping that was recently developed for Reclamation in the North American Vertical Datum of 1988 (NAVD88) and horizontal projection of North

American Datum 1983 California State Plane Zone III (NAD_1983_NSRS2007_StatePlane_California_III_FIPS_0403_Feet).

This LiDAR data is the result of private and government entities working together under the guidance of Reclamation Survey Division. Fugro EarthData, Inc. acquired new Topographic and Bathymetric LiDAR data with Riegl VQ-820-G LiDAR system for areas of the San Joaquin River Restoration Project. The LiDAR was collected with a planned density of greater than 8 points per square meter. The measured density of the data is greater than 10 points per square meter averaged over the extent of the project area. The project encompassed an area of approximately 335 square miles. The LiDAR system including an inertial measuring unit (IMU) and a dual frequency airborne GPS receiver was used for the LiDAR acquisition. LiDAR data acquisition was performed January 9, 2015 thru February 11, 2015 at 300m AMT (above mean terrain), with 30 percent overlap between the flight lines. Ground control survey was provided by the Reclamation, and check point survey data was provided by O'Dell Engineering. Point Cloud and DEM products were produced with a resolution of 1 foot GSD utilizing the LiDAR data

The data was tiled into 1600 foot by 1600 foot tiles. Extensive testing was run on the data to assess the settings that are needed for the automated routines. These settings were used to run an automated routine on the data to separate the points into ground and non-ground point classifications. At the completion of the automated routines, the data was edited manually to ensure the automated routines placed the points in the appropriate classifications. Points that were mis-classified with the automated routines were placed in their appropriate classification by production analysts. The bathymetric data was maintained in the tile structure throughout the project, and anything under water was classified as ground. The tiles were then run through another automated routine to place the non-ground points into their appropriate classifications, by vegetation type, building, noise, etc. The Riegl 820 LiDAR system collects points on top of the water, and the ground below the water surface. It is important to note that the points on the surface are classified to a vegetation classification, as that is what the automated routine read the points as. The finished tiles were subject to an independent QC performed by a different production analyst and automated QC routines to ensure compliance with the project requirements and classifications. Gridded DEM files in 32-bit floating point IMG format, 1 foot GSD, were produced using the ground classification, and tiled to the same layout as the LiDAR point cloud. These DEM's went through another QC to ensure no data gaps, tile edge artifacts, and missing ground points, or additional non-ground points being used in the calculations. In addition to DEM files, ASCII files of the ground classification points were extracted from the LAS data. Intensity images in GeoTIFF format were also produced and delivered.

The below water topography from the LiDAR was not used because there were several locations where it did not produce reliable data and therefore the bathymetry is based upon two different bathymetric surveys listed in Table 3-2 performed by Reclamation Technical Service Center. The surveys were performed using the same vertical and horizontal datum as the LiDAR.

Table 3-2.—Dates of Bathymetry Surveys in Reach 2B and 3

Reach	Date of Bathymetric Survey
2B	March 2015
3	June 2014

3.2.2 Development and Calibration of 1D Model

The HEC-RAS model was developed using HEC-GeoRAS 10.2. HEC-GeoRAS 10.2 is an extension to ArcGIS 10.2 and available for download at: http://www.hec.usace.army.mil/software/hec-georas/. ArcGIS 10.2 is a geographic information system (GIS) for working with maps and geographic information (https://www.arcgis.com).

The location of the cross sections was determined based upon a previous HEC-RAS model of Tetra Tech [2013] that was based upon LiDAR data collected in 2008. The hydraulic roughness values were calibrated to observed water surfaces collected in 2010 and 2011 as part of this study.

The hydrology, hydraulics, and sediment transport have been analyzed in Reclamation [2015]. The hydraulics in the Bypass have been updated to reflect the current grading plan and structural design. The cross section layout used in the hydraulic model in the Bypass is given in Figure 3-3.

The cross section geometry used in Reach 3 is the cross section geometry expected after 25-yr simulation of the SRH-1D sediment model. The future geometry was used because there is significant adjustment of the Reach 3 expected because of the resupply of sediment to this reach. Initially, there will be an elevation difference between the downstream end of the Bypass and Reach 3 that will decrease as sediment is deposited in the deeper pools of Reach 3. A detailed discussion of the changes expected in Reach 3 is found in Reclamation (2015b).

The roughness in the low flow channel of the Bypass was assumed to be 0.03, and the floodplain was assumed to have a roughness of 0.08. There is considerable uncertainty regarding the roughness in the Bypass because it is not fully possible to estimate the future dynamics and vegetation growth. The estimates are intended to be for the case far into the future after the vegetation has reached a relatively stable state.

There are two basic hydraulic conditions in the Bypass: 1. The Bypass Control Structure Gates will be fully open and Restoration flows are passing through the

Bypass, and 2. The Bypass Control Structure Gates will be partially closed with both Restoration Flows and Delivery Flows occurring.

3.2.3 Development of 2D Model

A two-dimensional depth averaged (2D) model of the Bypass was developed using SRH-2D (Lai, 2008). It was developed to assess the detailed velocity distribution within the Bypass. The 1D model (HEC-RAS) only computes the cross sectional averaged velocity and not the velocity distribution transverse to the flow direction. It is necessary to get a more detailed velocity distribution to assess channel stability and fish passage and habitat concerns.

The 2D model uses the same topography within the Bypass and roughness as the 1D model. In Reach 3, however, the 2D model uses the topography from the existing conditions model. The 2D model is not calibrated because it is only used to simulate conditions in the Bypass and there is not calibration data available.

3.3 Restoration Flows in the Bypass

Restoration flows will occur primarily when the Bypass Control Structure gates are fully open. The water surface profiles for this condition are given in Figure 3-4. The channel bed in Reach 3 was taken from the simulated condition after 25 years as described in Section 5.1 because the upper portion of Reach 3 is expected to aggrade as the result of the project. There is limited water surface drop across the channel and at all flows there is expected to be no significant water surface drop across the two grade control structures located at approximately Bypass stations 3200 and 3600.

Example cross sections and the associated water surface elevations in the Bypass are given in Figure 3-5, Figure 3-6, and Figure 3-7, for cross section numbers 3147, 2147, and 1147, respectively.

The channel velocities for flow between 50 and 4,500 cfs are given in Figure 3-8. The cross sectional average velocity is less than 4 ft/s for the entire channel. The channel depths for flows between 50 and 4,500 cfs are given in Figure 3-9. The channel depths are greater than 1.2 ft for all flows above 100 cfs.

The water surface elevations through the Bypass Control Structures are shown in Figure 3-10. Notice that even at a flow of 4500 cfs through the Bypass, the water surface elevations at the structure are below the normal pool elevation of 154.5 ft in Mendota Pool.

The velocity results using the 2D model are show in Figure 3-11 and Figure 3-12 for flows of 1000 and 4500 cfs respectively. The velocity in the main channel is between 2 and 3 ft/s in the main channel for the majority of the Bypass at a flow of 1000 cfs. The velocity increases within and just downstream of the Bypass control structure because of the constriction caused by the structure. The velocity also increases at the downstream end because the 2D model uses the bathymetry from the existing conditions instead of the future conditions after sediment is deposited in Reach 3. The high velocities at the end of Bypass are expected to decreases to those throughout of the majority of the Bypass once the reach stabilizes.

The velocities at a flow of 4500 cfs are typically 2 to 3 ft/s within the main channel of the Bypass. Just downstream of the Bypass control structure the velocities are higher, between 4 to 5 ft/s.

3.4 **Delivery Conditions**

It is difficult to determine the frequency with which deliveries to Mendota Pool from the San Joaquin River will occur. The historical frequency is not necessarily a reliable indication because of shifts in operational rules for the Delta-Mendota Canal flows, the changes in operations caused by the SJRRP itself, and potential changes in the precipitation amount and distribution caused by climate change. The only two years in which deliveries from the San Joaquin River occurred since Friant Dam's completion in 1942 have occurred in the last 3 years.

The water surfaces in Reach 2B will be significantly higher under delivery conditions because the water surface elevation will need to be sufficient to reach the pool elevation, which is typically between 154 and 154.5 ft. It is necessary to compute the water surface elevations in Reach 2B because a portion of the Reach 2B levees will be constructed as part of this design. Their construction will be combined with the regrading of Columbia Canal, which is located along the north side of the Bypass and Reach 2B. The levees in Reach 2B will be designed to the case when all 4,500 cfs is passed through Mendota Dam as this will create the highest water surface condition in Reach 2B.

The water surface profile in Reach 2B for the case of 4,500 cfs being routed through Mendota Pool is given in Figure 3-13. The profile is intended to provide the design condition for the levees upstream of the control structure including the effects of subsidence. It is assumed that the area around Mendota Pool could subside up to 5 ft over the next 25 years (Table 2-3). To maintain gravity driven water deliveries to areas outside of the subsided zone, the elevation of Mendota Pool will have to remain constant while the area around it subsides. Therefore, to develop design conditions for structures and levees the water surface of Mendota Pool was increased 5 ft.

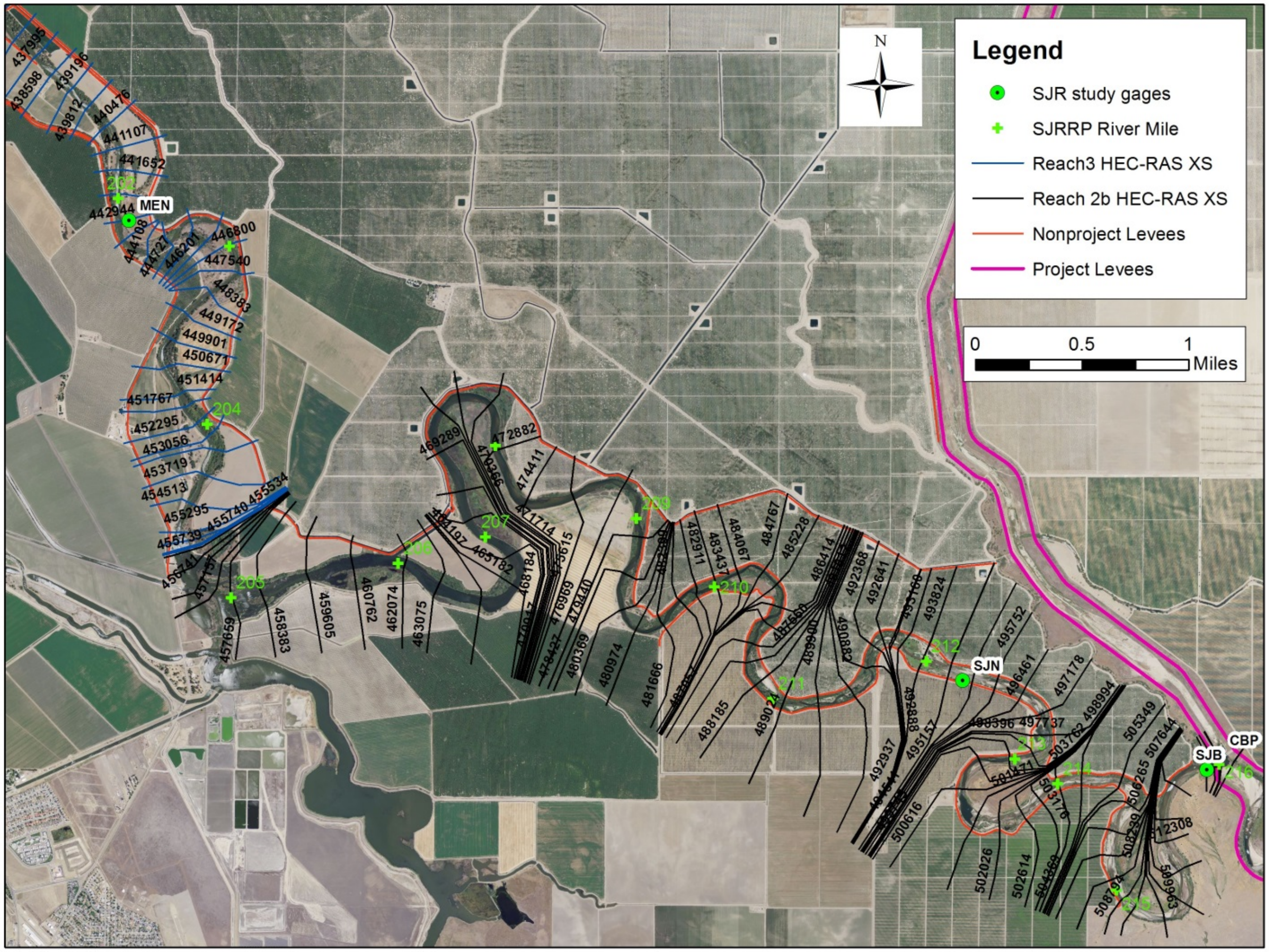


Figure 3-2.—Cross section layout Reaches 2B and 3 based upon locations of Tetra Tech [2012].

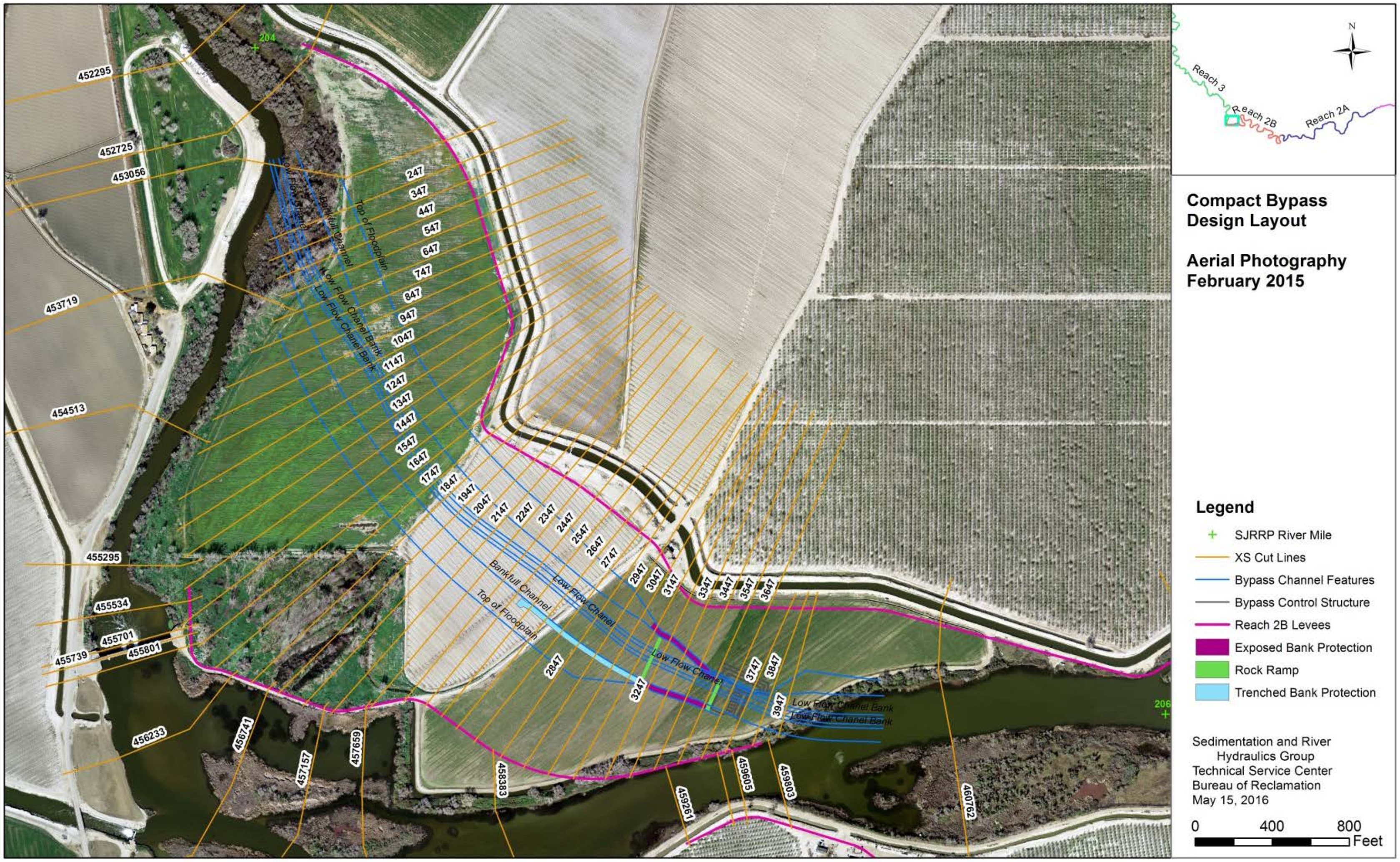


Figure 3-3.—Cross section layout for Bypass.

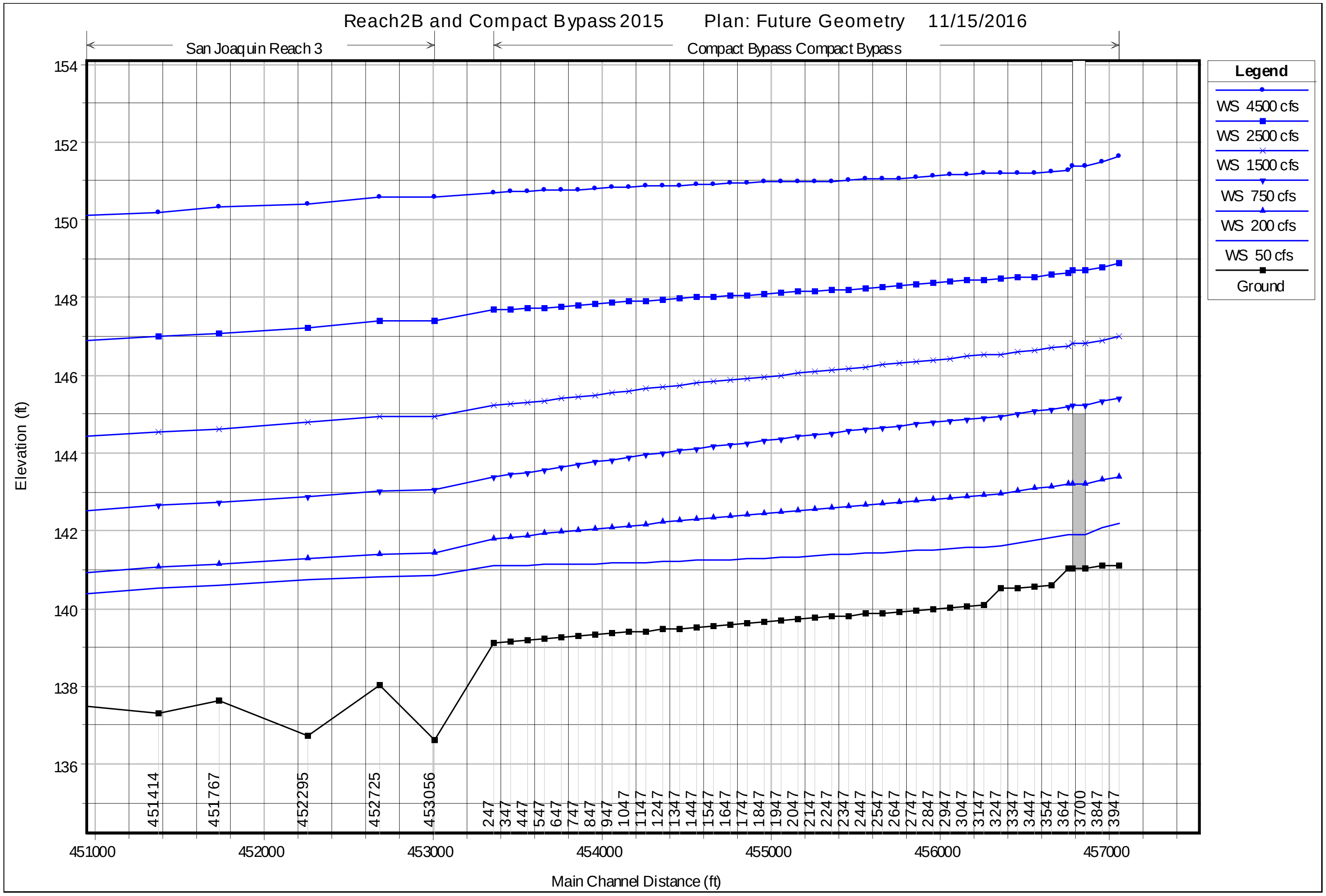


Figure 3-4.—Water surface profile in Bypass for flows between 100 and 4500 cfs for expected future conditions after channel adjustment.

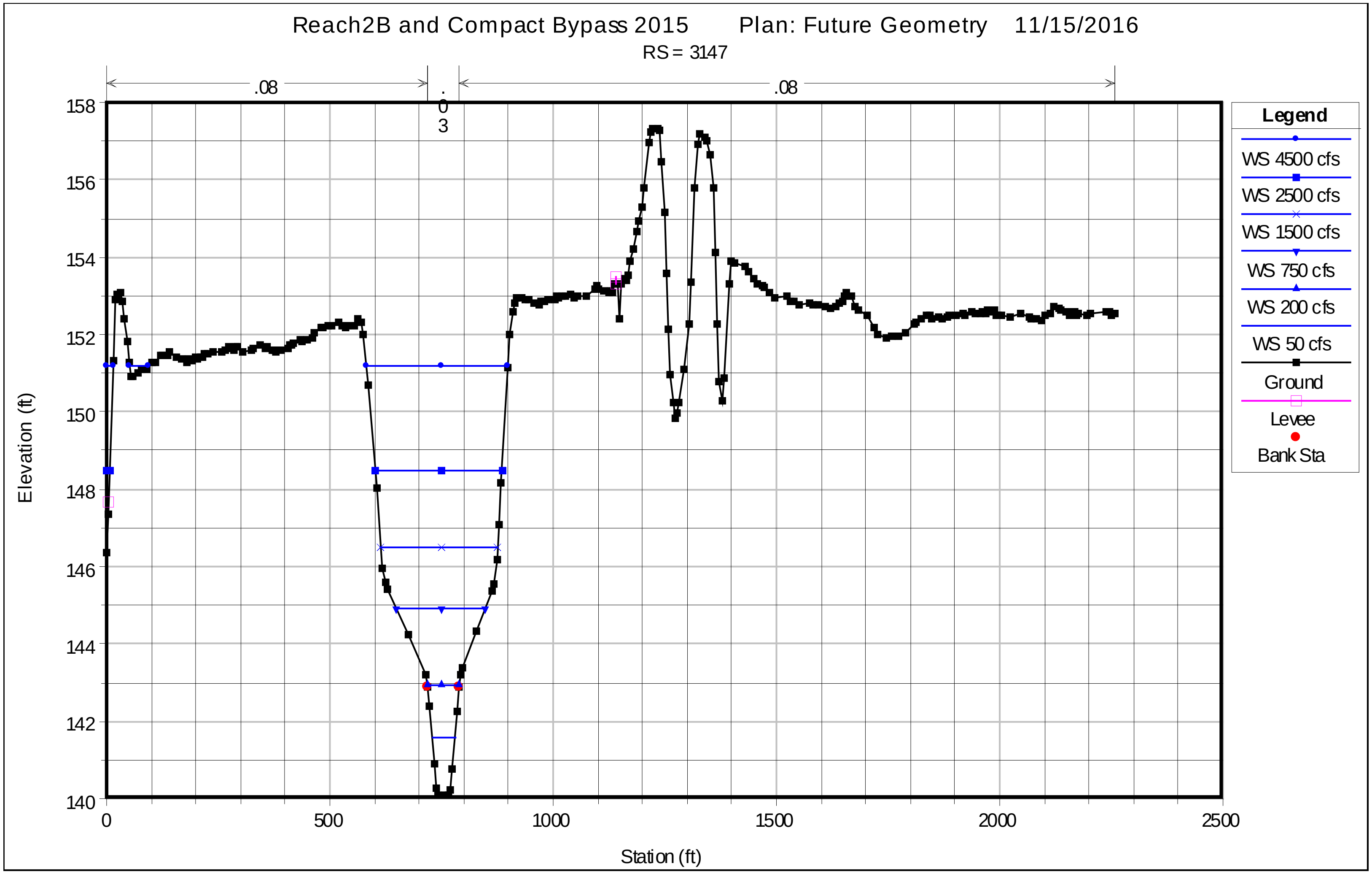


Figure 3-5.—Cross section 3147 in Bypass showing water surfaces.

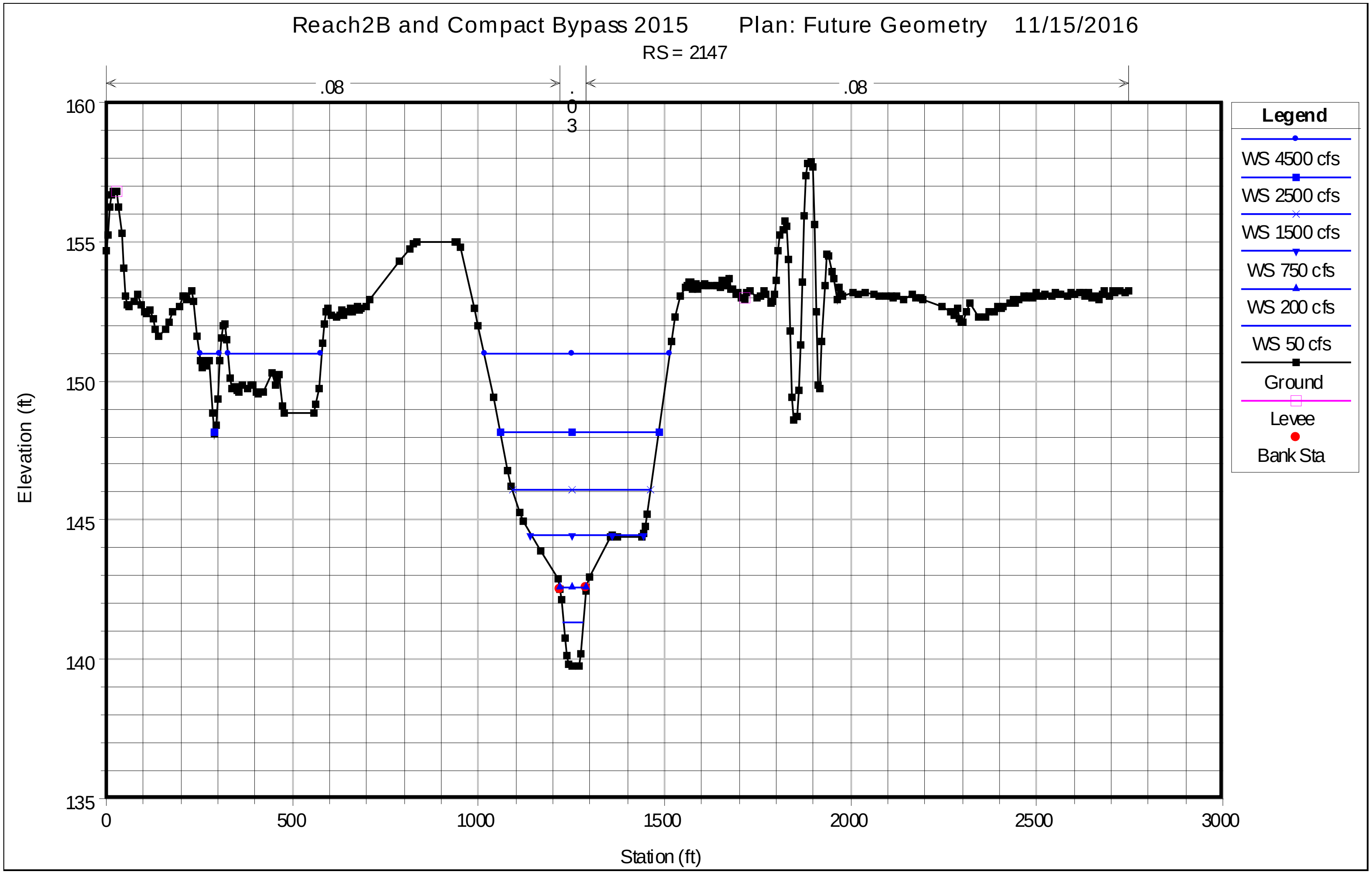


Figure 3-6.—Cross Section 2147 in Bypass showing water surfaces.

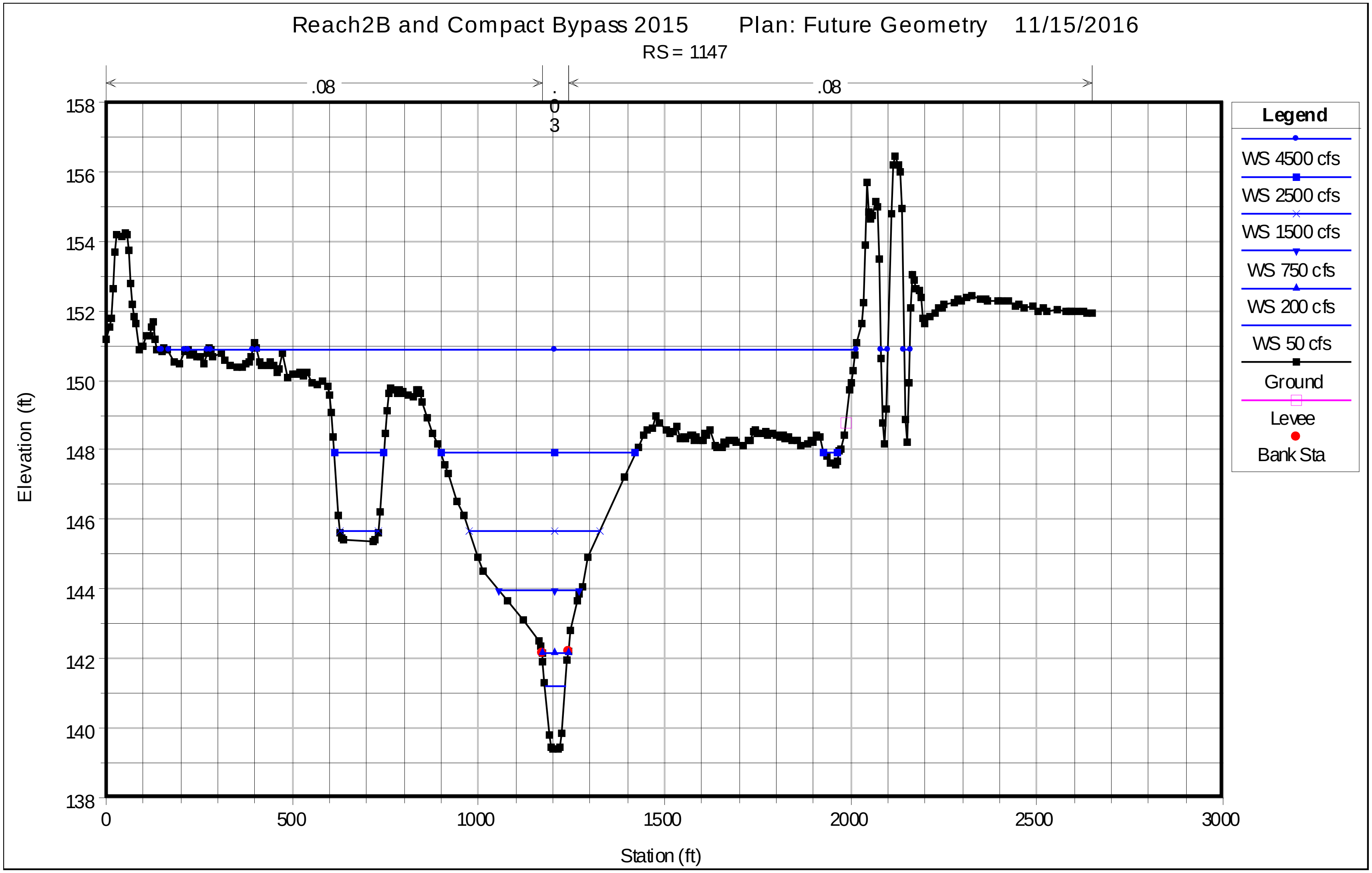


Figure 3-7.—Cross section 1147 in Bypass showing water surfaces.

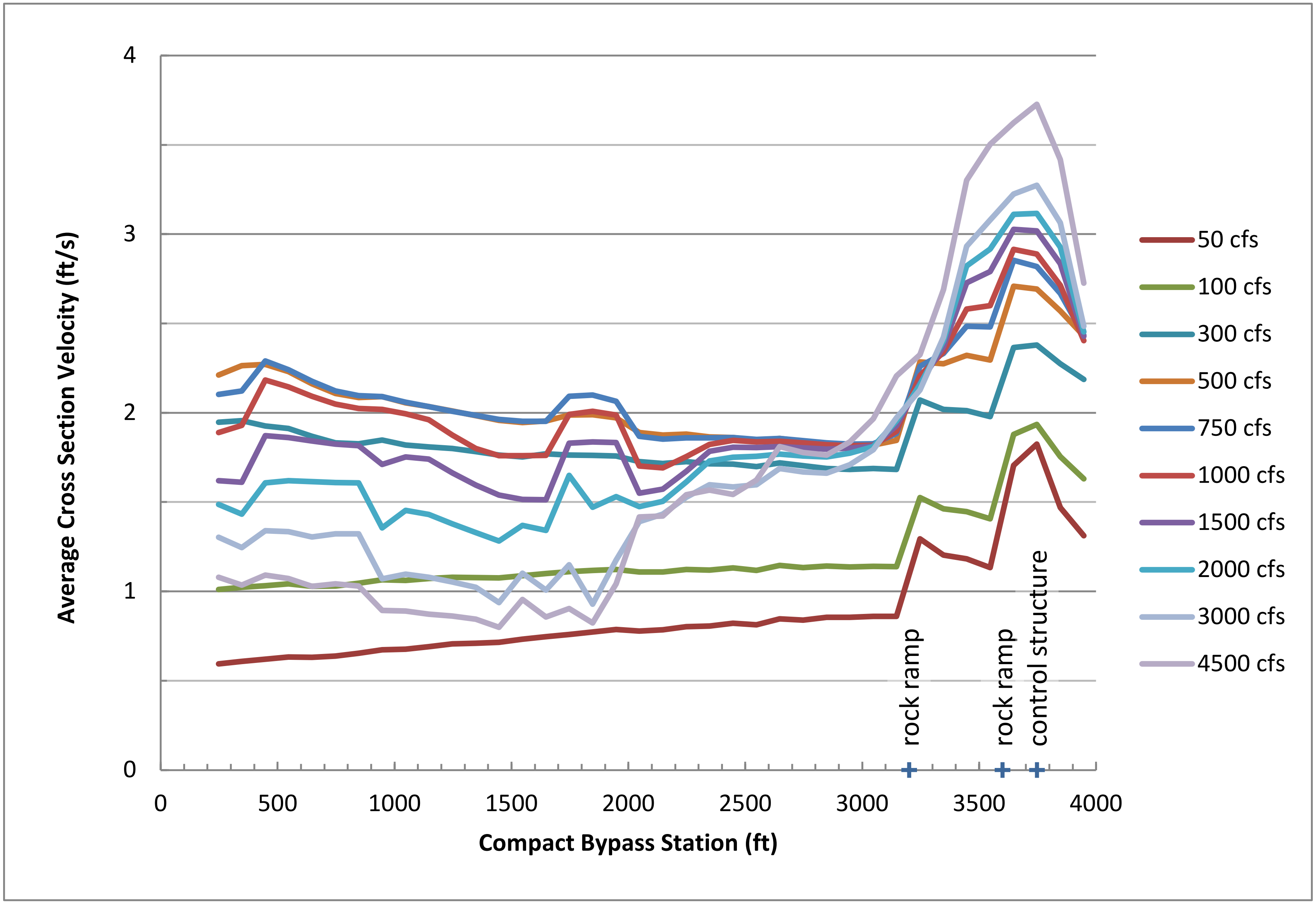


Figure 3-8.—Average cross section velocity in Bypass for flows between 50 and 4500 cfs.

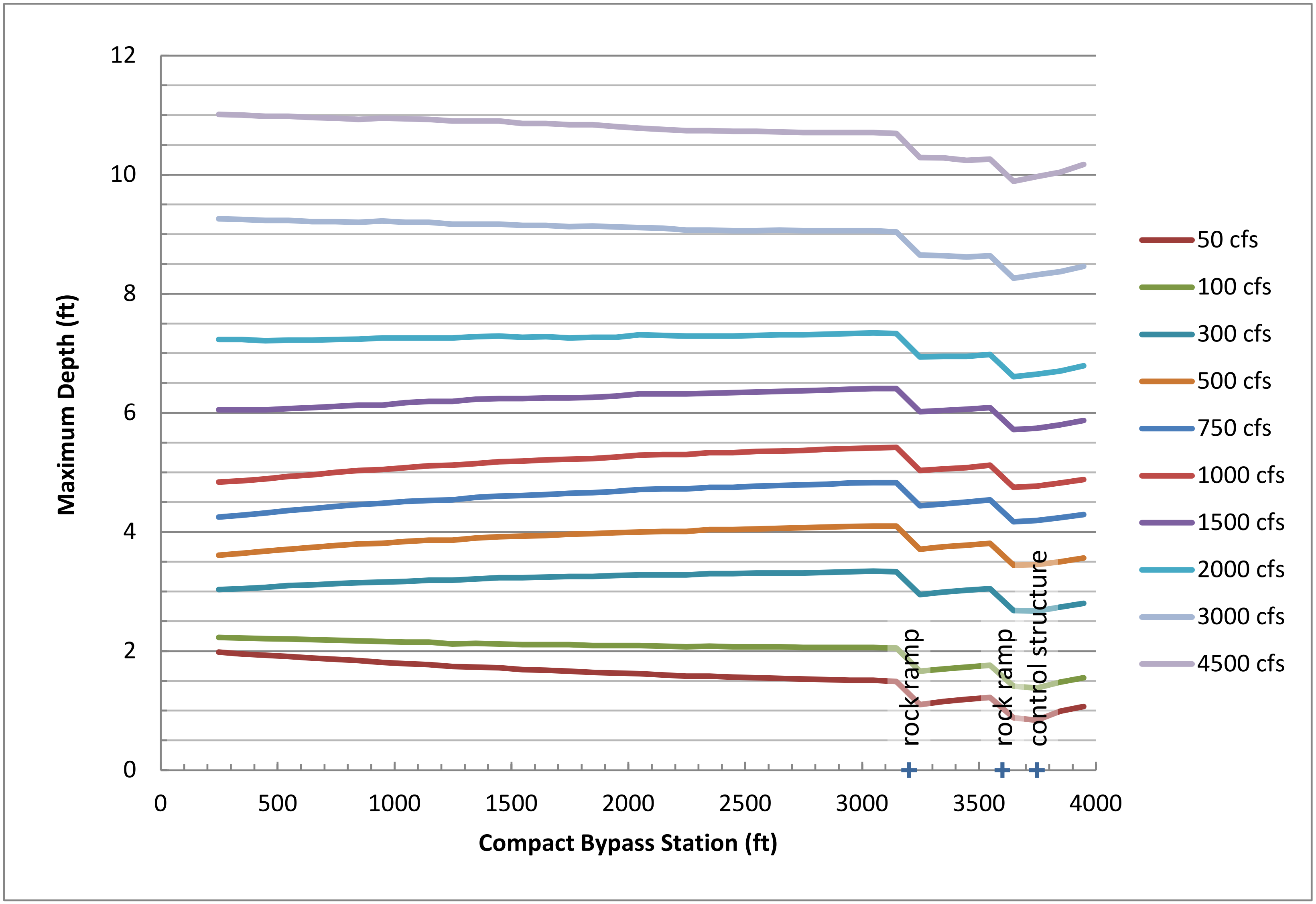


Figure 3-9.—Channel depth in Bypass for flows between 50 and 4500 cfs.

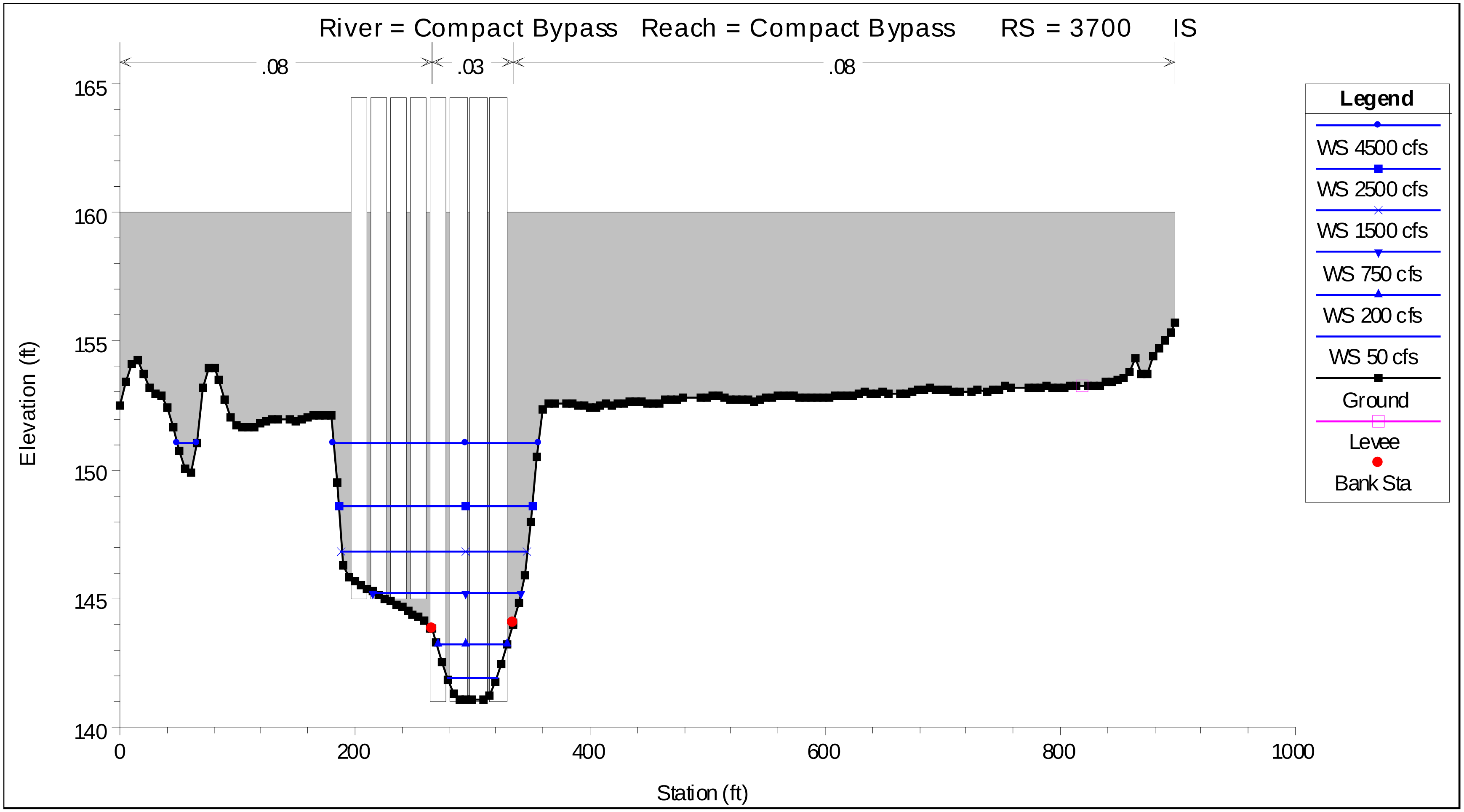


Figure 3-10.—Water surfaces at control structure at head of the Bypass. The structure walls and abutments are shown in gray.

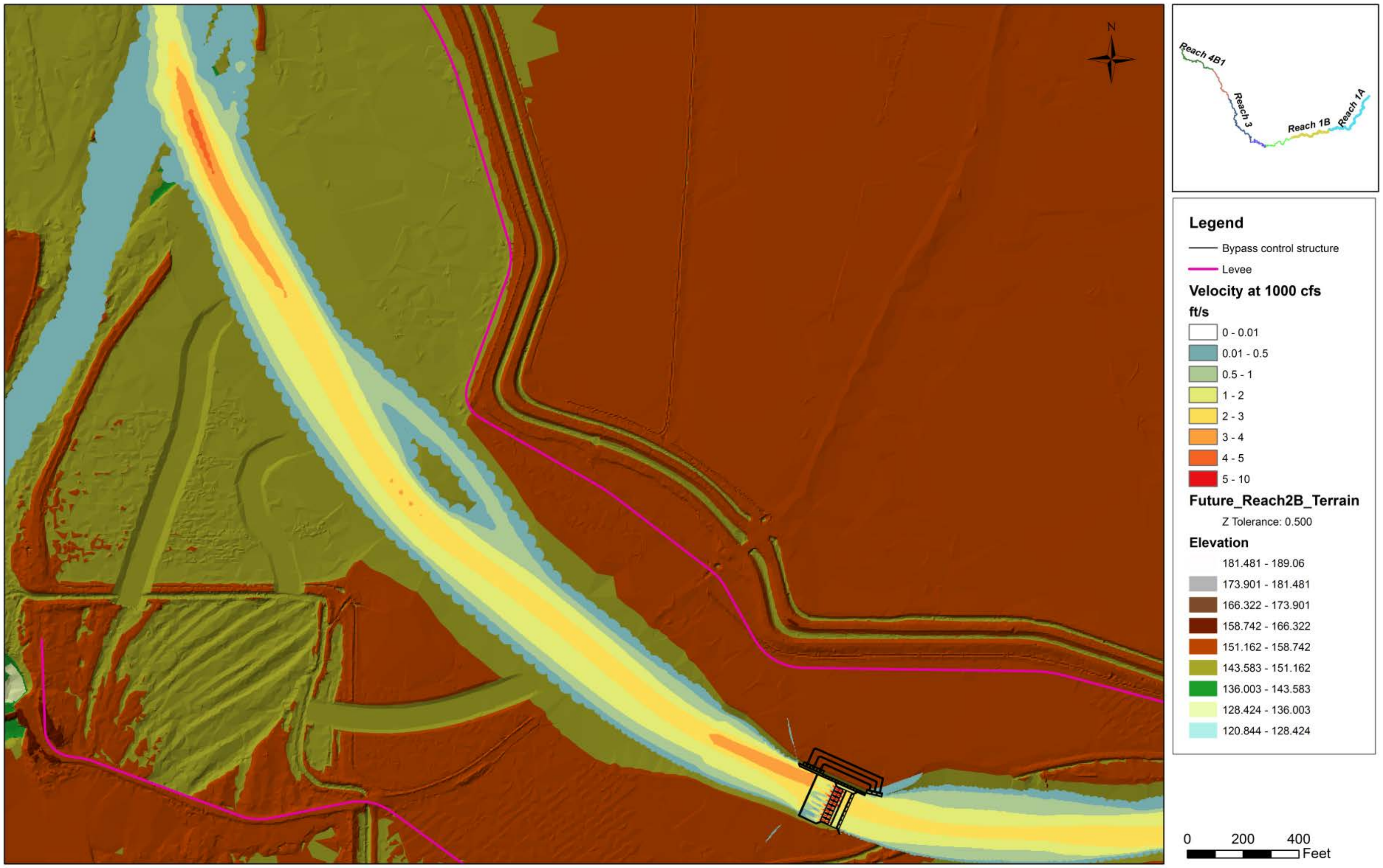


Figure 3-11.—Simulated velocity distribution in the Bypass using SRH-2D at a flow of 1000 cfs in Bypass.

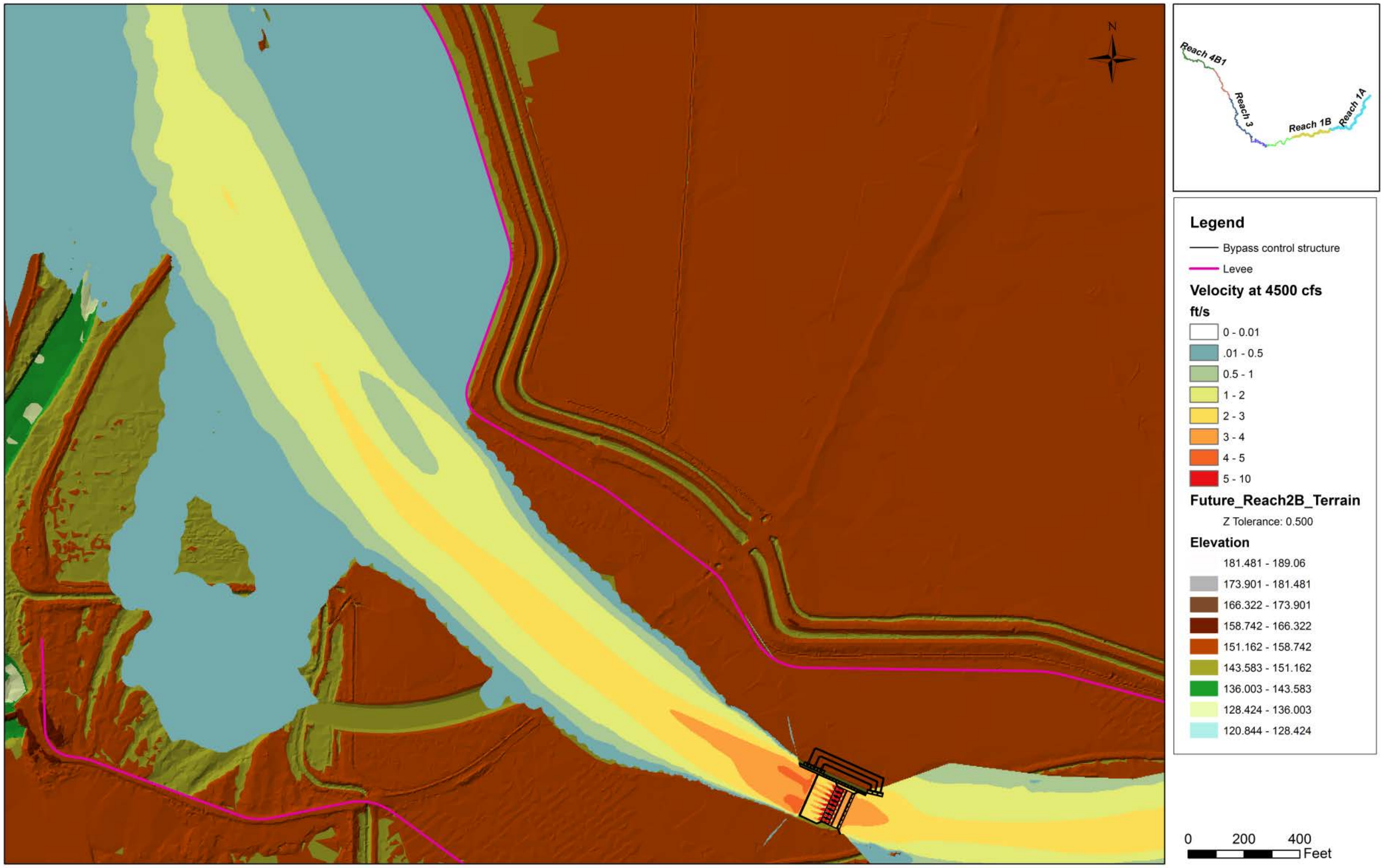


Figure 3-12.—Simulated velocity distribution in the Bypass using SRH-2D at a flow of 4500 cfs in Bypass.

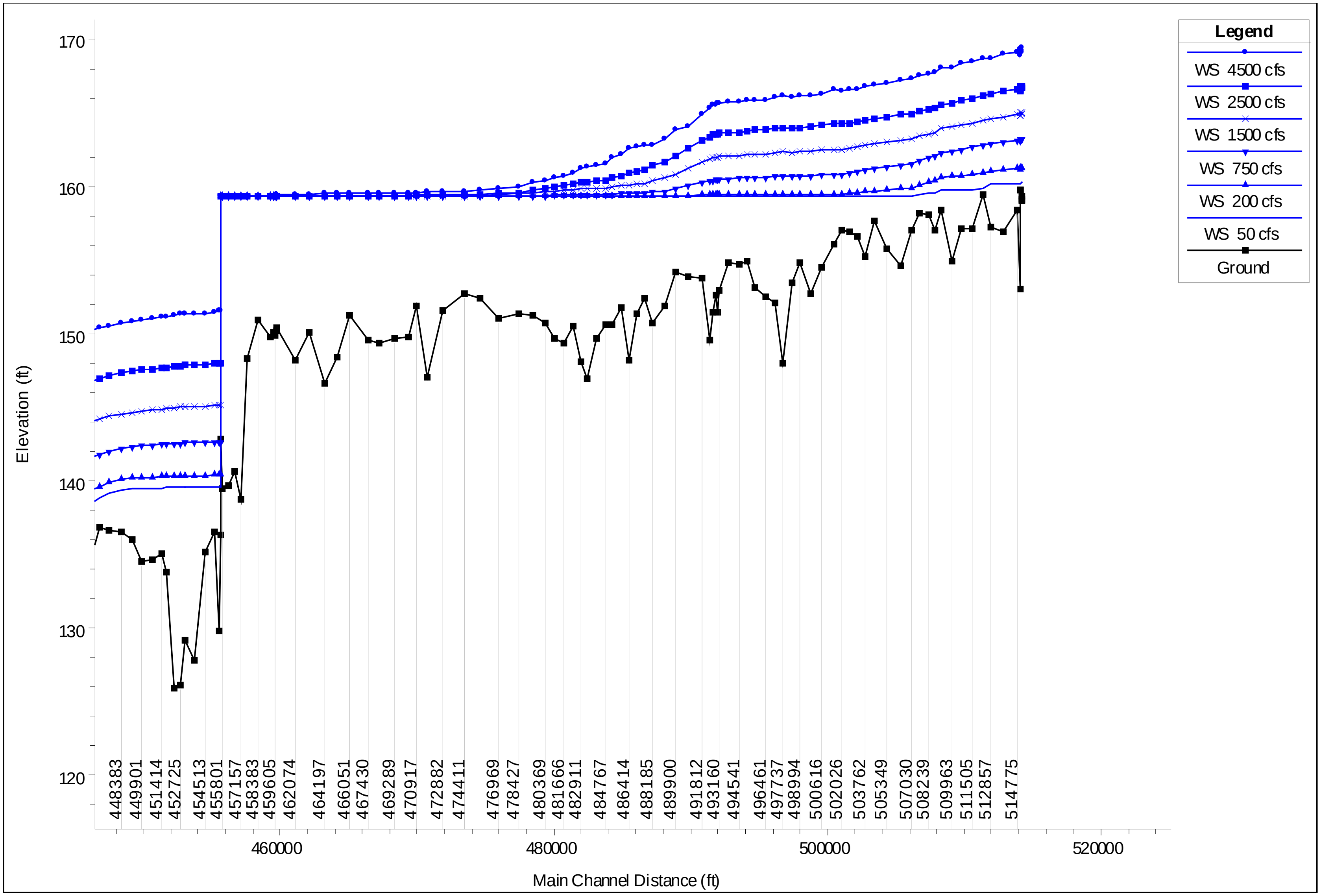


Figure 3-13.—Water surface profile in Reach 2B for Delivery Conditions assuming that the water surface required for delivery rises 5 ft relative to ground surface to account for subsidence.

4 Revegetation Background Data

4.1 Site History

The earliest available photographs of the site were taken in 1937 (Figure 4-1), after the construction of Mendota Dam (built in 1871), and suggest the area had already been influenced by both the dam and agricultural practices to some extent. The photos depict several relatively large areas of dense vegetation within the project area identified in red. In contrast, other large areas in the central and northwestern portions of the project area appear to be more sparsely vegetated and may have been cleared for grazing. A small isolated open water area can also be seen, potentially implying a connection to the floodplain prior to the creation of the dam and/or an effect of the dam in elevating groundwater levels in this area.

More recent color aerial photography (Figure 4-2) shows patterns of soil color variation similar to the bare/vegetated pattern in the northwestern portion of the project area. This may indicate there are areas with soil or hydrologic conditions that are potentially less favorable for woody vegetation.

Figure 4-1.—Aerial photograph of Bypass project area from 1937. Compact Bypass project area is in red.

Figure 4-2.—Aerial photograph of Bypass project area from 2014.

4.2 **Site Conditions**

4.2.1 Soils

Currently available soils information includes USDA Natural Resources Conservation Service soil classification maps, geotechnical soil borings, and field soil measurement points. The northwestern third of the project area is currently inaccessible for surveys, and further soil sampling is planned for the project area that will be used to refine the vegetation species composition and layout in future drafts of the design. Existing soils classifications are presented in Figure 4-3 and summarized in Table 4-1.

The Madera area soil survey identifies five different soil series within the project area:

- Chino loam – slightly saline-alkali (CgaA)
- Chino loam – moderately saline- alkali (CgbA)

- Columbia loamy sand (CoA)
- Grangeville fine sandy loam – slightly saline-alkali (GbA)
- Wunjey very fine sandy loam – strongly saline-alkali (WxA)

Figure 4-3.—Soil series for Compact Bypass project area.

The soils in the Bypass are generally stratified alluvial deposits from granitic parent materials with 0 to 1 percent slopes. Drainage is moderate to poor, attributed partially to a lowered water table from groundwater pumping; drainage may be slower if groundwater becomes shallower. Salinity levels in the riparian planting zone may only be problematic in the Wunjey series, which normally contain an excess of salts and alkali. Water holding capacity is low to moderate and rooting zones are deep to very deep.

Table 4-1.—Soil series characteristics summary for the Compact Bypass.

Soil Series	**Chino loam**	**Chino loam**	**Columbia loamy sand**	**Grangeville fine sandy loam**	**Wunjey very fine sandy loam**
Map Unit	CgaA	CgbA	CoA	GbA	WxA
Texture	loam, silty clay loam	loam, silty clay loam	loamy sand, stratified sand to silt loam	fine sandy loam, sandy loam, stratified loamy sand to silt loam	very fine sandy loam, stratified very fine sandy loam to silt loam
Drainage	poor	poor	poor	poor	well-drained
Water Capacity	moderate	moderate	low	moderate	low
Salinity	slight to moderate	moderate to strong	not specified	slight to moderate	strong
Erosion Hazard	moderate	moderate	moderate	slight	slight

Geotechnical boring data is currently preliminary and located at the perimeter of the Bypass project area associated with proposed structure locations. Classifications are generally sandy loam with a minor representation for loam, consistent with the NRCS series.

Hand-augured central boring and composite samples, as well as EM38 readings, were taken at three points within the southern boundary of the Bypass project area. The borings were approximately 5 ft deep. Sample locations were within the Grangeville fine sandy loam (Sample 4), Chino loam moderately saline-alkaline (Sample 5), and Chino loam slightly saline-alkaline (Sample 6) mapping units. These data are summarized in Table 4-2.

Table 4-2.—Hand-augured central boring and composite soils data summary for the Compact Bypass project area.

Sample	**Texture**	**Moisture**	**pH**	**ECe (dS/m)**
4	silt loam, fine sandy loam	very moist - nearly dry	7.5-8.0	1.5-3.2
5	loam, silt loam, fine sandy loam	very moist - moist	6.8-7.5	1.8-5.4
6	loam, fine sandy loam, loamy sand	very moist - dry	6.8-7.1	1.1-1.5

Soils data collection is ongoing and may inform refinements to the final revegetation design.

4.2.2 Groundwater Hydrology

For the purpose of the revegetation design, it is assumed that once the channel is excavated (up to 10 ft deep) and flows are initiated in the Bypass, the groundwater elevation will be relatively consistent with the baseflow elevation across the riparian areas. This would put the depth to groundwater at a maximum of 10 to 15 ft within the riparian planting zones, which is within the range of suitability for establishment. Most of the channel will be within 5 ft of the groundwater elevations. Although this scenario is unlikely to describe the actual groundwater elevations with a high degree of accuracy once the Bypass is fully functional, it is considered adequate for the design stage and there are no special considerations with groundwater elevations at this time.

4.2.3 Vegetation

Currently, most of the project area is agricultural, but there are native species present along the margins of the project area. Native vegetation adjacent to and upstream of the Bypass has been identified in the course of several monitoring efforts. Plant community mapping surveys have documented California bulrush marsh, Baltic Rush, California Rose, riparian bank herbs, Dogbane, button willow thickets, Sandbar willow, Gooding’s willow, Oregon ash groves, saltgrass flats, California mugwort brush, creeping wildrye grassland, and Fremont cottonwood forest vegetative alliances.

Other reported habitats included Valley Foothill riparian, elderberry savannah, riparian scrub, willow scrub, annual grassland, and other various herbaceous and aquatic habitats.

Invasive vegetation has been documented upstream of the Bypass (Meadows et al., 2015). Species of concern include giant reed (*Arundo donax*), red sesbania (*Sesbania punicea*), Chinese tallow (*Sapium sebiferum*), edible fig (*Ficus carica*), and tamarisk (*Tamarix* spp.).

5 Design Description

The following elements of the 60% Bypass Design are described in this section:

- Excavation of the Channel,
- Bed and Bank Erosion Protection,
- Revegetation, and
- Irrigation.

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 were analyzed in Reclamation (2015b). The option selected in the report was Option 2, which had the lower sill elevation of the two options (a sill elevation of 141.5 ft). The 60% design made the following changes from the 30% design (Reclamation, 2015):

1. The low flow channel now has a slight sinuous pattern. The sinuous pattern is to promote the development of a more complex habitat within the Bypass.
2. The elevation of the control structure is at 141 ft instead of 141.5. The decrease in elevation will reduce the need for grade control within the Bypass.
3. The grade control structures are moved to just downstream of the flow control structure instead of at the end of the Compact Bypass. They will be integrated into the hydraulic dissipation of the control structure at the upstream end of the Bypass.
4. The cross section is slightly altered to eliminate the small terraces and instead create gradual transitions in elevation. The gradual transitions will be easier to revegetate.

5.1 Channel Excavation and Pilot Channel

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 immediately upstream of the Mendota Pool having a much smaller slope than the most upstream portion of Reach 2B. The change in slope is due to the sediment that has deposited behind Mendota Dam, which was originally built in 1871 and more than 100 years of sedimentation has occurred 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.

Reclamation (2015b) recommended a sill elevation of the upstream control structure of 141.5 ft. The sill elevation was decreased to 141 ft to reduce the need for grade control in the Bypass. Further reduction in the sill elevation is not recommended for two reasons: (1) the amount of deposition within the Bypass in the first few years after flow introduction could become excessive. Significant, but tolerable deposition is already expected after flows are introduced in the Bypass, but lowering the sill further could create enough deposition that would impede the operation of the flow control structure or fish passage facilities. (2) Reach 2B will become steeper than Reach 2A and therefore could potentially incise throughout the reach. In the current design, the slopes of Reach 2B and 2A are approximately equal (within 3%).

The design elevations at the beginning and ending of each Reach are given in Table 5-1. The existing and design profiles along the stream centerline in Reach 2A through the upper portion of Reach 3 are given in Figure 5-1 and the design profiles for the Bypass are given in Figure 5-2. Note that the grading of the levees are not shown in the two figures and that the levees will tie into the control structure.

The slope in the Bypass is slightly higher than the slope in Reach 2B or Reach 3, and therefore two grade control structures are necessary. These grade control structures are described in Section 5.2.2.

The typical cross section of the excavation is shown in Figure 5-3. The low flow channel is approximately 70 ft wide and has an average depth of approximately 3 ft. It is designed to contain approximately 200 cfs. The overbank transverse slope toward the low flow channel is 0.02 (50H:1V) and a flow of 1200 cfs is designed to have about 1 foot of depth in the overbank. The overbank transverse slope increases to 20H:1V at a distance of 135 ft from the center of the channel cut. The floodplain cross section is intended to produce a range of channel depths regardless of the flow.

Because the entrance to the Bypass is located approximately 7 ft below the current thalweg of Reach 2B, a pilot channel will be constructed to create a smoother transition between Reach 2B and the Bypass channel (Figure 5-2). The pilot channel will be 70 ft wide with 2H:1V side slopes excavated within Reach 2B, upstream of the junction between the Bypass and San Joaquin River. The pilot channel excavation will continue at a slope of 0.0013 upstream for a distance of approximately 1 mile. The excavation will be performed just prior to the reintroduction of high flows to the Bypass so that sediment does not refill the channel. The excavation will likely have to be performed from a barge while there is flowing water in the channel. Approximately 70,000 yd^3 of material will be removed and some of the material excavated from the pilot channel could be placed in the bed of the Bypass low flow channel to a max depth of 1 foot. This would be approximately 5,000 yd^3 of material. The remaining material could be placed at the confluence of the Bypass and Reach 3. This issue is discussed further in the following section.

5.1.1 Simulation of channel evolution

The channel will likely evolve in time and a sediment transport and mobile bed simulation was performed using SRH-1D to estimate the bed change over time. Two conditions were simulated: 1) excavation of the pilot channel and 2) no excavation of the pilot channel. The flow and sediment input used in the simulation have been described previously in Reclamation (2015b). The flows were modified in these simulations to reflect the fact that the maximum flows in Reach 2B will be 1300 cfs until the Reach 2B levees are rebuilt.

<u>With pilot channel</u>

The evolution of the minimum bed elevation for the first condition (with the pilot channel) is shown in Figure 5-6 and Figure 5-7. As shown in Figure 5-6, there is significant incision in Reach 2B for the 6 miles immediately upstream of the Bypass. The majority of the incision occurs within the first 5 years, and by year 15 the river appears relatively stable. The Bypass reach has a complex response in that it shows erosion at 0.5 years, particularly in the downstream portion of the reach, where there is 2 ft of erosion. By the end of year 1, most of the channel is depositional. The reach then reaches a maximum height of deposition of approximately 1 ft at year 5. After year 5 the reach begins to slowly erode, but there is variation in the bed elevation from year to year, with wet years causing more erosion and dry years resulting in deposition. At the end of the 25-year simulation, the bed elevations are within 1 foot of the design elevation which is considered acceptable variation in the bed profile.

The cumulative sediment loads at year 25 are shown in Figure 5-12. The majority of the erosion into Reach 2B occurs in the first 6 miles upstream of the Bypass. Approximately 670,000 tons of sediment is expected to erode from Reach 2B over the 25 year period. The majority of the deposition occurs in the lower portion of the Bypass and upstream portion of Reach 3. The sand size sediment load at the end of Reach 3 with the Compact Bypass is practically identical to the sediment loads under Existing Conditions over the 25 year of simulation. It important to note that Reach 3 is currently in a sediment deficit due to the presence of Mendota Dam and because subsidence has increased the bed slope in the reach.

A significant portion of floodplain deposition is expected to occur within the Bypass, which may increase the flow necessary to inundate the floodplain. However, the deposition is also expected to increase the complexity of the floodplain habitat. Separate flood channels are expected to form and some vegetation may be eroded or buried, but it is expected that this process will actually be beneficial to the habitat in the Bypass in the long term.

Without pilot channel

For the simulation that did not include the construction of the pilot channel, approximately 2 to 3 ft of deposition occurred in the Bypass in the first year when flows are routed into the Bypass (Figure 5-8 and Figure 5-9). Sediment would fill the low flow channel and cause large amounts of deposition in the floodplain. The pilot channel should decrease the magnitude of this deposition, but large amounts of deposition are still expected in the Bypass in the first few years after flows are allowed to enter. There is up to 7 ft of deposition in Reach 3 immediately below the Bypass that gradually decreases to zero deposition approximately 2 miles downstream of the Bypass. Most of the deposition occurs in the pools in Reach 3, immediately downstream of the Bypass. Further downstream in Reach 3, the model predicts erosion within Reach 3 because despite the additional sediment being supplied from Reach 2B, there was historically a net deficit of sediment supplied to this reach.

The river bed elevation within the Bypass is expected to erode back to the original design elevations by year 15. By year 25, the Bypass is expected to return to approximately design conditions, with slight deposition downstream of the Bypass Control structure. The deposition is considered a net positive because the grade control structures will essentially be buried and the stream grade will be uniform.

Approximately 740,000 tons of sediment is expected to erode from Reach 2B over the 25 year period. Similar to the pilot channel scenario, the majority of the sediment is passed into Reach 3 and either deposits in the first 2 miles or is transported through Reach 3.

Discussion

There is some channel adjustment expected in Reach 2B, Bypass, and Reach 3 when flows are introduced to the Bypass channel. While some channel adjustment is expected and even beneficial, some additional modification to the size of the pilot channel and the location where the pilot material is placed could limit the adjustment and some of its negative consequences.

With the current pilot channel, the excessive deposition in the Bypass channel is eliminated and the expected final channel equilibrium is relatively close to the design. However, the downstream portion of the Bypass channel may erode 2 feet and create incision that destabilizes the bank. Without the pilot channel, there is about 3 feet of deposition expected in the upper portion of the Bypass.

To limit the deposition in the upstream portion of the channel and still prevent temporary erosion in the downstream portion of the channel, it is suggested that the size of the pilot channel be reduced and the material be placed in the downstream portion of the Bypass and/or in Reach 3. Additional sensitivity studies on the size of the pilot channel and where the material is placed will be conducted to refine the design in the next phase.

The two grade control structures (described in Section 5.2.2) are considered necessary because of the uncertainty in the future bed elevations and the need to protect the siphon and Bypass control structure.

Table 5-1.—Assumed stable channel elevations for various reaches as estimated by long term (25-yr) sediment transport simulations. Elevations are given to nearest foot.

	Upstream Elevation (ft)	**Downstream Elevation (ft)**	**Reach Design Slope (-)**
Reach 2A	186	161	0.00035
Reach 2B	161	141	0.00036
Bypass Reach	141	139	0.00050
Reach 3	139	116	0.00023

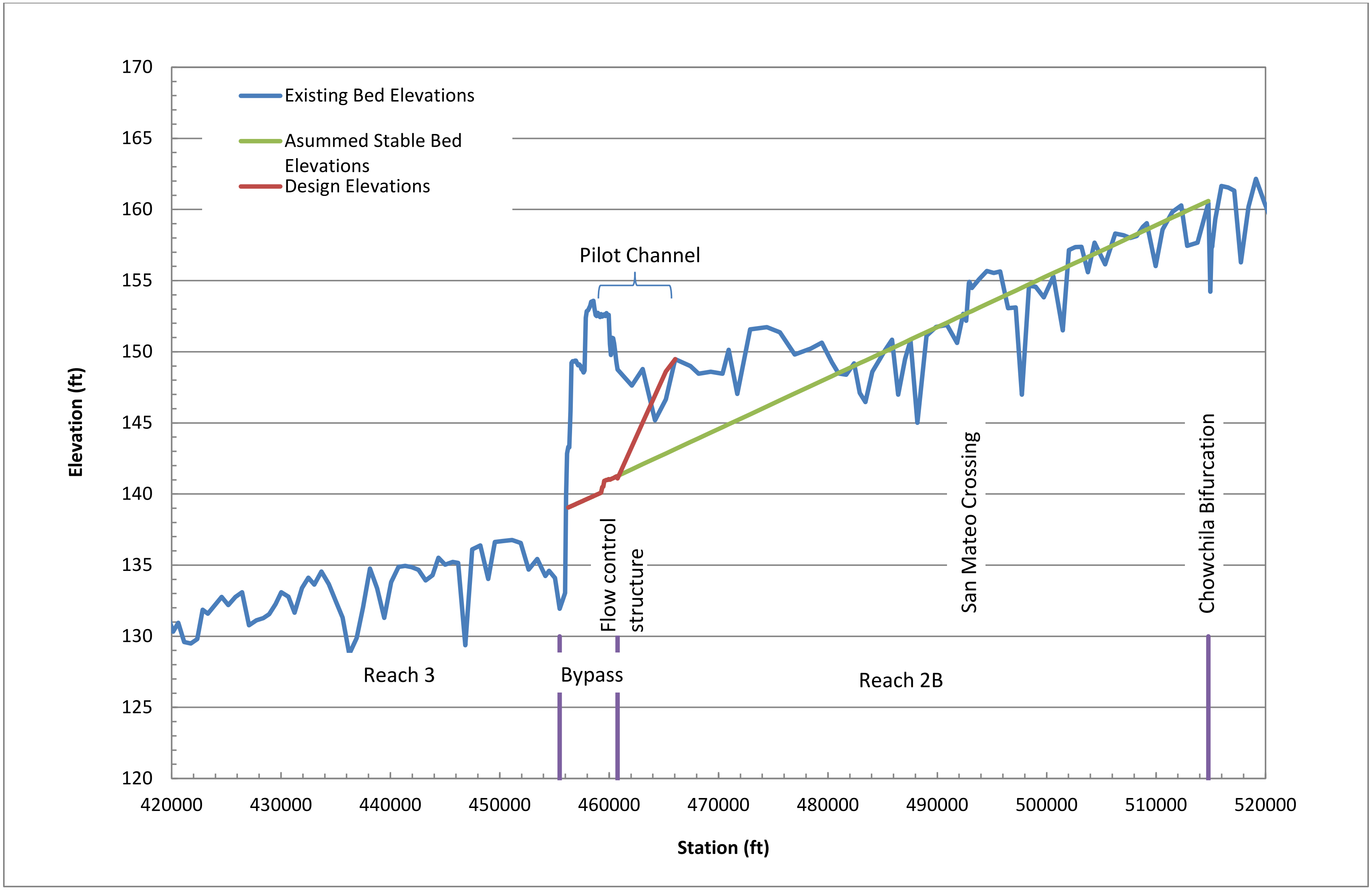


Figure 5-1.—Existing and Design Profiles in Reach 2B through Compact Bypass.

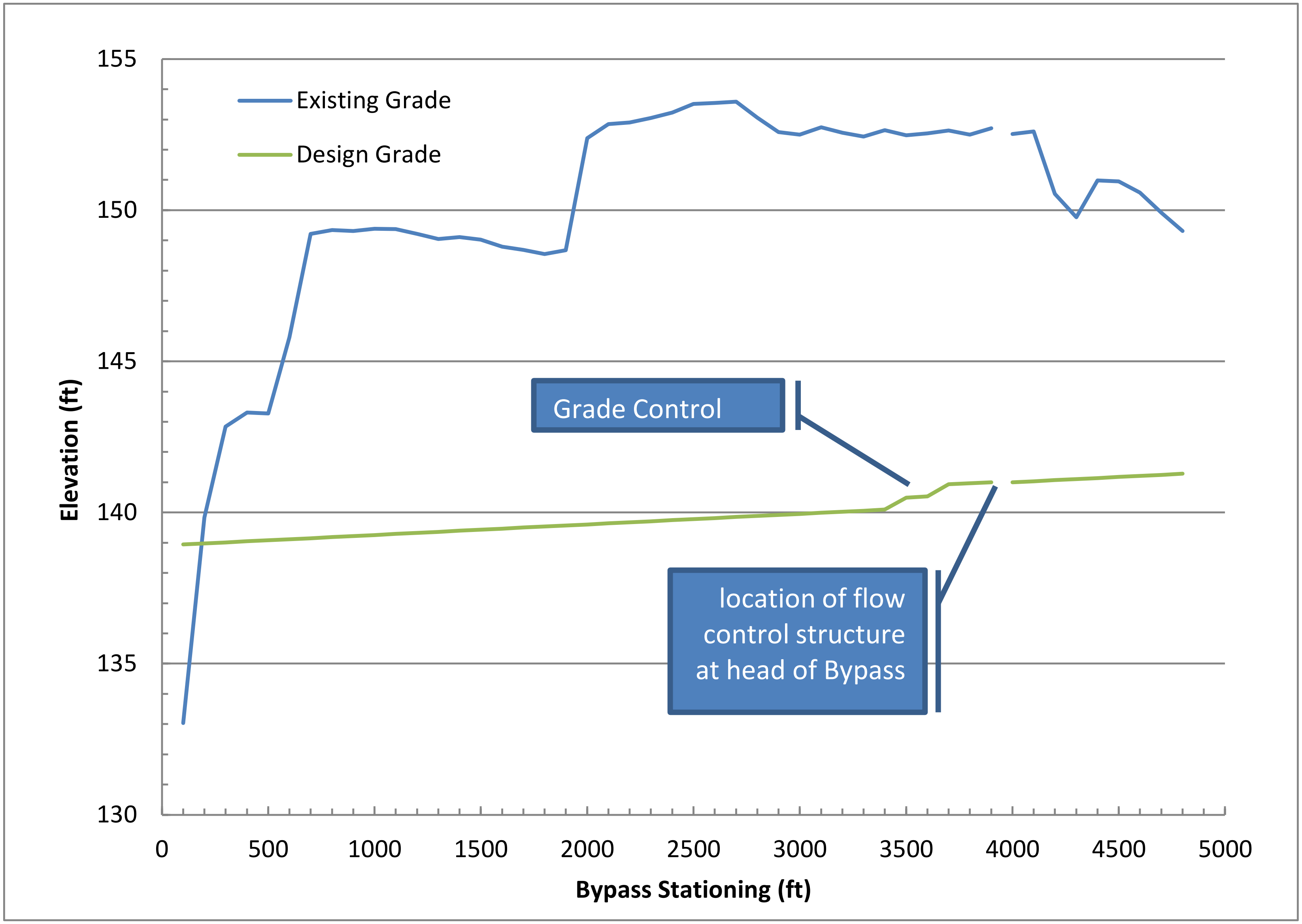


Figure 5-2.—Existing and Design Profiles in Compact Bypass.

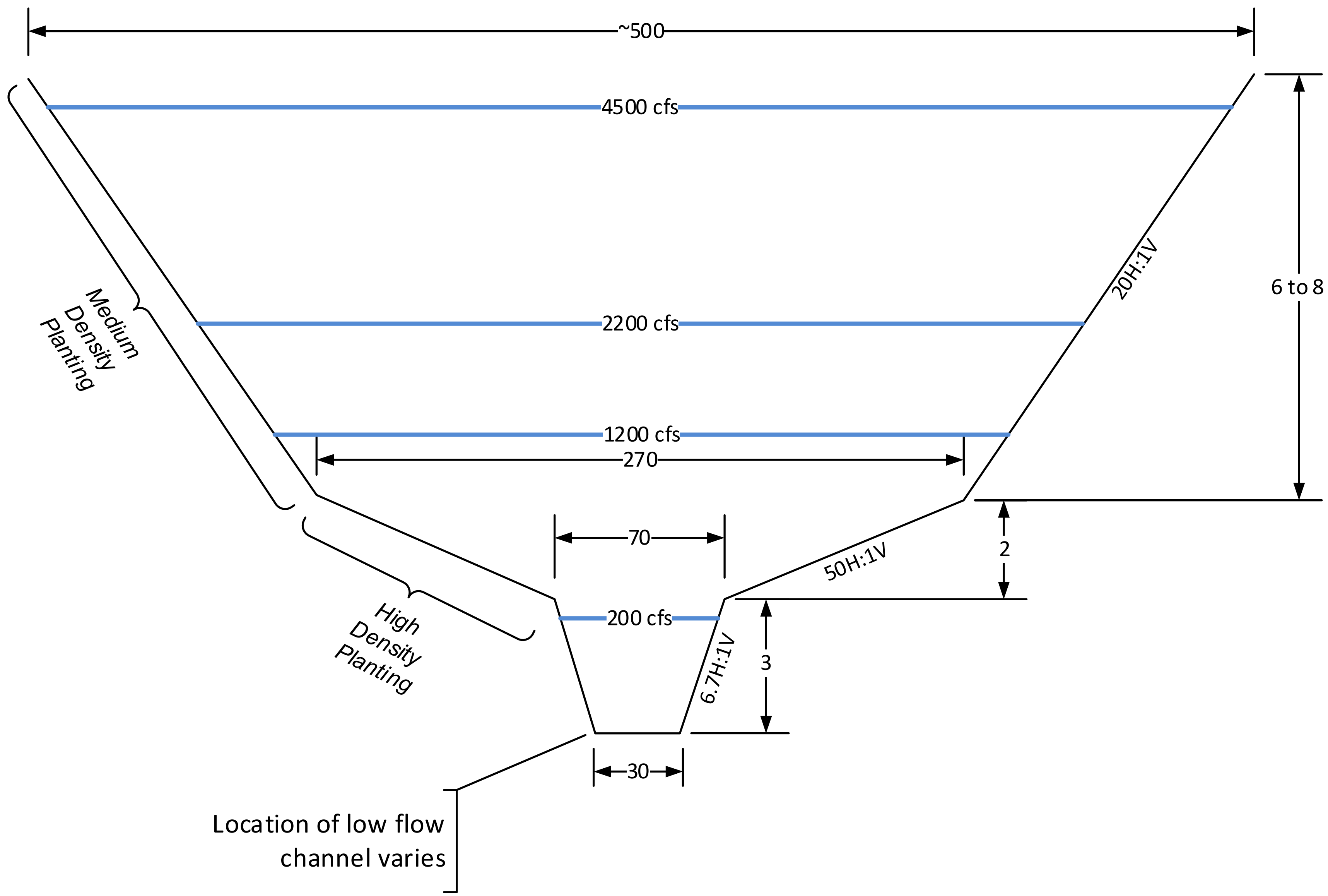


Figure 5-3.—Typical cross section in Compact Bypass. Distances are in feet.

Figure 5-4.—Planview Layout of Bypass including approximate flow control and grade control location.

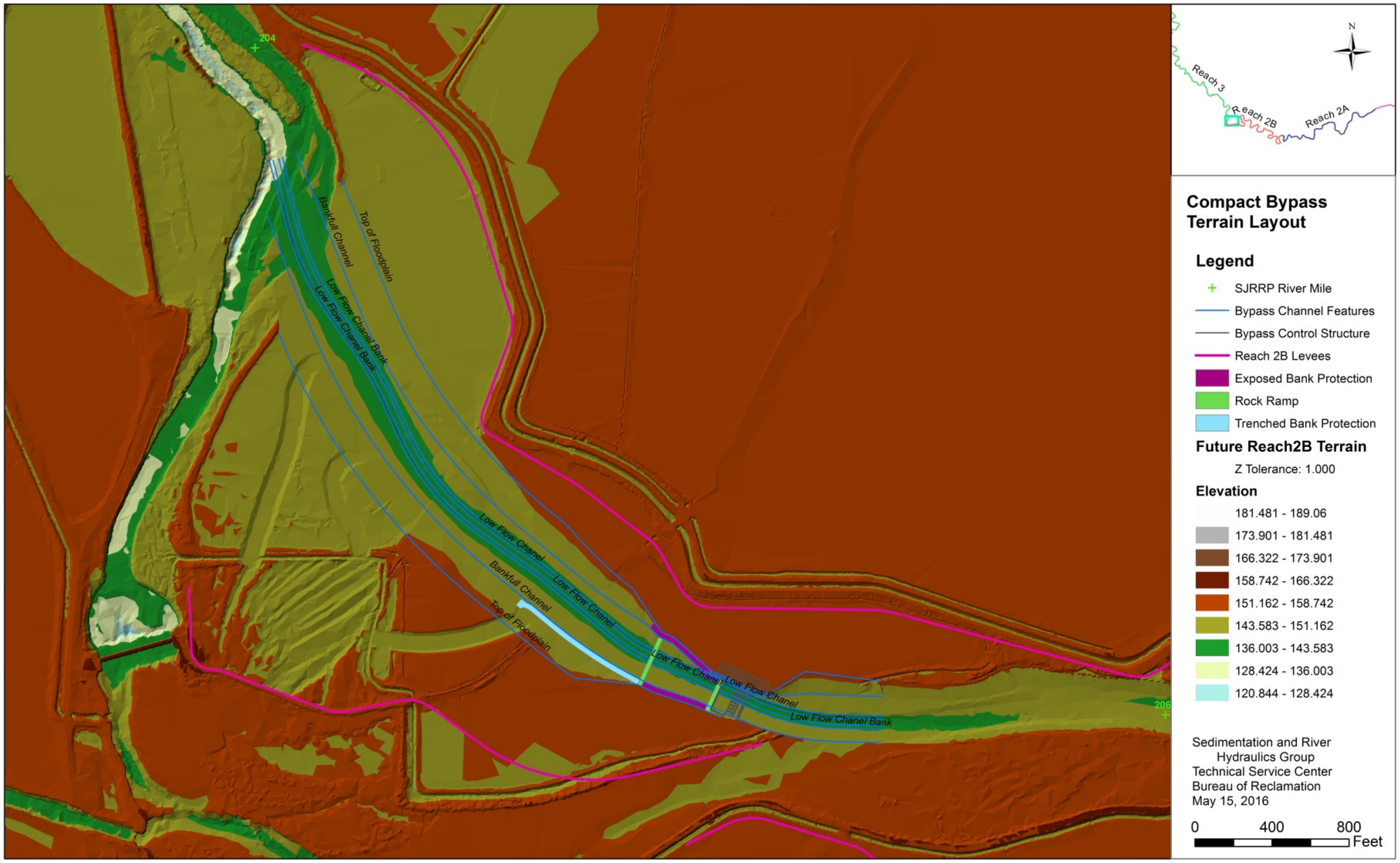


Figure 5-5.—Planview of Bypass showing modified terrain.

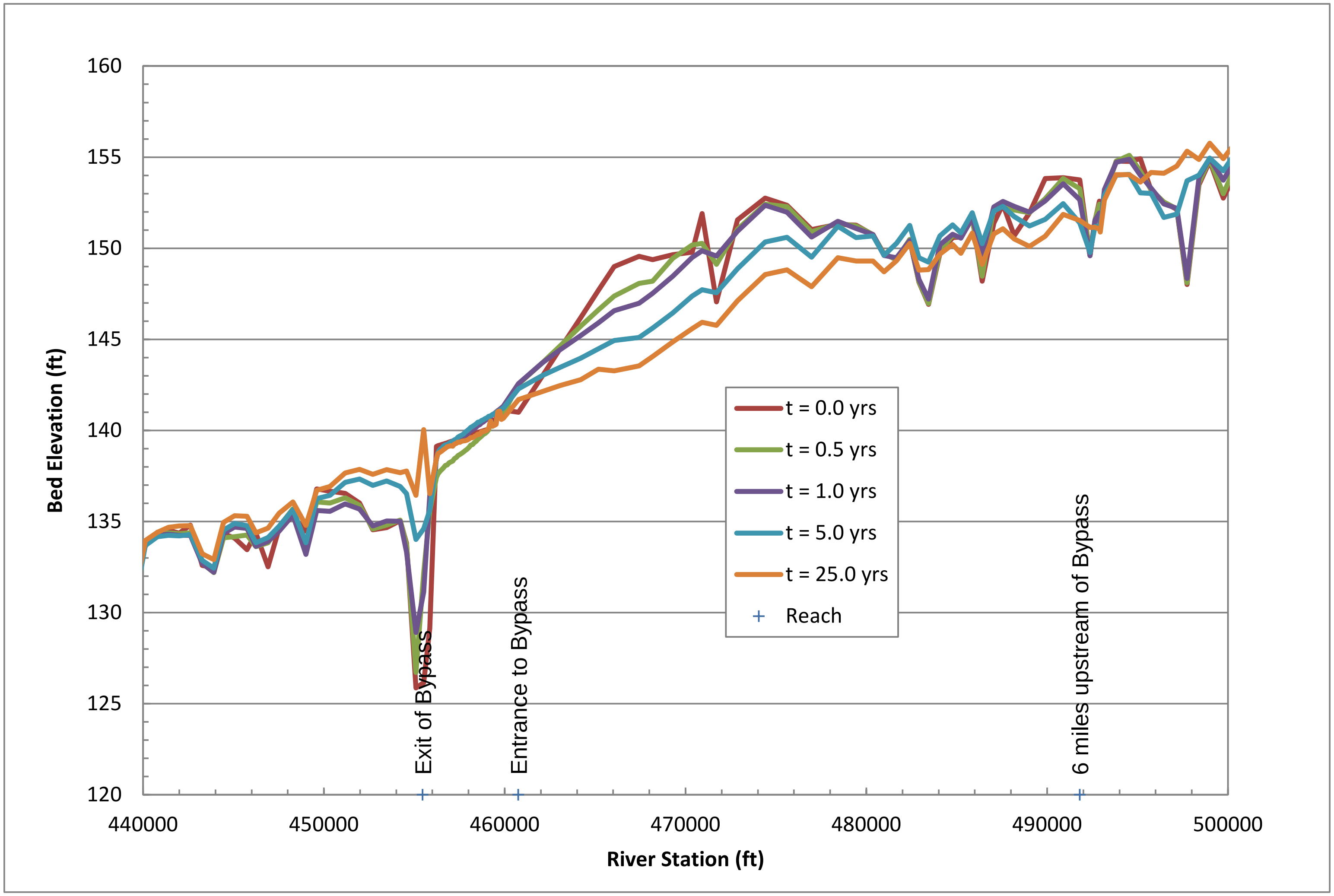


Figure 5-6.—Evolution of Reach 2B and 3 bed profile with pilot channel.

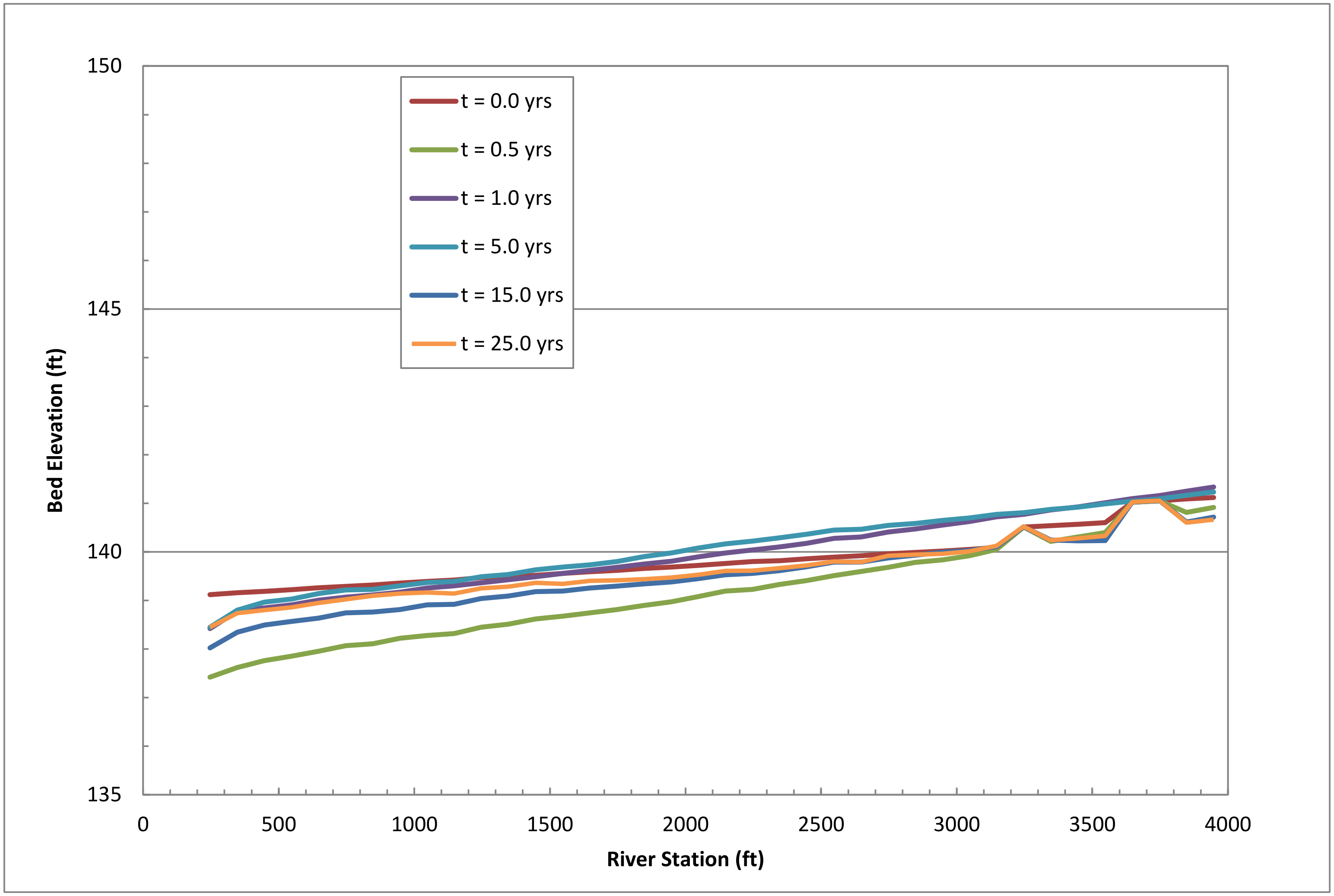


Figure 5-7.—Evolution of Compact Bypass bed profile with pilot channel. River station is relative to downstream end of Compact Bypass Channel.

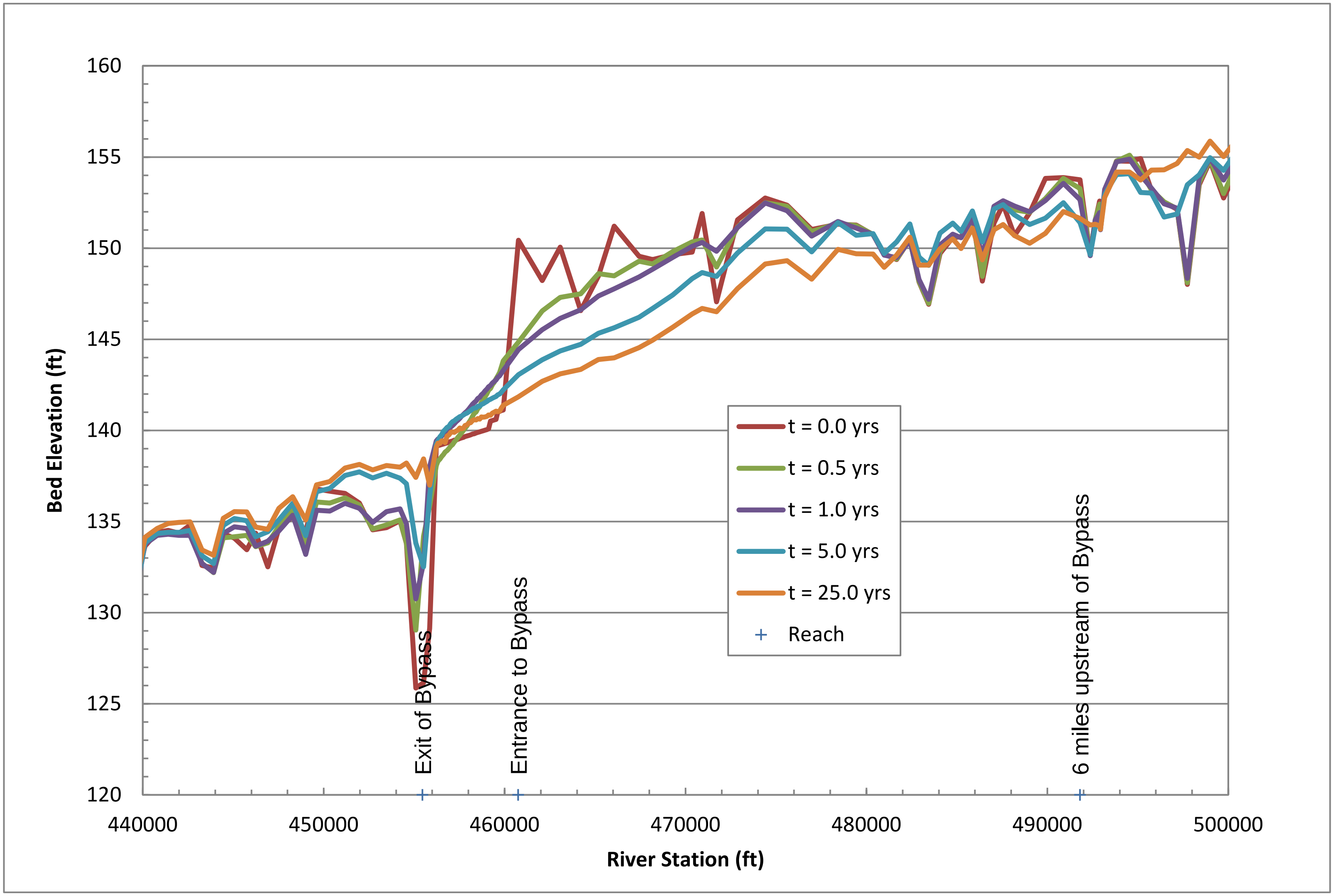


Figure 5-8.—Evolution of Reach 2B and 3 bed profile without pilot channel.

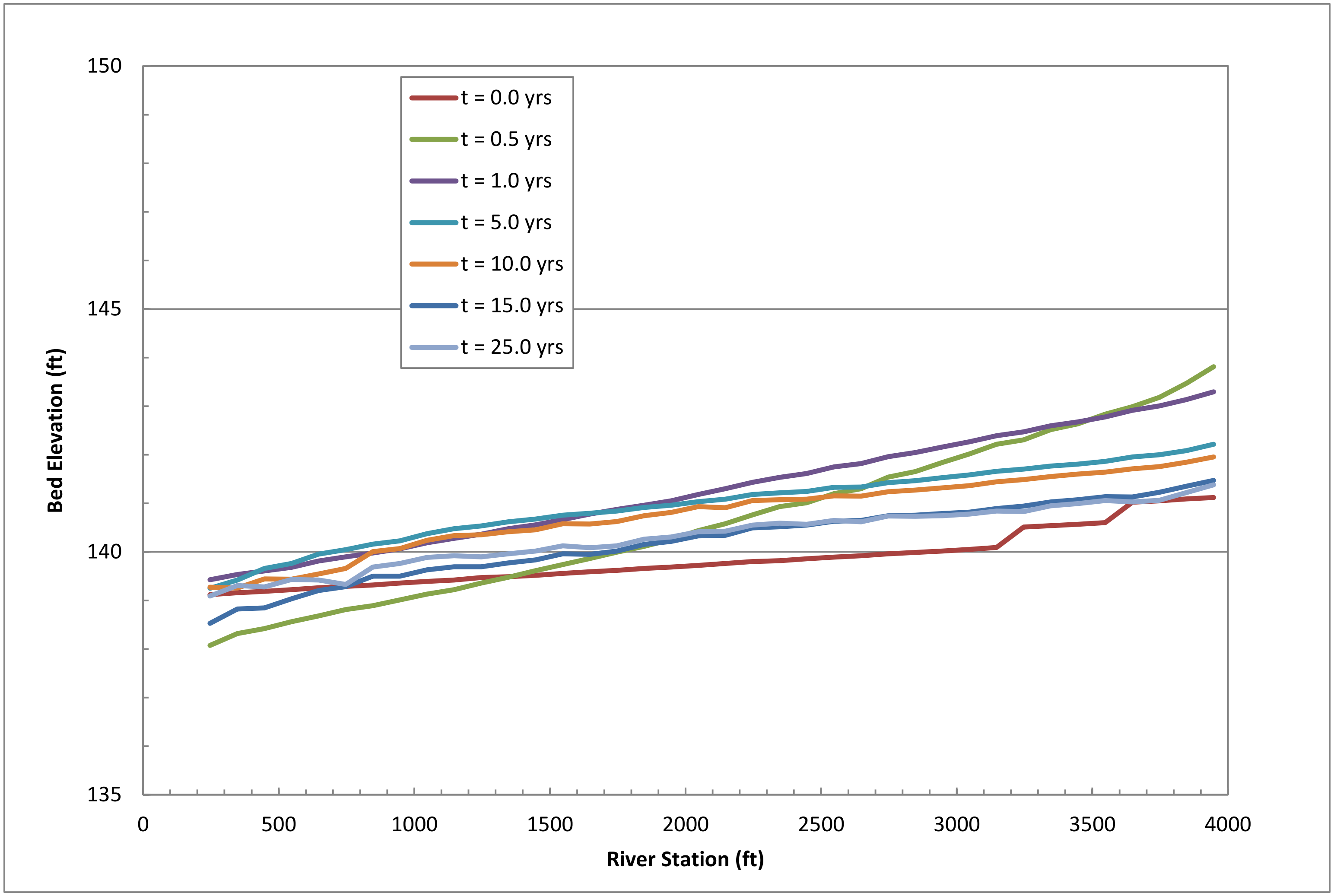


Figure 5-9.—Evolution of Compact Bypass bed profile without pilot channel. River station is relative to downstream end of Compact Bypass Channel.

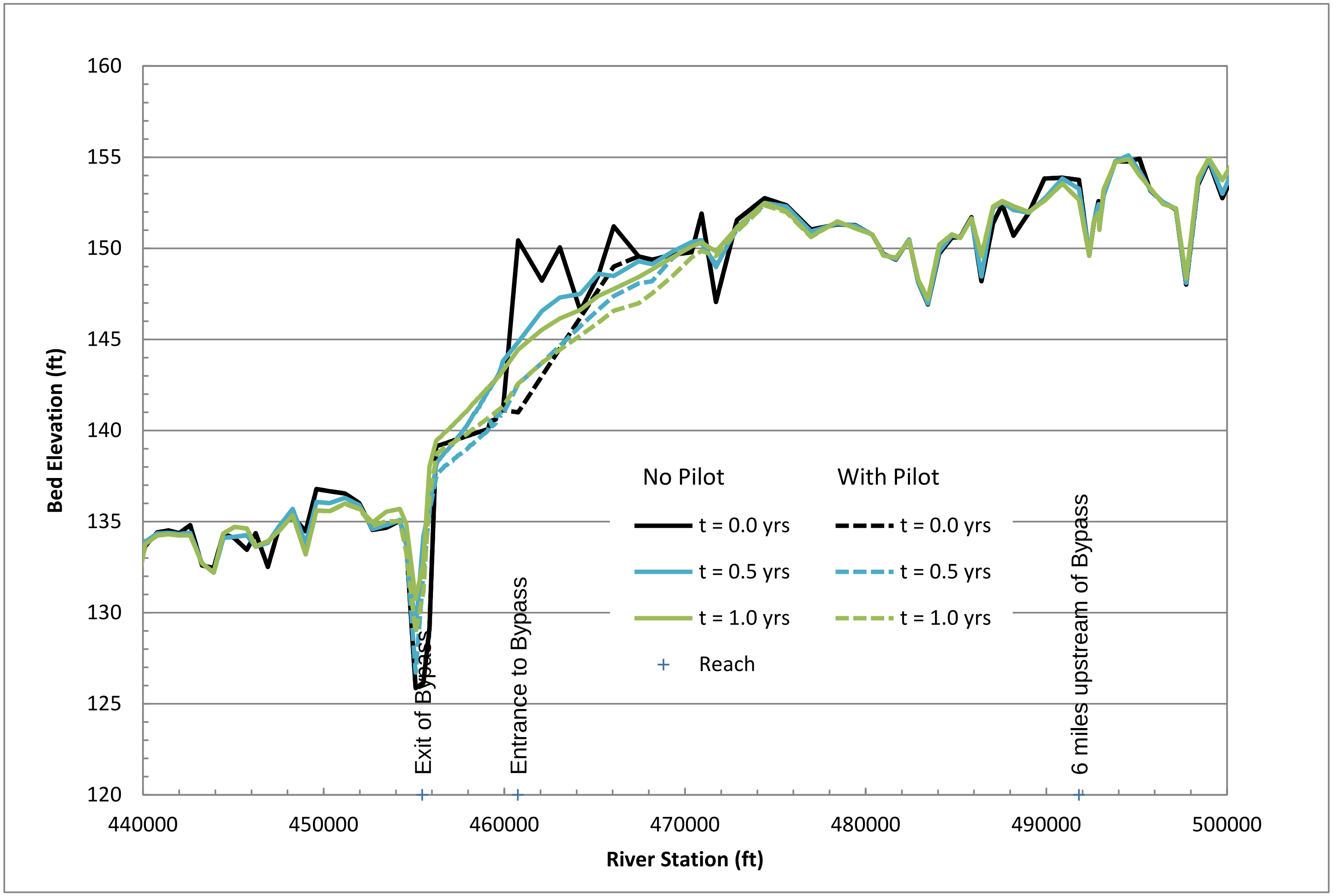


Figure 5-10.—Comparison of bed elevation with and without pilot channel for initial conditions, 0.5 years, and 1.0 years after beginning simulation.

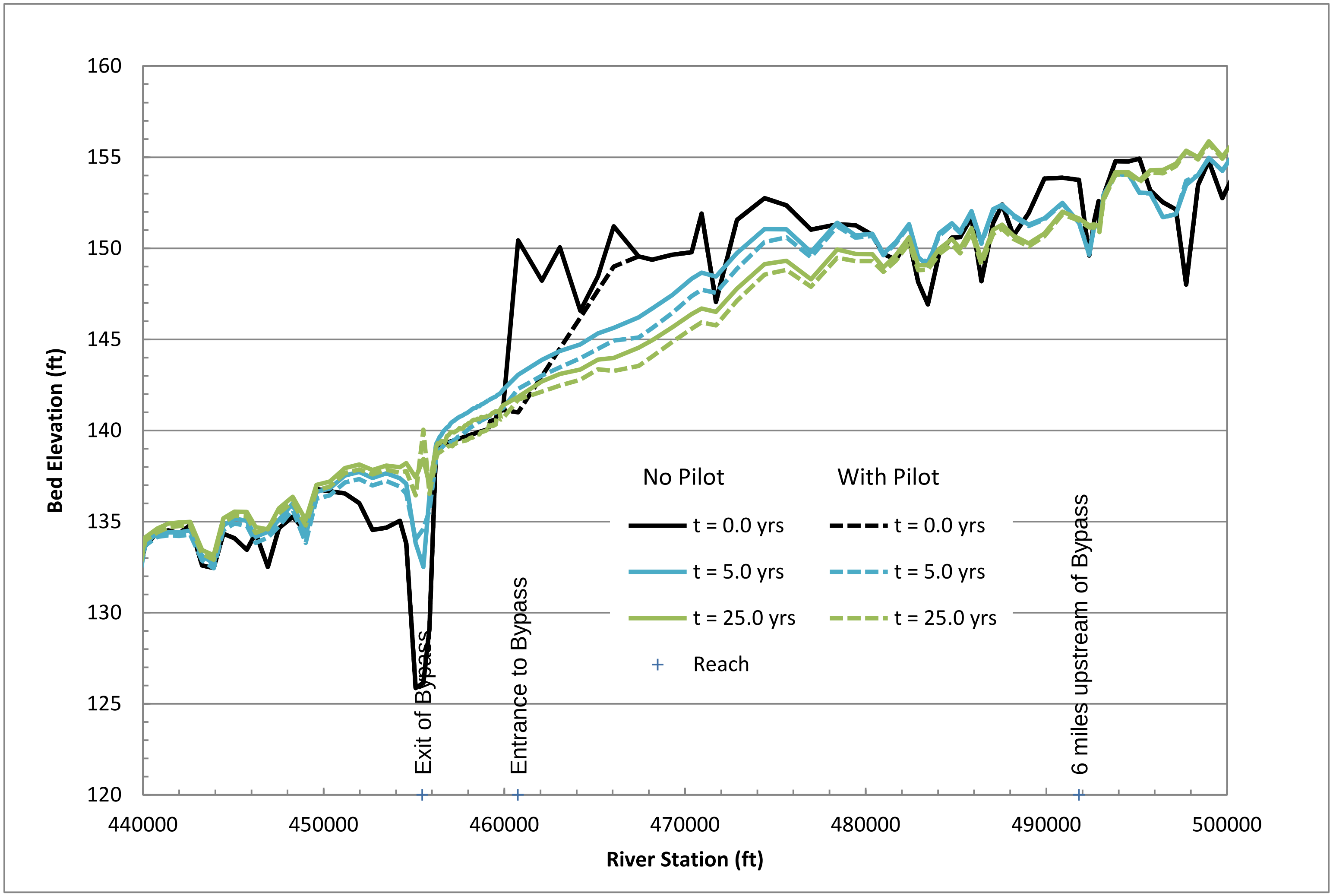


Figure 5-11.— Comparison of bed elevation with and without pilot channel for initial conditions, 5 years, and 25 years after beginning simulation.

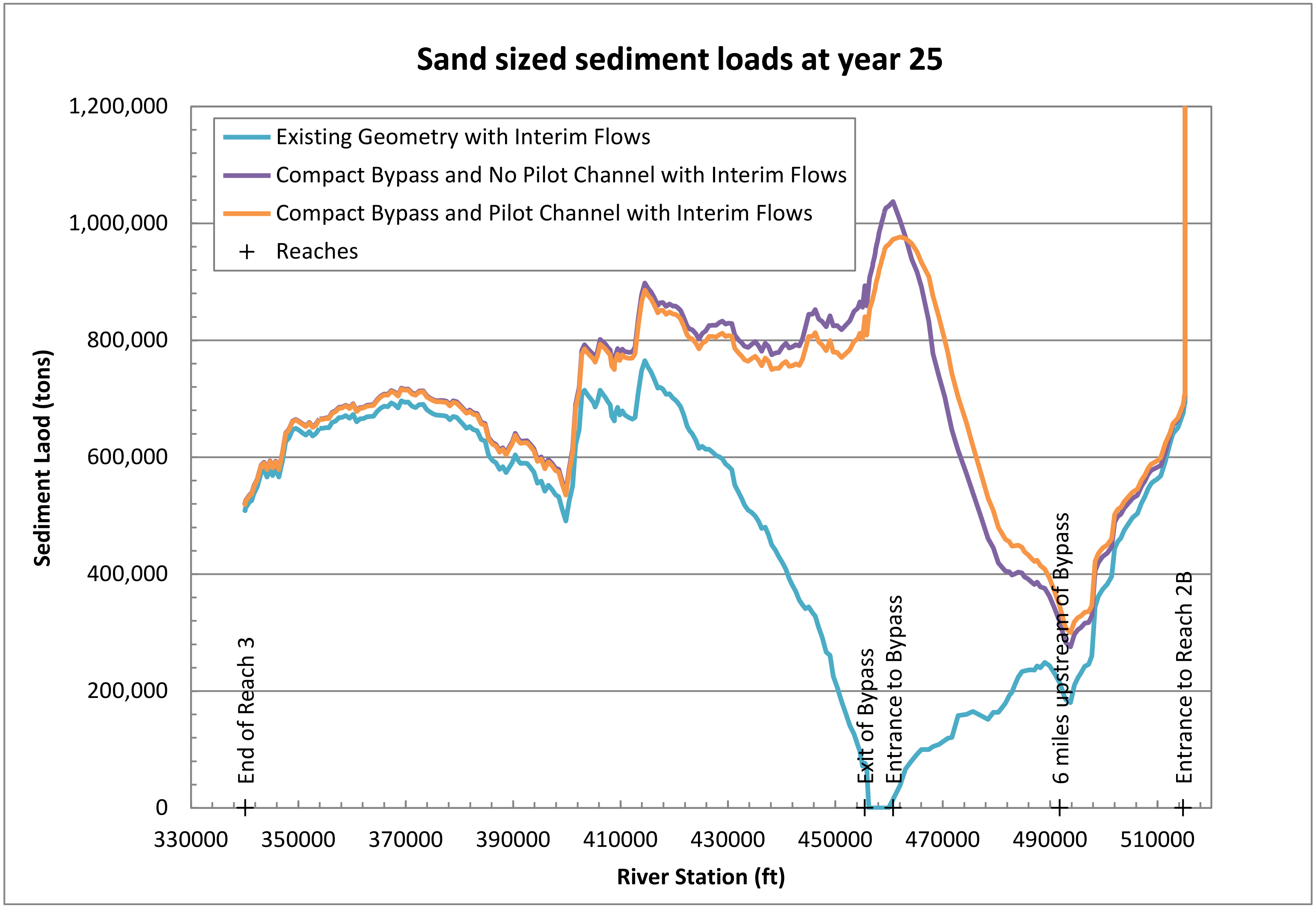


Figure 5-12.— Comparison of sand sized cumulative sediment load in simulated reach at year 25 for Existing Conditions and for Project conditions (Compact Bypass) with and without pilot channel.

5.2 **Bed and Bank Erosion Protection**

There are four features necessary to control bed and bank erosion immediately downstream of the flow control structure:

1. Energy dissipation
2. Grade control
3. Permanent bank protection
4. Temporary stabilization of low flow channel

It should be emphasized that the bed and bank erosion protection measures will only permanently stabilize the river in the vicinity of the flow control structure and siphon crossing. The vast majority of the Bypass will not be stabilized with permanent material such as rock and concrete. Instead, the revegetation and flow reintroduction plan will create a corridor that will function similar to other non-stabilized reaches of the San Joaquin River. The revegetation plan is described in Section 5.3. The justification for not stabilizing the majority of the channel is that the channel velocities are typical of the other portions of the San Joaquin. The cross sectional averaged velocities in the majority of the Bypass are less than 2.5 ft/s and natural vegetation will be sufficient to stabilize the banks on a long term basis (Gray and Sotir, 1996; Reclamation, 2015). In addition, an objective of the bypass is to provide habitat for juvenile salmon and permanent stabilization features are unlikely to provide sustainable quality habitat.

5.2.1 Energy Dissipation

Immediately downstream of the control structure, an energy dissipation structure will be necessary to prevent scour when the gates are partially closed. *Reclamation Engineering Monograph No. 25* (EM No. 25, Reclamation, 1984) is used to design the stilling basin size. A stilling basin USBR Type I is recommended so that no baffle blocks are required. Figure 6 and 7 within the Monograph can be used to estimate the length of stilling basin required to dissipate the hydraulic jump. The assumed quantities are given in Table 5-2, which is for the case when there are deliveries to Mendota Pool under subsided conditions and there is 4500 cfs being passed down the Bypass. It is assumed that only the 4 gates with the lower sill elevation are being operated. Therefore, the width of gate opening is only 56 ft.

The basin length using Figure 6 of the monograph gives 57 ft while that using Figure 7 gives 65 ft. A basin length of 75 ft is recommended to account for uncertainty in the computation and so that uniform flow conditions will exist downstream of the stilling basin. The basin length may also need to be adjusted based upon the location of the fish ladder that will be adjacent to the stilling basin.

The basin will be recessed approximately 2.5 ft below the sill elevation of the upstream gates according to the criteria in Reclamation [1984] which requires the downstream lip to be equal to 0.2* D_w, where D_w is the tailwater depth. There are two sets of gates, one at an elevation of 141 ft and another set at 145 ft. The basin will also have a transverse slope to the basin so that deepest part of the basin is on the right side of the channel, similar to the gates. The lip at the downstream end will have a 4H:1V slope to bring the downstream basin elevation up to the channel elevation.

Table 5-2. Stilling Basin Design Input Variables and Results.

Input Quantities	**Variable**	**Value**	**Units**
Flow	Q	4500	cfs
WSE upstream	Z1	161	ft
Width	W	56	ft
Discharge Coefficient	Cd	0.8	
Sill Elevation	Zsill	141.0	ft
Tailwater computed from HEC-RAS model			
Tailwater Elevation	Z2	152.4	ft
Conjugate Depth			
Velocity	V	28.7	ft /s
Depth	D1	2.8	ft
Froude	Fr1	3.0	
Conjugate Depth	D2	10.7	ft
Basin Length from Figure 6 of EM No. 25			
Basin Length/D1	Lb/D1	20.24	
Basin Length	Lb	57	ft
Basin Length from Figure 7 of EM No. 25			
Tailwater depth	D_w	11.4	ft
Basin Length/D2	Lb/D2	6.1	
Basin Length	Lb	65	ft
Final Recommended Basin Length	**Lb**	**75**	**ft**

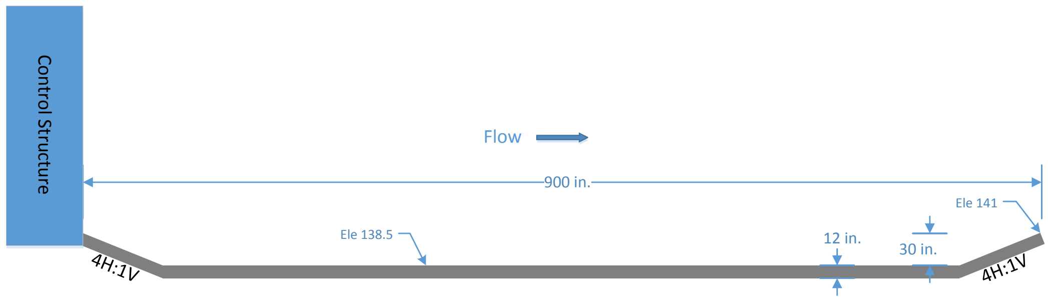


Figure 5-13.—Conceptual drawing of stilling basin downstream of Compact Bypass Control Structure.

5.2.2 Grade Control

There are two grade control structures. The most upstream one will begin immediately downstream of the flow control structure. The siphon crossing is located upstream of the second grade control structure so that the grade control structure also serves to protect the siphon crossing. Each will have approximately 0.4 ft of bed elevation drop across it.

Each structure will have a maximum downstream slope of 0.04 and be a minimum of 25 ft in length in the streamwise direction.

The references used to design the grade control are: *Rock Ramp Design Guidelines* (Reclamation, 2007) and *EM1110-2-1601* (U.S. Army Corps of Engineers, 1994).

<u>Rock Size</u>

The size of the rock is determined by using the following equation from *EM1110-2-1601* (U.S. Army Corps of Engineers, 1994).

$$D_{30} = \frac{1.95S^{.555}q^{2/3}}{g^{1/3}} \qquad \text{Eq 1}$$

where,

S = bed slope
q = flow per unit width (cfs/ft)
g = acceleration of gravity (ft^2/s)

The input and results for this equation are given in Table 5-3. The unit discharge is computed assuming that the channel width is 270 ft, which is the width of the bankfull channel. The D50 is computed using recommendations from Lagasse (2006) that state D50 = 1.2*D30.

If rounded rock is used, the diameters need to be increased by 25 percent as recommended in *EM1110-2-1601*. The recommended gradations for the rock ramp are given in Table 5-4. Vandalism and/or theft of the stones could be a serious problem when the channel is dry for extended periods because large rock is relatively rare in this region. *EM1110-2-1601* recommends a minimum weight of the median size material of 80 lb to prevent theft and vandalism. Therefore the rock size should be of sufficient size to prevent vandalism, at least without the use of heavy equipment.

Table 5-3.—Data for sizing of material in rock ramps.

Variable	Value	Units
S	0.04	-
q	16.7	ft^2/s
g	32.2	ft/s^2
Flow Concentration Factor	1.25	-
D30 - angular	0.78	ft
D50 angular	0.98	ft

Table 5-4.—Recommended gradations for grade control, assuming angular rock and using riprap classes found in Lagasse et al. (2006). Assumed specific weight of 165 lb/ft^3.

Class III Riprap	***Percent Lighter by Weight***						
	15		***50***		***85***		***100***
	Min	***Max***	***Min***	***Max***	***Min***	***Max***	***Min***
Weight (lb)	32	93	120	210	310	510	1100
Equivalent Diameter (in)	7.3	10.5	11.5	14	15.5	18.5	24

Filter

No filter fabric will be used, but a granular filter should be included beneath the material in the rock ramp. The filter material is designed according to the *Rock Ramp Design Guidelines* (Reclamation, 2007). The filter recommendations in Reclamation (2007) are:

$$\frac{D_{50,Filter/Riprap}}{D_{50,Base}} < 40 \quad \text{Eq 2}$$

$$5 < \frac{D_{15,Filter/Riprap}}{D_{15,Base}} < 40 \quad \text{Eq 3}$$

$$\frac{D_{15,Filter/Riprap}}{D_{85,Base}} < 5 \quad \text{Eq 4}$$

Because the ramp will be excavated into a silty/sandy material, two filter layers are necessary. The upper filter (Layer 2) will be mostly gravel material and the lower filter (Layer 1) will be mostly sand size. The recommended gradations using the above criteria are in Table 5-5.

Table 5-5.—Filter gradations for grade control structures.

	Percent Finer by Weight						
	15		***50***		***85***		***100***
	Min	***Max***	***Min***	***Max***	***Min***	***Max***	***Max***
Filter Layer 2 Diameter (mm)	7	9	10	14	59	82	100
Filter Layer 1 Diameter (mm)	0.2	0.3	0.3	0.4	1.6	2.3	4

<u>Bed Scour</u>

There will be some scour downstream of each structure and the methodology of Bormann and Julien (1991) was used to compute the expected scour downstream of the grade control structures. The scour depth, y_s, is computed as:

$$y_S + d_p = \frac{0.611}{[g \sin(\phi+\beta')]^{0.8}} \frac{q^{0.6} U_0}{{d_{90}}^{0.4}} sin(\beta') \quad \text{Eq 5}$$

The parameter β' is the maximum side angle of scour hole and is computed as:

$$\beta' = 0.316 \sin\lambda + 0.15 \ln\left(\frac{d_p+Y_0}{Y_0}\right) + 0.13 \ln\left(\frac{Y_t}{Y_0}\right) - 0.05 \ln\left(\frac{U_0}{\sqrt{gY_0}}\right) \quad \text{Eq 6}$$

The diffused distance to the maximum scour depth, L_s, is computed as:

$$L_S = 1.861 \left[\frac{\sin\phi}{g(s-1)\sin(\phi+\beta')}\right]^{0.8} \frac{{Y_0}^{0.6} {U_0}^{1.6}}{{d_s}^{0.4}} \quad \text{Eq 7}$$

where:

d_p = height of grade control structure (m)
ϕ = submerged angle of repose of bed sediment = 25 degrees = 0.436 radians
d_s = sediment size (m)
U_0 = jet velocity of water entering tail water (m/s)
Y_0 = thickness of jet entering tailwater (m)
Y_t = tailwater depth (m)

β' = maximum side angle of scour hole
γ, γ_s = specific weight of water
ρ, ρ_s = mass density of water
s = specific gravity of sediment = 2.65
g = acceleration of gravity = 9.8 m^2/s

The variables are also defined in Figure 5-14. The input variables and resultant scour downstream of the grade control structures are given in Table 5-6. The computed scour depth is 4.8 ft. The recommended scour depth at this stage is modified based upon the results from the bank protection scour to be more conservative.

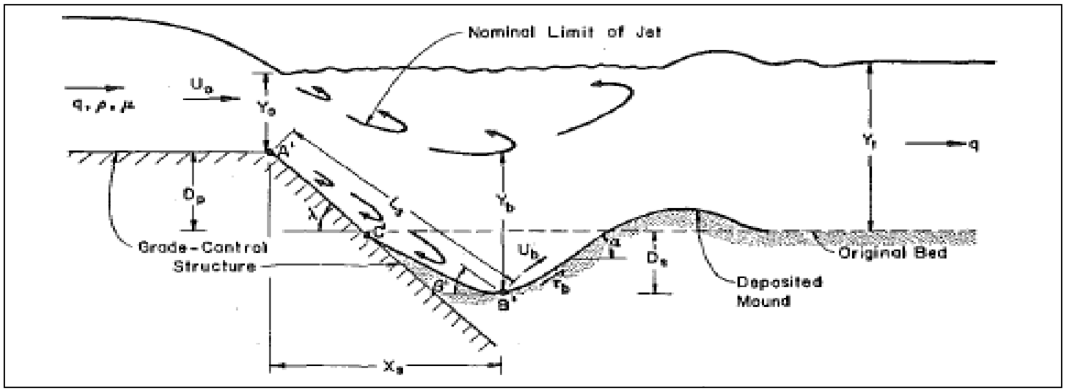


Figure 5-14.—Scour downstream of grade control figure from Borman and Julien (1991).

Table 5-6.—Input and output variables for scour computation downstream of the grade control structures.

Variable	Value	Units
U_0	15.5	ft^2/s
Y_0	11.4	ft
Y_t	11.4	ft
U_0	4	ft/s
d_{90}	0.0033	ft
d_p	0.4	ft
y_S	4.8	ft
L_S	29	ft

The predicted scour from the grade control is less than the scour predicted along the bank protection structure. It is recommended that the scour depth from the bank protection (7.5 ft) be used for design purposes until further verification that the scour will be significantly less.

<u>Layer Thickness and Transverse Width</u>

The layer thickness of the rock ramp is set at 3 ft or 1.5 * D100, slightly greater than recommended in Reclamation (2007), which recommends the thickness to be equal to the D100. The layer thickness is increased because it is expected that the structure will initially be buried by sand and that there will be significant loss of material following the introduction of flows to the Bypass. There will be an additional 7.5 ft of scour protection on the downstream toe to account for the scour on the downstream side. The thickness of each filter layer should be 0.75 ft as recommended in HEC11 (Federal Highways Administration, 1989). The section view of a typical grade control structure profile is given in Figure 5-15.

The rock ramp will span the width of the bankfull channel, which is 270 ft wide, and transition into the bank protection that is placed from the flow control structure to the rock ramp. The total volume of riprap is expected to be approximately 1,750 yd^3 at each structure.

The rock ramp will have an inset low flow channel to ensure that minimum depth criteria are met, which will be 1.2 ft of depth at a flow of 50 cfs.

<u>Maintenance</u>

There is expected to be some loss of rock material after each high flow, and additional rock material may need to be placed after high flow events. It is estimated that 20% of the rock (approximately 350 yd^3 at each structure) may need to be replaced every 3 to 5 years.

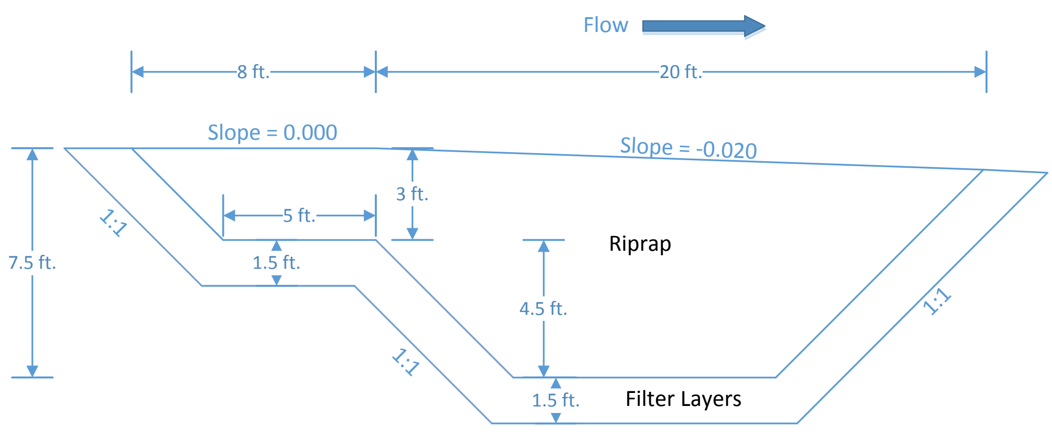


Figure 5-15.— Conceptual profile section of grade control structure.

5.2.3 Permanent Bank Protection

There will be 3 types of bank protection designed into the system: (1) Exposed Bank Protection that will be located between the control structure and the downstream most rock ramp. The purpose is to permanently stabilize the bankfull channel and prevent flanking of the rock ramps. (2) Trenched bank protection that will become exposed only if the low flow channel migrates toward the bank. The purpose of the trenched bank protection is to provide backup to the natural vegetated bankline. (3) Temporary stabilization of the low flow channel with biodegradable material. This section details the permanent bank protection, items (1) and (2). The next section will detail the temporary stabilization of the low flow channel.

<u>Rock size</u>

The bank protection will consistent of approximately the same size of rock material as the grade control. The riprap size was also checked against the methods recommended in EM-1110-2-1601 “Hydraulic Design of Flood Control Channels” (USCOE, 1994) for bank protection and it was found to be smaller than the material specified for the rock ramps. At this stage of design it is recommended to use the same material for the bank and rock ramp.

Scour

Several methods for computing the scour at the base of the bank protection are described below.

Neill

The depth of scour below thalweg elevation, d_s, is predicted by Neill (1973) as reported in Reclamation (1984):

$$d_s = Zd_i\left(\frac{q_f}{q_i}\right)^m \qquad \text{Eq 8}$$

where:

m = exponent varying from 0.67 for sand to 0.85 coarse gravel
d_i = bank full depth
q_i = bank full discharge
q_f = design discharge per unit width
Z = 0.5 for straight reach, 0.6 for moderate bend, 0.7 severe bend

Z = 0.6 was selected for a moderate bend.

Lacey

The scour equation of Lacey (1930) as reported in Reclamation (1984) is:

$$d_s = Z0.47\left(\frac{Q}{f}\right)^{1/3} \qquad \text{Eq 9}$$

where:

Q = Flow rate in channel at design discharge (ft^3/s or m^3/s)
f = $1.76\sqrt{d_{50}}$
Z = 0.25 for straight reach, 0.5 for moderate bend, 1.25 for vertical rock bank
d_{50} = mean grain size in mm

Z= 0.5 was selected for a moderate bend.

Blench

The scour equation of Blench (1969) as reported in Reclamation (1984) is:

$$d_s = Z \frac{q_f^{2/3}}{F_{bo}^{1/3}} \qquad \text{Eq 10}$$

where:

q_f = design discharge per unit width
F_{bo} = $1.75 d_{50}^{\;0.25}$
d_{50} = mean grain size in mm
Z = 0.6 for straight, 1.0 for moderate bend, 1.25 for vertical rock bank or wall.

Z = 1 for was selected for a moderate bend as recommended in Reclamation (1984).

EM1601

The COE manual EM1601 (COE, 1994) recommends using the following equation:

$$d_s = S_f Z d_m - d_f \qquad \text{Eq 11}$$

where:

d_m = average depth in the crossing upstream of the bend.
d_f = depth of thalweg at bend
S_f = Safety Factor = 1.14
Z = factor based upon radius of curvature to width ratio
= $3.37 - 0.66\ln(R/W)$ for sand bed
= $3.37 - 0.7\ln(R/W)$ for gravel bed

The radius of curvature is approximately 3000 ft for the Bypass and the assumed top width is the bankfull top width of 270 ft.

Recommended Scour

The results of the scour computation are presented in Table 5-7. The recommended design scour is taken as the average scour estimated from the four methods and rounding to the nearest half foot.

Table 5-7.—Design scour estimates for high flow bank protection in Bypass.

Location	Design Scour Estimates (ft)				
	Neill (1973)	Lacey (1930)	Blench (1969)	EM1601	**Design Scour**
Bypass	6.6	3.6	11	8.7	7.5

Layout and Layer Thickness

The bank protection will be placed as a rock filled trench that extends from the stilling basin to the downstream most rock ramp along both sides of the channel. The rock filled trench will transition between the outside of the Bypass control structure to the bank full channel location as defined in Figure 5-4. The volume of the trench was estimated by assuming that the rock extends from the trench elevation to 7.5 ft below the Bypass thalweg which would equate to approximately 13.5 ft height. The layer thickness was assumed to be 2 ft or 1 * D100. An additional 50% is added to account for stone loss and irregular placement because the material will be launched during scour events. The total volume necessary is 73 ft^3/ft placed within the trench.

The trench in which the rock is placed will be 5 ft deep and have a bottom width of 14.5 ft with 1.5H:1V side slopes. The rock will be placed along the base and up one side of the slope. The trench will be backfilled with the excavated soil and the riprap can be covered with 1 foot of topsoil as shown in Figure 5-17.

There may also be a filter required to prevent loss of soil through the riprap. Two filter layers may be required as was the case with the rock ramps. The filter thickness for each layer is recommended to be 0.5 ft in this case.

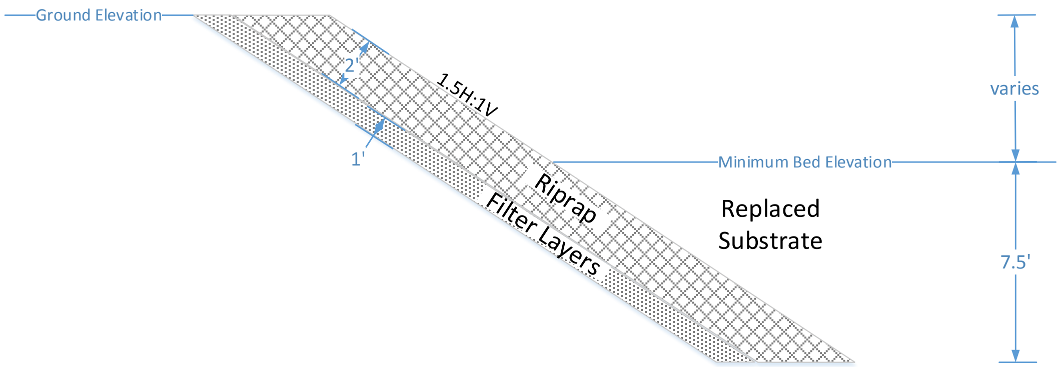


Figure 5-16.—Conceptual cross section of riprap lined bank.

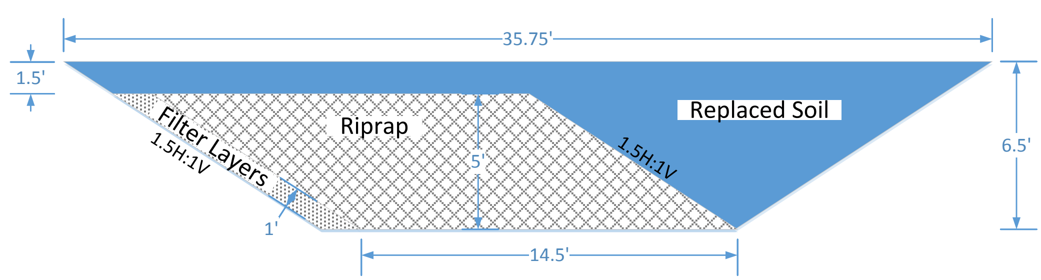


Figure 5-17.—Conceptual cross section of riprap filled trench.

Maintenance

There will be maintenance required after high flow events at exposed bank protection areas. The maintenance will occur at select locations due to local scour at the structure. It is expected that 5% of the total original volume will need to be added every 3 to 5 years.

5.2.4 Temporary stabilization of low flow channel

The current plan calls for low flows (less than 200 cfs) to be introduced into the Compact Bypass a year after the initial planting. Therefore, to stabilize the low flow channel we recommend biodegradable Fabric Encapsulated Soil (FES) lifts to be placed on the low flow channel banks. The FES lifts will be place above grade and the lowest lift will be place upon a bed of riprap for scour protection (Figure 5-19).

The FES technique consists of live cut branches (brush layers) interspersed between lifts of soil wrapped in natural fabric, e.g., coir, or synthetic geotextiles or geogrids. The live brush is placed in a criss-cross or overlapping pattern atop each wrapped soil lift. The fabric wrapping provides the primary reinforcement in a manner similar to that of conventional mechanically-stabilized earth. The live, cut branches eventually root and leaf out, providing vegetative cover and secondary reinforcement as well.

Coir fabric is recommended as the fabric for the Bypass. Coir is a natural fiber extracted from the husk of coconut. It comes in various grades that have different size openings and unit tensile resistances. It is recommended that two layers of fabric are used. An inner fabric is required to hold fine soil particles in place and strong, durable outer fabric to provide strength to the constructed soil lift.

The suggested outer fabric should be woven from machine-spun bristle coir twines. This semi-permanent 100% biodegradable, strong and durable bristle coir woven blankets provide higher resistance upon installation while supporting growth and development of vegetation. The field functional longevity should be 4-6 years. The open weave in the outer fabric allows reseeding before and after installation. The opening should be approximately 0.5 in x 0.5 in and allow planting plugs through the blanket without cutting the blanket.

The inner fabric consists of 70% wheat straw and 30% coconut fiber stitched between two natural jute/scrim leno woven nets. The components are sewn together with biodegradable cotton thread. It is designed for erosion protection and will last up to 18 - 24 months while providing support for vegetation establishment. An example of the two layer fabric is given at: http://www.nedia.com/Soil_wrap_fabric.html.

The installation procedure is as follows:

1. Excavate a trench to a competent horizon below the likely depth of scour. The rock will be placed into this trench as specified in Figure 5-19.
2. Place select fill material on the fabric and compact it in 3 in lifts to a nominal thickness ranging from 12 to 30 in. Thinner lifts are used at the base of the structure, where shear stresses are higher. Temporary batter boards may be required at the front face to confine the select fill during the installation process and to form an even face.
3. The fabric sheet should be allowed to drape down or protrude beyond the front edge of each underlying lift of earthen fill to create at least a 3 ft overlap when it is pulled up and over the next lift. The exposed sections of geogrid or fabric layers are pulled up and over the faces of the fill layers (refer to typical drawing) and staked in place. The geogrids should be pulled as uniformly as possible before staking to develop initial tension in the geogrid or fabric. A tractor or winch pulling on a long bar with hooks or nails along its length works well for this purpose. The tensioned geogrid overlap sections should be secured in place using wood construction stakes spaced every 3 ft.
4. Layers of live cut branches are then placed criss-crossed atop the underlying wrapped soil lift. 2 to 3 in of topsoil should be mixed in with the cut branches. The top soil can be placed beforehand or spread over the top of a brush layer. Up to three (3) layers of live, cut branches interspersed with 1-2 in of topsoil can be placed in this manner. Select long branches of native tree species that are capable of vegetative propagation. An approximately equal mixture of Gooding's willow (*Salix gooddingii*), Sandbar willows (*Salix exigua*), and Freemont Cottonwood *(Populus fremontii*) is recommended as the plant material. The length of the branches will vary depending upon the desired depth of reinforcement, but they should be long enough to reach the back of an earthen buttress placed against a streambank while protruding slightly beyond the face. The diameter of the live cuttings will also vary depending on their length, but typically should range from ¾ to 2 in at their basal ends.
5. The process is repeated with succeeding layers of earth fill, live brush and geogrids (or fabric) until the specified height or elevation is reached. In this case, 5 layers of FES are recommended.

The flow used to size the scour and riprap is 475 cfs because even though only flow less than 200 cfs are scheduled to be released, it is possible that flow temporarily exceeds those amounts. The riprap size for scour protection of the low flow channel can be significant smaller than permanent bank protection for two reasons: 1. The low flow riprap will be placed below grade and therefore not subject to removal by vandals, 2. The design flow is substantially less.

The recommended riprap size is given in Table 5-4. The computed stable size was well below the Class I riprap, but Class 1 is likely the minimum commonly available. The computed depth of scour using the previously stated scour equations varied between 1 to 2 feet, but we recommend using 3 ft for the design scour to allow for additional bed variability. The same filter material can be used as stated in Table 5-5.

Table 5-8.—Recommended gradations for low flow scour protection control, assuming angular rock and using riprap classes found in Lagasse et al. (2006). Assumed specific weight of 165 lb/ft^3.

Class I Riprap	***Percent Lighter by Weight***						
	15		***50***		***85***		***100***
	Min	***Max***	***Min***	***Max***	***Min***	***Max***	***Min***
Weight (lb)	4	12	15	27	39	64	140
Equivalent Diameter (in)	3.7	5.2	5.7	6.9	7.8	9.2	12

Figure 5-18.—Example installation of FES showing layers of FES with willows planted between layers.

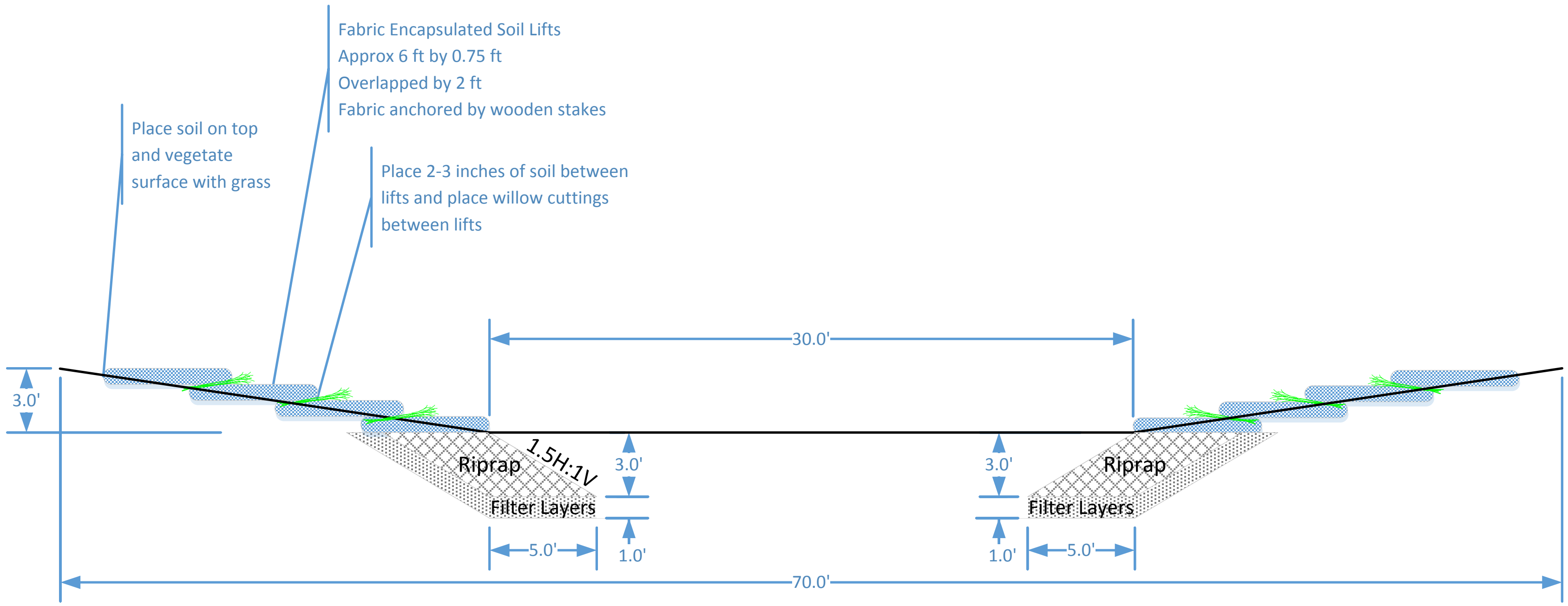


Figure 5-19.— Conceptual cross section showing placement of FES and low flow scour protection.

5.3 **Revegetation**

Revegetation within the Bypass will be intensive as there will be no existing plant communities within the excavated channel. Dense vegetation will need to be established before the channel is connected to river flows in order to stabilize soils and meet design specifications. Irrigation will be necessary to establish woody species, and the layout of irrigation lines will be the basis for planting locations.

5.3.1 Site Preparation

Because the primary riparian revegetation areas will be in the newly constructed Bypass, preparing the site for planting should not require major root-ripping or biomass removal, but will require specific preparation of the seedbed and furrows for cutting and containerized plantings. The top 12-18 inches of topsoil should be scraped and stockpiled, then replaced on the Bypass excavated surface (except for the low flow channel) at the completion of the construction phase. Disking, ring-rolling/cultipacking, and/or planning and creating berms will be required for final preparation of the seedbed. Other processes to facilitate installation of the irrigation system may be necessary, and may also potentially be incorporated into the construction efforts.

5.3.2 Planting Materials

At least two years lead-time is anticipated to obtain sufficient seed and planting stock for the revegetation of the Bypass. Local sources of plant material are preferred due to adaptations to site conditions, providing better potential for establishment success. However, sourcing plant materials from a variety of different parent populations helps to increase intraspecific genetic diversity, which is also an important component of long-term sustainability.

A local nursery will be required to propagate sufficient numbers of woody planting materials and potentially much of the required seed. Existing nurseries in the area may be able to provide at least some of the required quantities, but lead time and budget for setup and maintenance of a nursery specific to the project (and future SJRRP projects) may be necessary. Coordination with local landowners will be integral to this process.

Use of commercially available planting materials may also 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.

5.3.3 Species Selection

The suite of species selected for planting was based upon the relative inundation and erosion potential, and are delineated into several zones: 1) High Density

Riparian, 2) Mid Density Riparian, 3) Low Density Riparian, 4) Upland, and 5) Upland Woody. Each of these zones is described below and the specific species in each zone are given in Table 5-9 through Table 5-13.

Revegetation species zone descriptions:

1. High Density Riparian - Areas (11.2 acres) will likely support emergent wetlands and flood tolerant woody species. This zone is located primarily within the bankfull channel and may be inundated for extended periods during wet years or high summer flow events. This zone will be heavily planted with woody shrubs and trees (873 plants per acre) and seeded between irrigation rows with herbaceous species. The planting mix and spacing are designed to maximize shading and other fish habitat characteristics, provide competitive understory cover to enable a diverse influx of species as the vegetative community matures, and provide sediment stability in areas susceptible to scour.

2. Mid-Density Riparian - Floodplain areas higher in elevation than the high density plantings and with lower potential for erosion (11.5 acres). Woody species will be planted at 240 plants per acre with a seeded herbaceous understory. Planting design will incorporate patches of open herbaceous, cluster of shrubs, tree groves, and intermixed areas to provide multi-species habitat and promote system stability (pollination, trophic levels, etc.).

3. Low-Density Riparian – The remainder of the floodplain as well as some upland connective channels (13.8 acres) will be planted more sparsely (138 plants per acre) with woody riparian species and a herbaceous understory, to provide some habitat characteristics, allow fish passage, and add to the diversity of planting densities.

4. Upland - Areas perched above the floodplain (84.1 acres) are not likely to support riparian vegetation development and recruitment. These areas will be seeded with a diverse mix of grasses and forbs. The purpose of revegetating the upland areas is primarily to stabilize soils and prevent invasive species colonization, and may provide some habitat component.

5. Upland Woody – Subsections of the Upland zone (10.8 acres) were identified as historically occupied by woody vegetation, and designated for low-density woody plantings (138 plants per acre) under irrigation. These plantings will increase species diversity, promoting the establishment of upland oak galleries and mid-story shrubs for support of overall system diversity and vigor.

Species planting densities are averages over the entirety of the particular zone, and actual planting locations will not be even distributions of all species at the stated composition percentage (see Section 5.3.4).

All zones with the exception of zone 4 (Upland) will be planted with woody species in rows along irrigation lines. Between rows, herbaceous species will be seeded with alternating swaths of grasses and forbs to facilitate weed management with selective herbicides (Table 5-14). The Upland zone will be seeded only with no irrigation.

Table 5-9.—Irrigated revegetation species planting zones.

Zone	Acres	Width between rows (ft)	Spacing along rows (ft)	Plants per Acre	Total Plants
High Density Riparian	11.2	5	10	871	9,728
Mid Density Riparian	11.5	12	15	242	2,789
Low Density Riparian	14.4	16	20	136	1,963
Upland Irrigated	10.8	16	20	136	1,470
				TOTAL	15,950

Table 5-10.—Species for revegetation: Zone 1 High Density Riparian.

Common Name	Scientific Name	Veg Type	Comp. (%)	Total Plants	Planting Type
Gooding's willow	*Salix gooddingii*	Tree	25	2,423	Cutting
Fremont cottonwood	*Populus fremontii*	Tree	20	1,944	Cutting
mulefat	*Baccharis salicifolia*	Shrub	10	972	Cutting
common buttonbrush	*Cephalanthus occidentalis*	Shrub	10	972	Container
sandbar willow	*Salix exigua*	Shrub	10	972	Cutting
arroyo willow	*Salix lasiolepis*	Shrub	10	972	Cutting
baltic rush	*Juncus balticus*	Tule	5	491	Plugs
California blackberry	*Rubus ursinus*	Shrub	5	491	Container
red willow	*Salix laevigata*	Tree	5	491	Cutting

Table 5-11.—Species for revegetation: Zone 2 Mid-Density Riparian.

Common Name	Scientific Name	Veg Type	Comp. (%)	Total Plants	Planting Type
Gooding's willow	*Salix gooddingii*	Tree	15	418	Cutting
coyote brush	*Baccharis pilularis*	Shrub	10	279	Container
mulefat	*Baccharis salicifolia*	Shrub	10	279	Cutting
Fremont cottonwood	*Populus fremontii*	Tree	10	279	Cutting
valley oak	*Quercus lobata*	Tree	10	279	Container
Califoria wildrose	*Rosa californica*	Shrub	10	279	Container
red willow	*Salix laevigata*	Tree	10	279	Cutting
arroyo willow	*Salix lasiolepis*	Shrub	10	279	Cutting
common buttonbrush	*Cephalanthus occidentalis*	Shrub	5	139	Container
California blackberry	*Rubus ursinus*	Shrub	5	139	Container
blue elderberry	*Sambucus nigra ssp. caerulea*	Shrub	5	139	Container

Table 5-12.—Species for revegetation: Zone 3 Low-Density Riparian.

Common Name	Scientific Name	Veg Type	Comp. (%)	Total Plants	Planting Type
Gooding's willow	*Salix gooddingii*	Tree	15	294	Cutting
coyote brush	*Baccharis pilularis*	Shrub	10	196	Container
mulefat	*Baccharis salicifolia*	Shrub	10	196	Cutting
common buttonbrush	*Cephalanthus occidentalis*	Shrub	10	196	Container
Fremont cottonwood	*Populus fremontii*	Tree	10	196	Cutting
valley oak	*Quercus lobata*	Tree	10	196	Container
Califoria wildrose	*Rosa californica*	Shrub	10	196	Container
red willow	*Salix laevigata*	Tree	10	196	Cutting
California blackberry	*Rubus ursinus*	Shrub	5	99	Container
arroyo willow	*Salix lasiolepis*	Shrub	5	99	Cutting
blue elderberry	*Sambucus nigra ssp. caerulea*	Shrub	5	99	Container

Table 5-13.— Seeded species for revegetation: Zone 4 Upland

Common Name	Scientific Name	Veg Type	Comp. (%)	PLS per acre (lb.)	Total PLS (lb.)
blue wildrye	*Elymus glaucus*	Grass	17	3	252.4
dwarf barley	*Hordeum depressum*	Grass	14	5	420.6
purple needlegrass	*Stipa pulchra*	Grass	14	3	252.4
Douglas' sagewort	*artemisia douglasiana*	Forb	14	1	84.1
small fescue	*Vulpia microstachys*	Grass	12	1	84.1
Great Valley gumweed	*Grindelia camporum*	Forb	9	1	84.1
common tarweed	*Centromadia pungens*	Forb	8	0.25	21.0
alkali sacaton	Sporobolus airoides	Grass	7	0.1	8.4
alkali mallow	*Malvella leprosa*	Forb	3	10	841.3

*PLS = Pure Live Seed

Table 5-14.—Planted species for revegetation: Zone 5 Upland Woody

Common Name	Scientific Name	Veg Type	Comp. (%)	Total Plants	Planting Type
valley oak	*Quercus lobata*	Tree	35	518	Container
coyote brush	*Baccharis pilularis*	Shrub	15	216	Container
California wildrose	*Rosa californica*	shrub	15	216	Container
California blackberry	*Rubus ursinus*	Shrub	15	216	Container
quail bush	*Atriplex lentiformis*	Shrub	10	152	Container
silver lupine	*Lupinus albifrons*	shrub	10	152	Container

Table 5-15.—Herbaceous species for seeding between irrigation lines: Zones 1-3

SEEDED SPECIES: FORB MIX					
Common Name	**Scientific Name**	**Veg Type**	**Comp. (%)**	**PLS per acre (lb.)**	**Total PLS (lb.)**
western goldenrod	*Euthamia occidentalis*	Forb	19	2	48.2
Great Valley gumweed	*Grindelia camporum*	Forb	27	3	72.4
Douglas' sagewort	*artemisia douglasiana*	Forb	26	2	48.2
narrow-leafed milkweed	*Asclepias fascicularis*	Forb	20	8	193.0
common tarweed	*Centromadia pungens*	Forb	8	0.25	6.0
SEEDED SPECIES: GRASS MIX					
Common Name	**Scientific Name**	**Veg Type**	**Comp. (%)**	**PLS per acre (lb.)**	**Total PLS (lb.)**
dwarf barley	*Hordeum depressum*	Grass	21	8	193.0
saltgrass	*Distichlis spicata*	Grass	21	1	24.1
Meadow barley	*Hordeum brachyantherum*	Grass	20	4	96.5
beardless wildrye	*Leymus triticoides*	Grass	20	3	72.4
small fescue	*Vulpia microstachys*	Grass	18	1.5	36.2

*PLS = Pure Live Seed

All numbers are raw totals and do not include contingency or buffer.

5.3.4 Plant Layout

Specific distribution, clustering, and within-zone plant guilds and associations may be further refined if more detailed soil data become available. Mixed species implementation and high planting densities will provide a buffer for uncertainty in species survival and adaptation as well as serve to establish a diverse vegetation community and canopy structure.

5.3.5 Planting Implementation

Woody species will need to be planted by hand and should not require specialized equipment. Screens or cardboard containers will be installed to minimize browsing damage and herbicide overspray. Plantings will correspond with irrigation line emitters spaced accordingly (Section 5.4.4.2).

The upland areas and base-flow channel will be seeded immediately after construction is completed, or may be slightly delayed to coincide with fall/winter precipitation. Seedings can be conducted with a no-till drill or other methods and equipment, provided they can establish good seed-soil contact and appropriate burial depths.

Within the irrigated zones, areas between irrigation lines will be left fallow for two years following the installation of woody species. This will allow weeds, particularly aggressive perennial species, to germinate and be controlled with mechanical and chemical methods. Weed control prior to planting generally increases the success of riparian revegetation by reducing competition and pushing the system past the early successional stages.

These areas will be seeded and planted after the two year weed suppression period. Seeded sites will likely require seedbed preparation and potentially incorporation after seeding depending on the existing conditions and method. The layout and irrigation system is designed to allow standard agricultural seeding equipment to be utilized.

The base-flow channel will also be seeded with a grass cover crop to prevent invasive species colonization until flows are initiated in the channel.

5.3.6 Monitoring and Maintenance

Monitoring and maintenance will be conducted for 10 years following revegetation: Yearly for the first 3 years, then every other year up until year 7, and a final assessment at year 10 (total of 7 monitoring years). This may ultimately be incorporated into a larger overall monitoring program for SJRRP revegetation efforts. Development of specific monitoring protocols will be based on the goals of the project and will key on habitat metrics. These would potentially include a field-survey of successful plant establishment (live vs. dead), vigor (growth rate, photosynthetic measurements, etc.), and coverage (stem density or canopy cover) for desired species, and invasive species occurrences as well as aerial or satellite imagery analysis, GIS integration, vegetation transects/quadrats, and other potential tasks. Monitoring reports should include recommendations for adaptive management strategies to be applied as data become available.

Areas where vegetation fails to establish or otherwise does not meet the restoration goals should be evaluated for potential causes, and practices amended for re-establishment. This may include soil amendments, changes in species selection or irrigation regime, and re-planting or seeding.

Soil moisture, sediment transport, and hydrologic changes may also be monitored, and would likely be part of a larger effort to assess the overall performance of the Bypass per the rearing habitat objectives.

5.3.7 Invasive Species

Management of invasive species will be critical, especially during the short term (minimum of 3 years) to ensure that the desirable vegetation dominates the landscape and provides habitat diversity, productivity, and sustainability. An invasive vegetation management plan will be part of the final revegetation design; Task 4 is the implementation of the invasive vegetation management plan by the Contractor.

Integrated methods for weed suppression are typically more economical and effective than any one method used alone. Mechanical control such as tillage and hand removal may be utilized, and mowing can also be effective for some species. Combining mowing or other mechanical biomass removal with herbicide applications must be timed correctly. Foliar applications alone can also be effective and may be a better choice is weed biomass is not extensive. Other innovative techniques for promoting native vegetation over invasive species may be explored, this will be particularly important in the upland areas where no irrigation will occur.

Known weeds in the vicinity of the project area and potential upstream sources of invasives include scarlet wisteria *(Sesbania punicea*), giant reed (*Arundo donax*), edible fig (*Ficus carica*), tree of heaven (*Ailanthus altissima*), Chinese tallow (*Triadica sebi*fera), tamarisk (*Tamarix* spp.), and blessed milkthistle (*Silybum marianum*). Various common herbaceous weeds will almost certainly proliferate in the project area as well.

Seeding of the riparian zones (Zones 1-3, see task 6) will be delayed for 2 years from the completion of the grading. This will allow pre-germination control efforts to be integrated into the site preparation stage to knock down early germinating weeds after soil disturbance, as well as non-selective post-germination methods. Two years of well-timed mechanical, chemical, or a combination of methods should reduce the amount of aggressive, early germinating species that are well adapted to disturbance and could be problematic competitors for native species establishment.

The upland zones will be seeded at the completion of grading with a grass/forb mix and may benefit from pre-emergent application of herbicides before seeding. After germination, other methods such as mechanical removal or spot treatments of herbicide may be necessary.

After establishment of seedings, selective herbicides, spot treatments, or mechanical removal may be used to control invasive weeds in strips planted to grasses and forbs. Areas around irrigated trees and shrubs may also need to be kept clear of competing vegetation using spot applications of non-selective herbicides, registered for use within the drip-line of trees, such as glyphosate. Upland seeded areas will rely on the competitive ability and early timing, as well as spot treatments with herbicides to keep invasive species in check.

Invasive species control will use non-toxic substances and methods that do not cause harm to endangered species. Any herbicides used will be non-toxic to aquatic species at applied rates. All herbicides must be applied in accordance with the label and by a certified applicator as required by state and federal regulations, and so as no harm shall come to fish or other desirable species.

5.3.8 Herbivory

Herbivore damage to newly planted or germinated vegetation can be alleviated with screens, chemical deterrents, or other exclusion methods. Mowing can also be used to eliminate cover for rodents and small mammals that may cause damage to planted species. Herbivore control will not use poisons; rodent holes may be removed only after providing one-way exit gates to enable any possible endangered species to exit prior to filling in holes.

Local experience from adjacent orchards may provide insight as to the level or necessity expected for herbivory management; cardboard barriers (milk cartons) may suffice.

5.3.9 Schedule

All woody plantings and upland seeding should be completed within one season following excavation of the Bypass and irrigation system setup. An overall schedule including the excavation and flow reintroduction schedule is given in Table 5-15. Seeding is typically done in the late fall or winter to maximize use of seasonal precipitation and first-year growth. Woody cuttings and transplants should be installed in the winter or early spring.

All plantings and seedings will ultimately be more successful if coordinated with natural precipitation. This will be more critical for the upland zone where no irrigation will occur, whereas irrigated areas may produce successful establishment with less sensitivity to timing.

5.3.10 Vegetation Evolution

Vegetation within the Bypass is expected to change in composition and structure from the initial planting effort over time. There is a good deal of uncertainty as to what the equilibrium state will look like due to a variety of factors (climate, soils, hydrology, sediment transport, etc.) that are difficult to predict. Initial revegetation efforts are designed to introduce enough desirable vegetation and propagules into the system in order to make valuable habitat the most likely outcome, although it cannot be guaranteed without persistent monitoring, maintenance, and potentially reseeding or replanting some areas.

Succession of disturbed areas without intervention can vary widely, but generally initiates with herbaceous annuals, typically weedy species, then evolves towards perennial grasses, forbs, and finally to a multi-tiered structure with understory, woody shrubs, and trees given suitable riparian conditions. By installing native shrubs and trees in the Bypass, the landscape will progress more rapidly and with more certainty towards a mature stage with diverse structure and dense canopies.

Flows through the Bypass will have a significant effect on how the vegetation evolves. Episodic scouring flows will be necessary to propagate cottonwoods and willows, and maintaining sufficient groundwater levels is critical for support of all riparian species within the Bypass. Extended periods of below-normal groundwater levels may shift the vegetation community towards a less robust and more herbaceous/woody scrub type of system with lower habitat value.

Other maintenance activities such as weed suppression and irrigation also have the potential to substantially shape the evolution of vegetation in the Bypass. Although invasive species might decline over time naturally if native species are able to gain a foothold, they will likely persist as a significant proportion of the community and lower overall habitat quality.

Table 5-16.—Schedule for excavation, revegetation and flow reintroduction, schedule is assumed to start in Winter of Year 0 termed “Winter 0”.

Component	Begin	End
Source Plant Materials	Fall -2	Fall 0
Bypass Channel Excavation	Winter 0	Fall 0
Installation of Irrigation system	Summer 0	Fall 0
Initial Planting of Zones 1, 2, 3, and 5	Fall 0	Spring 1
Seeding Zone 4	Fall 0	Winter 0
Vegetation Maintenance and Invasive Control	Fall 0	Fall 3
Seeding of Understory in Zones 1, 2, 3, and 5	Fall 2	Fall 2
Removal of Irrigation System	Winter 3	Winter 3
Introduction of Base Flows (up to 200 cfs) – can be sooner if low flow channel stabilized using FES	Spring 3	-
Construction of Pilot Channel in Reach 2B	Winter 4	Winter 4
Introduction of Bank Full Flows (up to 1200 cfs)	Spring 4	-
Introduction of High Flows (up to 4500 cfs)	Spring 5	-

5.4 Irrigation

5.4.1 Water Requirements

The riparian corridor alongside the bypass channel area will require irrigation for a period of 3 to 5 years. This restoration area encompasses 55 acres of over 16,072 new riparian plants. This section describes the irrigation water requirements of these riparian species. The monthly irrigation requirement (F_g) was calculated by

$$F_g = \frac{(ET_C - P_e)}{I_e} \qquad \text{Eq 12}$$

where ET_C is the crop evapotranspiration, P_e is the effective precipitation, and I_e is the irrigation efficiency. Crop evapotranspiration was calculated by:

$$ET_c = K_c ET_o \qquad \text{Eq 13}$$

where $K_c$the crop coefficient and ET_o is the reference crop evapotranspiration (in/day). The crop coefficient integrates the effect of characteristics that distinguish typical field crop from the grass reference, therefore different crops have difference $K_c$values. To ensure that enough water would be available the forb crop coefficient of 1.05 was used in the design of the irrigation system taken from Gazal et al. (2006).

The Natural Resources Conservation Service (NRCS) National Engineering Handbook Part 623 Chapter 2 method was used for P_e in this design (NRCS National Engineering Handbook, 1993). A common irrigation efficiency for micro-spray irrigation ranges between 80 to 95 percent. This study assumed a conservative 80 percent irrigation efficiency to account for the conditions near the end of life of the system. ET_o monthly values (inches) and precipitation were obtained from the Department of Water Resources, California Irrigation Management Information System (CIMIS) at station name Los Banos # 56 (Figure 5-20, Table 5-16). The monthly values reported have been averaged from June 28, 1988 to September 21, 2015.

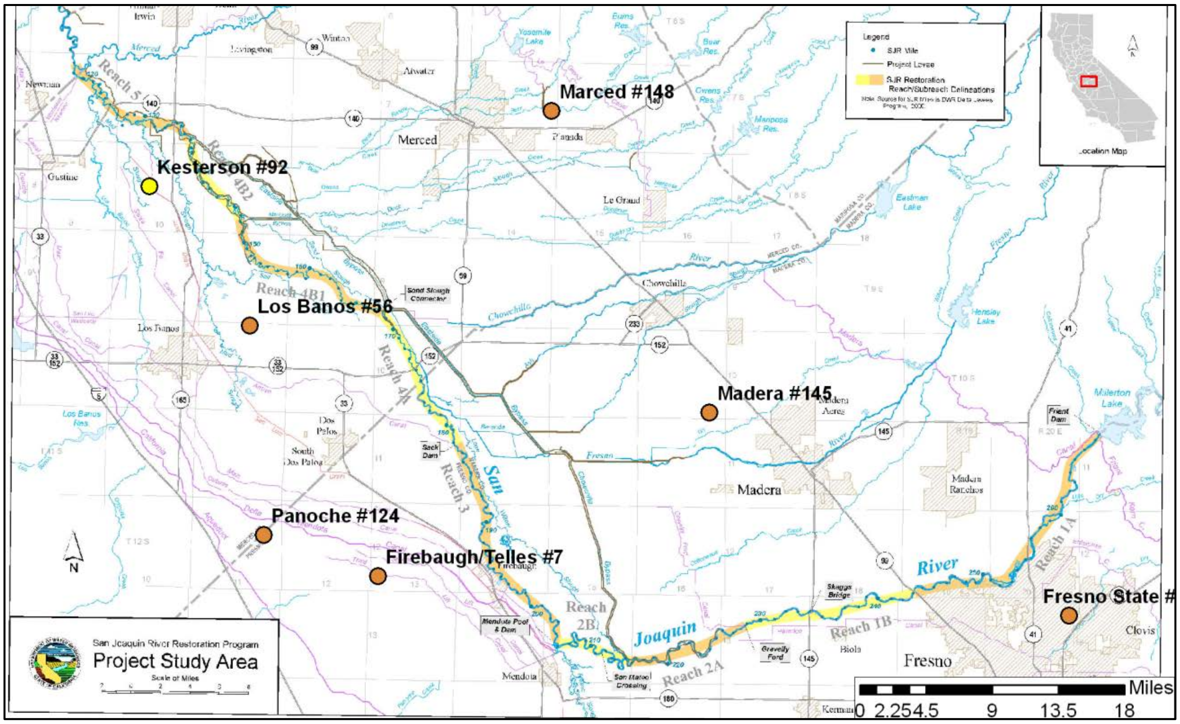


Figure 5-20.—Location of CIMIS stations near the project location.

Table 5-17.—Monthly ETo values in inches at station #56 Los Banos from September 21, 2015.

Type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOT
ETo (in)	1.18	2.03	3.83	5.60	7.60	8.46	8.22	7.49	5.61	3.79	1.86	1.08	56.75
P (in)	1.64	2.09	1.58	0.61	0.37	0.09	0.01	0.02	0.12	0.56	0.76	1.29	9.14

5.4.2 Soils Data

The irrigation water requirement is also impacted by the soil type, the soil infiltration capacity (hydraulic conductivity), and soil salinity. Data were collected on hydraulic conductivity and salinity within Reach 2B (Figure 5-21). The NRCS soil survey of Merced county has the predominate soil type as sandy loam, which corresponds to the soil hydraulic conductivity data collected showing moderate rates of infiltration. A micro-sprinkler system was chosen because of higher infiltration rates. Drip irrigation was ruled out because of the potential for non-uniform wetting in the desired wetting radius. Soil salinity data shows that electrical conductivity and salinity may be within acceptable levels, which indicate that application of irrigation water to flush salts will not be required initially. However, flushing irrigation may be required in year 2 or 3 if salinity builds up in soil.

The NRCS soil survey data also provides information on the available soil water supply (AWS) or the amount of water that is held within the soil for the plant for use will be referred to as the soil reservoir. As the plants grow the depth which water can be extracted from increases. Table 5-15 provides the area weighted soil reservoir depths for year 1, 2, 3, and full maturity.

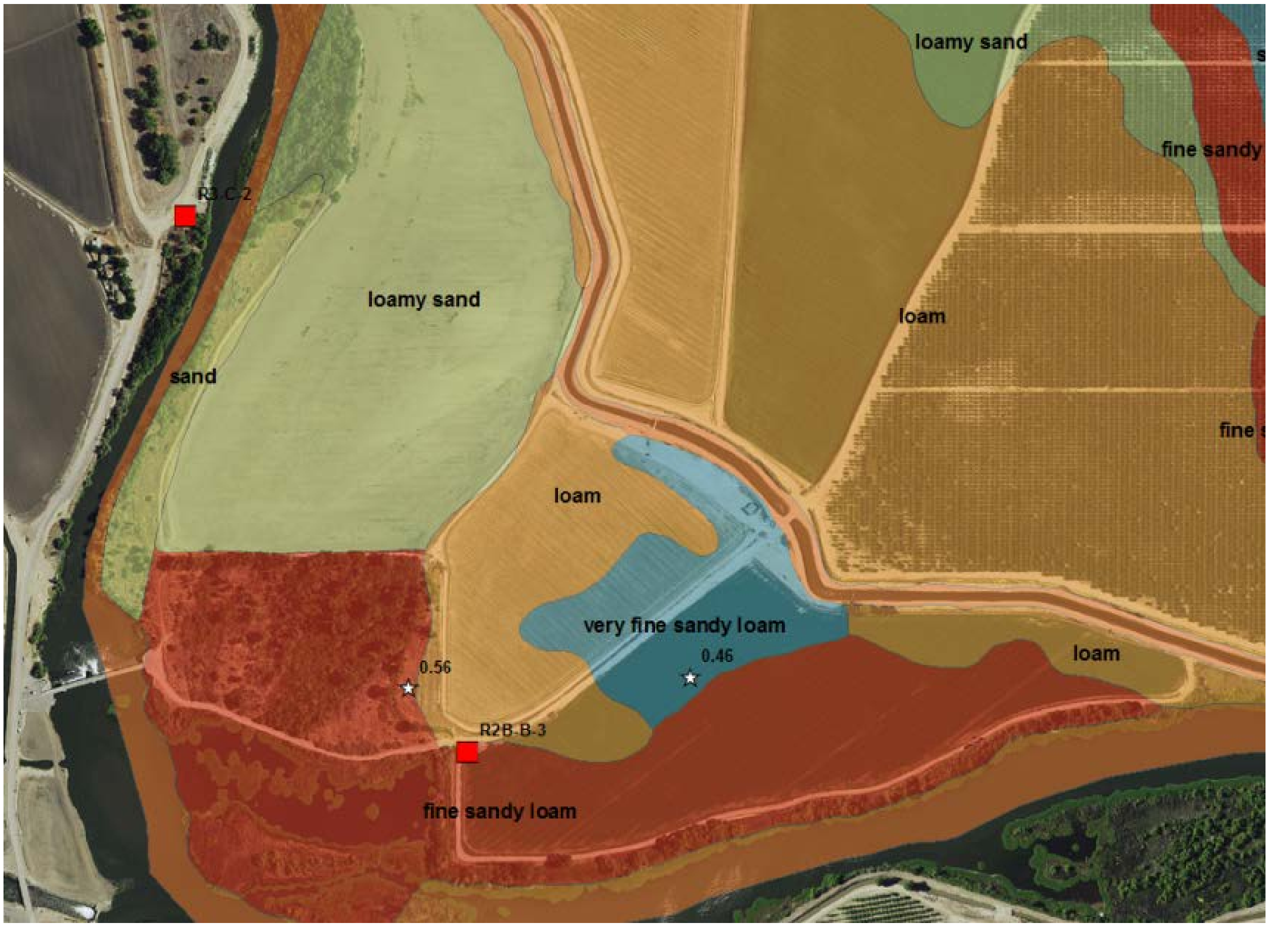


Figure 5-21.— Reach 2B soils texture, salinity, and hydraulic conductivity data. The white stars indicate soil salinity locations and values in dS/mm. The red squares are the locations of soil hydraulic conductivity test locations.

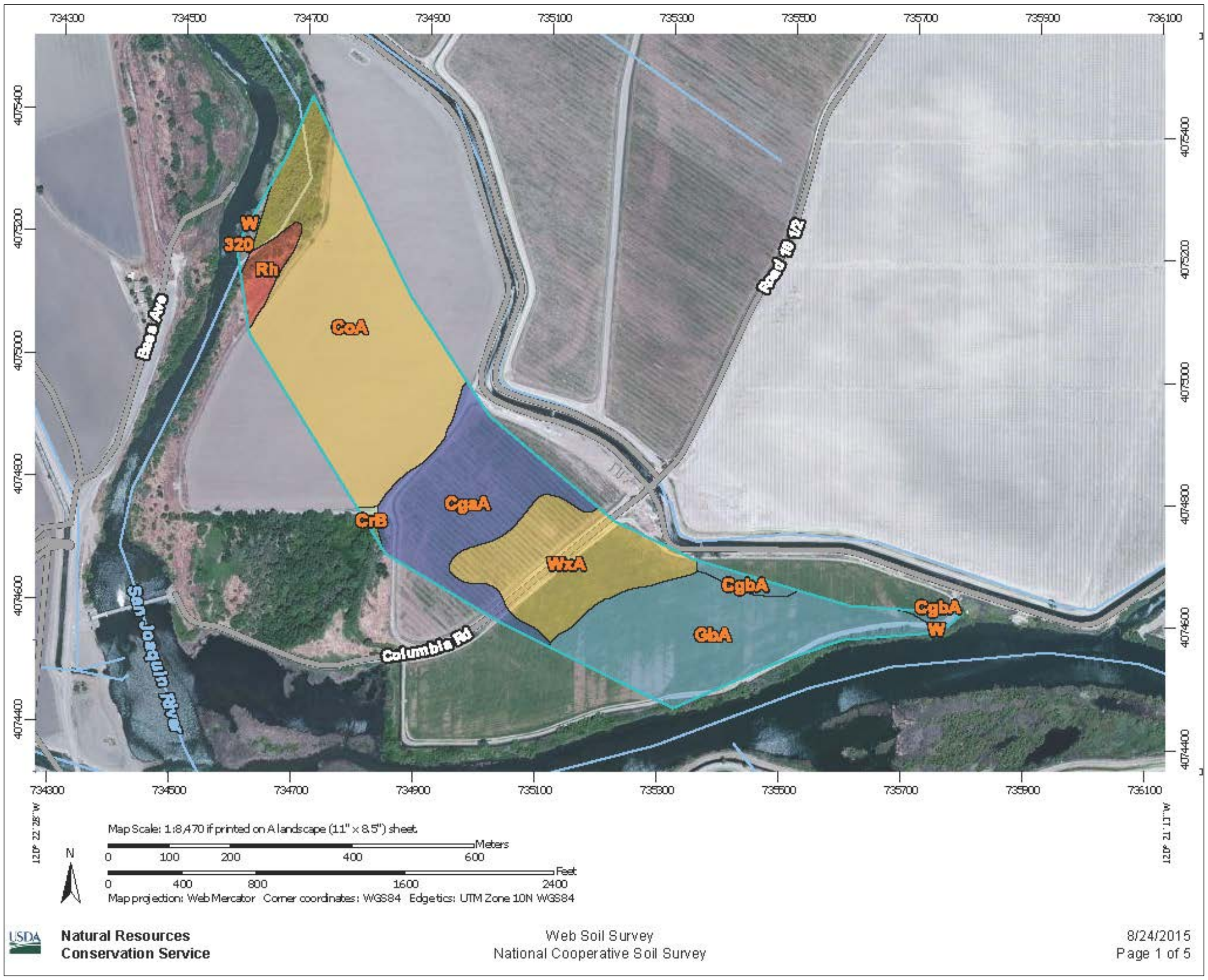


Figure 5-22.—NRCS Soil Survey Available water supply at 0 to 25 centimeters in the soil depth.

Table 5-18.—Area weighted capacity for the available water supply for reach 2B Bypass area.

Map Unit	Acres	Year 1	Year 2	Year 3
Chino Loam (CgaA)	13.7	0.3	0.6	0.9
Chino Loam (CgbA)	1.2	0.02	0.0	0.1
Columbia loamy sand (CoA)	30	0.35	0.7	1.0
Columbia soils (CrB)	0.3	0.00	0.0	0.0
Grangeville fine sandy loam (GbA)	17.1	0.29	0.6	0.9
Riverwash (Rh)	1.8	0.01	0.0	0.0
Wunjey very fine sandy loam (WxA)	11.8	0.12	0.2	0.4
Total	75.9	1.1	2.2	3.3

5.4.3 Irrigation Schedule

The amount of water required for the Bypass area is dependent upon the number of plants. There are approximately 16,072 plants within the Bypass revegetation area. To ensure there is enough water for row plants and inter-row plantings a conservative assumption was made on the irrigation water requirement by assuming all plants require the same amount of water as the forbs. Table 5-18 provides the total volume of water required by the project.

The irrigation schedule is determined by the volume of water required by the plants, the volume of water that can be stored in the soil, and surface soil hydraulic conductivity. The irrigation schedule per year was altered so the required amount of water was met but did not exceed the soil reservoir capacity. This irrigation schedule assumed winter rains. Additional irrigation schedules could be developed to account for drought conditions. Table 5-18 provides the number of irrigation days and the number of hours to be operated during those days. It also details the amount of water stored each month within the soil reservoir and how much water is lost to deep percolation. This equates to a total deep percolation loss of 1.7 ac-ft for the entire revegetation Bypass area and is an application efficiency of 96%.

Due to the desired wetting radius of 16 ft by 5 ft and predominate sandy loam soil type, drip irrigation was ruled out and a micro-sprayer system was chosen. The irrigation design layout will be discussed later. The emitter selected has a flow rate of 4.4 gallons/hour. Table 5-18 shows the numbers of days and hours in which the irrigation system will have to be operated in order to meet the irrigation water requirements for the plants. The total volume required to irrigate the Bypass revegetation area for years 1, 2, and 3 is 91.7 ac-ft, 96.0 ac-ft, and 100.7 ac-ft for respectfully. The irrigation volume per hour was calculated by:

$$IV\ (GPH) = I_T Q_e \qquad \text{Eq 14}$$

where IV is the irrigation volume (GPH), I_T is the total irrigation time (hours), and Q_e is the emitter flow rate (GPH). The total irrigation volume was calculated by:

$$TIV\ (ac-ft) = \frac{Q_e \times H}{(SG_w \times 43{,}560)} \qquad \text{Eq 15}$$

where TIV is the total irrigation volume in acre-feet, H is the number of irrigation hours, and SG_w is the specific gravity of water.

Table 5-19.—Irrigation schedule for the Reach 2B Bypass revegetation in Year 1, Year 2, and Year 3

Month	Year 1			Year 2			Year 3		
	Irrigation Days/month	Irrigation hrs/day	Volume (ac-ft)	Irrigation Days/month	Irrigation hrs/day	Volume (ac-ft)	Irrigation Days/month	Irrigation hrs/day	Volume (ac-ft)
JAN	12	0.75	2.0	12	0.75	2.0	10	0.75	1.6
FEB	9	0.75	1.5	11	0.75	1.8	17	0.50	1.8
MAR	23	1.00	5.0	19	1.25	5.2	16	1.50	5.2
APR	26	1.75	9.9	19	2.50	10.3	19	2.75	11.4
MAY	24	2.50	13.0	20	3.00	13.0	19	3.50	14.5
JUN	25	2.75	14.9	21	3.75	17.1	20	4.00	17.4
JUL	23	3.00	15.0	19	3.75	15.5	19	4.00	16.5
AUG	26	2.50	14.1	19	3.50	14.4	19	3.75	15.5
SEP	23	1.75	8.7	19	2.25	9.3	19	2.25	9.3
OCT	21	1.25	5.7	20	1.25	5.4	16	1.50	5.2
NOV	9	1.00	2.0	13	0.75	2.1	14	0.75	2.3
DEC	0	0.00	0.0	0	0.00	0.0	0	0.00	0.0
TOTAL	**221**	**19.00**	**91.7**	**192**	**23.25**	**96.0**	**188**	**25.00**	**100.7**

5.4.4 Irrigation Layout

5.4.4.1 Irrigation zones

The Reach 2B Bypass revegetation area was divided into three irrigation zones to increase pressure uniformity, reduce pipe sizes, and to increase flexibility in the irrigation schedule. The irrigation design capitalized pressure reduction by placement of pipe along the downslope. The irrigation zones and layout are delineated Figure 5-23. The plants and irrigation rows have been spaced at a varying distance defined by vegetation zone (Figure 5-14). Reach row is spaced at 16-foot intervals. This configuration achieves a planting density of approximately 500 plants/acre.

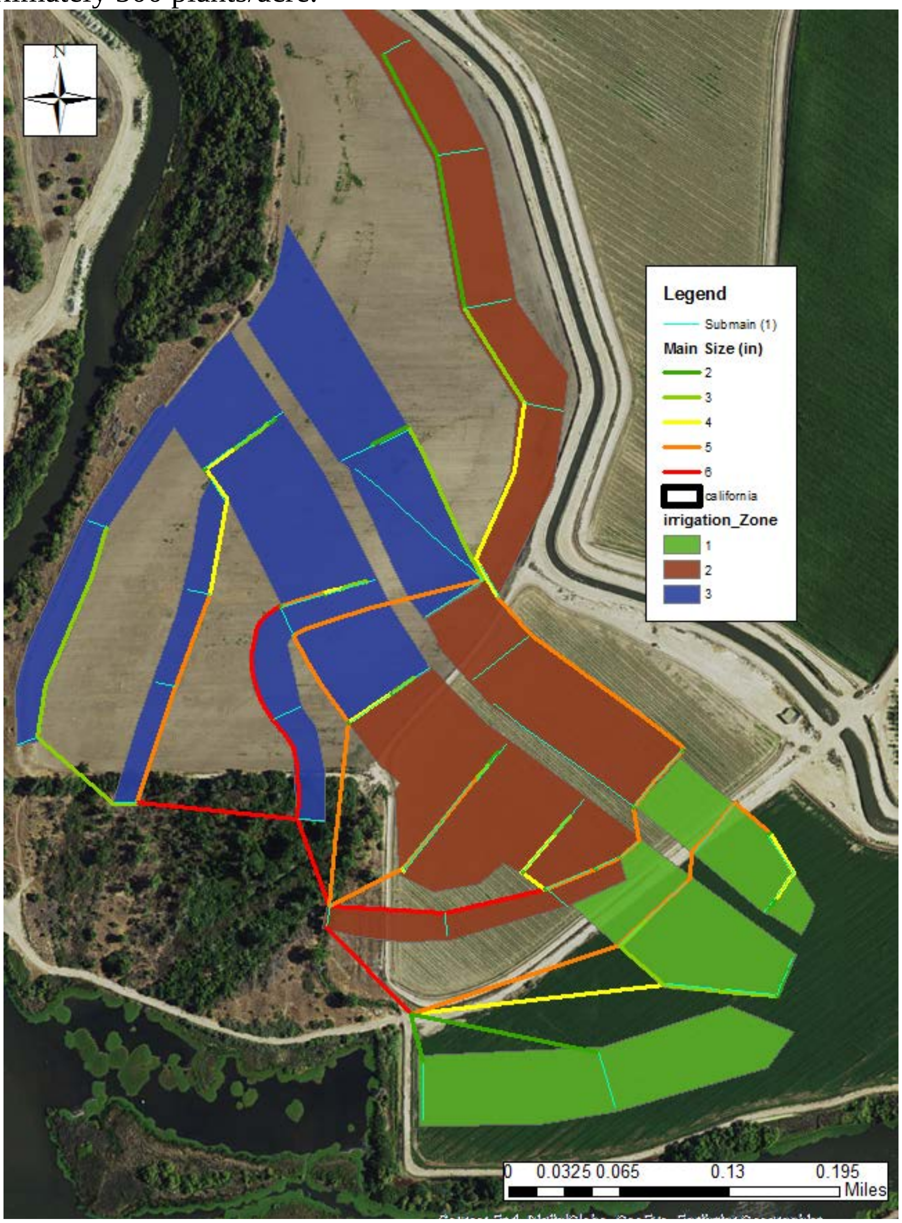


Figure 5-23.— irrigation zones and pipe layout.

Table 5-20.—Irrigation layout and irrigation zone delineated.

Vegetation Zone	Acres	Row spacing (ft)	Plant Spacing (ft)
Base Flow	5.3	N/A	N/A
Existing	17.2	N/A	N/A
High Density Riparian	11.5	5	10
Medium Density Riparian	8.9	12	15
Low-Density Riparian	9.7	16	20
Medium Density Brush	2.8	12	15
Oak Savannah	12.1	20	20
Upland	72	N/A	N/A

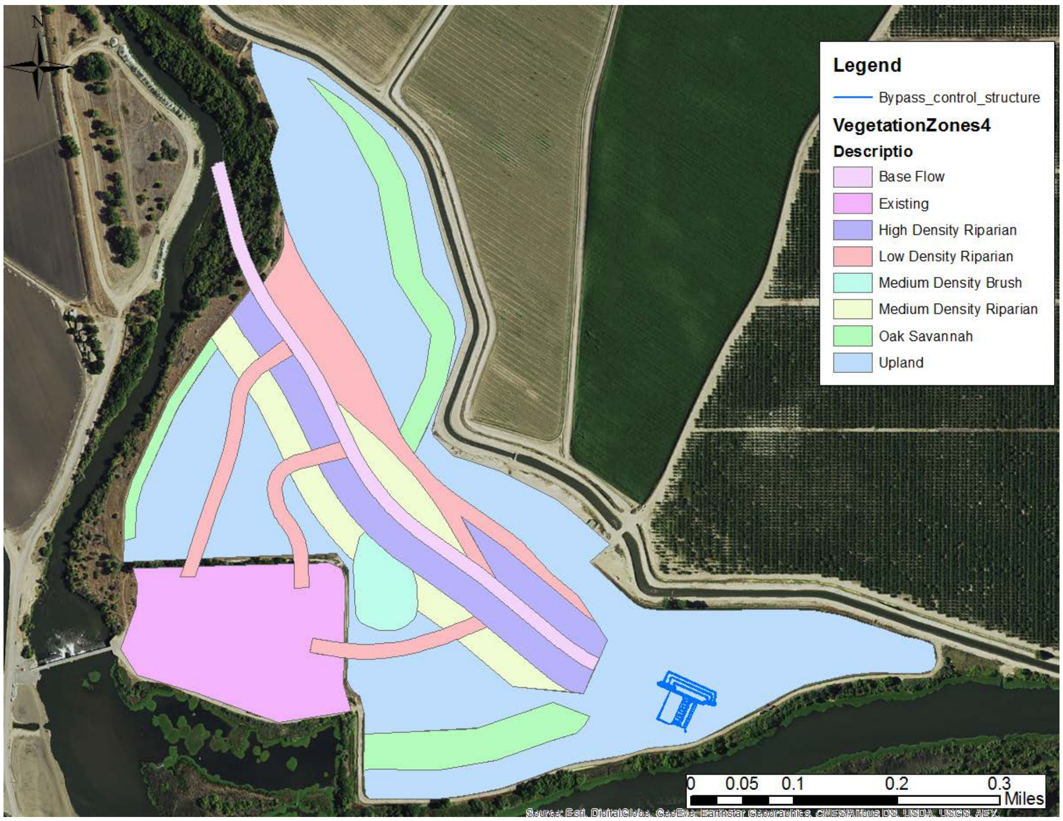


Figure 5-24.— Vegetation zones in Compact Bypass.

5.4.4.2 Emitters

Emitters will be located at every plant location, and are placed every 5 ft along the lateral row. As stated previously the selected emitters have a rectangular wetting area of 10 ft by 5 ft, a flow rate of 4.4 gallons per hour, and an operating pressure of 20 psi. A pressure regulating emitter was select to ensure irrigation uniformity even in the presence of pressure variation. Each emitter will require a 6-inch riser to meet its wetting radius. The emitter connects to the lateral tubing through a 1-foot feeder tube of polyethylene with a 0.140-inch inner diameter.

5.4.4.3 Pipe Sizes

The lateral lines that supply the emitters are a polyethylene resin 1.38-inch inner diameter pipe. This size was selected to minimize pressure loss, is rated for the operating pressure (a maximum of 42 psi), and the manufacture makes coil lengths that do not require couplers to meet the lateral lengths. Sub-mains and main pipe sizes were determined by examining pressure loss across the pipes from friction and head loss. The friction losses within the pipes were calculated by the Hazen-Williams equation:

$$P_d = \frac{4.52q^{1.85}}{c^{1.85}d_h^{4.8655}} \qquad \text{Eq 16}$$

where P_d is the pressure drop over the length of the pipe (psi/ft), q is the flow rate in (GPM), c is the design coefficient of friction, and d_h is the inside hydraulic diameter. A c value of 145 was selected for polyethylene pipe. The head loss was determined from the terrain developed for the Bypass design (Figure 5-5). The system was sized systematically by calculating loss through laterals, then sub-mains that supply the laterals, and finally losses through the main that supply the sub-mains. Table 5-20 provides the total pipe size quantities for the irrigation system.

Table 5-21.—Pipe size and quantities for the irrigation system.

Pipe Size (in)	Quantity (ft)
6	2,592
5	5,191
4	2,541
3	3,608
2	7,784
1.5	206,417

Table 5-22 - Emitter properties and quantities.

Brand	Type	Nozzle/type	Spray Pattern	Quantity
BowSmith or equivalent	Fan-Jet “PC” series	PC-4 with #30 Nozzle (Black)	Rectangular	16,072
BowSmith or equivalent	Feeder Tube	0.245 O.D Polyethylene feeder tubing		16,072
BowSmith or equivalent	Standard Coupling			16,072
BowSmith or equivalent	SK-C Stake	9”		16,072

5.4.4.4 Pumps

The current proposal for irrigation water is to develop an onsite well. The specifics of the well are not specified in this report. However, the design requires pumps to supply water to the Reach 2B Bypass. The irrigation schedule shows that the longest duration or irrigation on any day is 7.5 hours. One pump could feasibly supply each of the zones. This analysis or design has yet to be completed. Table 5-22 provides the required pumping rates and pressures for each irrigation zone. Irrigation zones are delineated in Figure 5-23.

Table 5-23 - Pumping pressures and flow rate for each irrigation zone.

Irrigation Zone	Pressure (psi)	Flow rate (GPM)
1	40	371
2	40	522
3	40	544

5.4.4.5 Filters

One of the highest costs of maintaining an irrigation system is unclogging particulates from emitters. Identifying these problematic locations and repairing them can lead to timely and expensive repairs and reduce overall distribution uniformity. To prevent emitter clogging from particulates, manufacturers of the selected emitters recommend a 150-mesh (opening size of 0.0041 inches) size for filtration. It is recommended a sand media filter be selected. The filter shall be placed in series just downstream of the pump. The filter shall have a maximum flow rate of 600 GPM and have a connection size of greater than 6 inches. Note there will be a pressure drop in the filter that is selected; therefore the pump may have to supply a higher pressure than what is prescribed in this report.

5.4.4.6 Air vents

It is highly recommended that air vents be incorporated at the end of each lateral line. Air vents release large volumes of air on startup to prevent air blockage and water hammer. Additionally, the air vent continuously releases pressure after the system has been pressurized to prevent water hammer. The air vents chosen for this study are a 1.5” kinetic air vent and vacuum regulator.

5.4.5 Irrigation System Maintenance

The irrigation system will need to be checked periodically for damage, clogs, and adequate performance. Annual maintenance will likely be necessary to make sure the system is operating correctly, and may require soil moisture monitoring to fully assess timing and duration (adaptive management).

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7 Appendix A Flow Exceedance Data

Station: SJB													
% exceedance	Month												
	All	1	2	3	4	5	6	7	8	9	10	11	12
0	5934.2	4500.0	4500.0	4500.0	3942.2	3732.4	5934.2	5087.7	2266.4	65.0	115.0	713.7	4500.0
0.1	4500.0	4500.0	4500.0	4344.4	3665.0	3610.1	5789.5	4718.9	1846.8	65.0	115.0	485.0	4500.0
0.5	3766.3	3416.1	3006.0	2626.1	3655.0	3460.9	4558.9	4500.0	923.9	65.0	115.0	485.0	3608.7
1	3655.0	2886.0	2465.1	2611.8	3655.0	3429.3	4388.7	4500.0	64.2	65.0	115.0	485.0	2081.9
2	3300.7	1916.6	2229.6	2275.3	3655.0	3140.8	4079.4	3771.7	45.0	65.0	115.0	485.0	976.7
3	2730.8	1622.5	2073.0	2198.5	3655.0	3062.9	3626.2	3184.9	45.0	65.0	115.0	485.0	534.6
4	2334.3	1241.2	1916.2	2077.7	3655.0	2963.2	3359.4	2345.2	45.0	65.0	115.0	485.0	155.0
5	2180.0	823.8	1731.6	1992.3	3655.0	2870.1	3080.0	1658.1	45.0	65.0	115.0	485.0	155.0
10	1513.9	175.0	1250.3	1588.4	3655.0	2397.2	2007.3	400.5	45.0	65.0	115.0	476.7	155.0
20	475.0	175.0	713.4	1225.0	2334.3	1596.4	862.6	78.3	45.0	65.0	115.0	475.0	155.0
25	253.6	175.0	523.8	1225.0	2180.0	777.5	269.2	45.0	45.0	65.0	115.0	397.2	155.0
30	175.0	175.0	240.6	1225.0	2180.0	388.6	148.5	45.0	45.0	65.0	115.0	373.3	155.0
40	155.0	175.0	175.0	1225.0	2180.0	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
50	155.0	175.0	175.0	1103.6	2144.9	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
60	115.0	175.0	175.0	557.2	1327.5	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
70	85.0	175.0	175.0	285.0	310.4	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
75	65.0	175.0	175.0	285.0	125.0	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
80	45.0	175.0	175.0	285.0	125.0	85.0	85.0	45.0	45.0	65.0	115.0	155.0	155.0
90	45.0	168.3	175.0	285.0	125.0	0.0	10.4	31.4	45.0	58.3	98.3	155.0	155.0
95	0.0	0.0	175.0	174.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	55.8	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Avg	444.5	263.1	452.0	882.6	1640.6	639.3	551.8	267.5	50.2	60.2	106.1	246.8	197.6