Attachment 6

Cursory Evaluation of Flood Impacts from Interim Flows

Modeling

SAN JOAQUIN RIVER RESTORATION PROGRAM

September 2009

Draft

EVALUATION OF POTENTIAL FLOOD EFFECTS ALONG THE SAN JOAQUIN RIVER FROM INTERIM FLOWS

In order to evaluate the potential flood effects from first year Interim Flows, a cursory evaluation was performed using existing 1-D hydraulic models of the San Joaquin River. In the analysis, model results were evaluated and compared to existing topographic mapping and evaluated for the potential of flooding, levee seepage, and levee and channel scour and erosion. Though this analysis is cursory and limited by the amount of existing data, the results from the available data demonstrated that the flood and seepage effects from a maximum release of up to 1300 cfs will be minor on most of the river system from Friant to Merced River. The results did indicate a few areas of concern for levee seepage and it is recommended that a comprehensive monitoring program be implemented to ensure seepage is monitored in these areas. Furthermore, the lack of geotechnical evaluations and real-time hydraulic and groundwater information as they relate to flows prevents a complete identification and understanding of seepage problem areas. It is suggested that the implementation of the Interim Flows program combined with geotechnical evaluations is the best way to fully understand how the river responds to flow and identify other critical areas where additional monitoring data is necessary. The following is a brief summary of the analysis.

POTENTIAL FLOOD EFFECTS

Based on the review of the available information on the system, the potential flood effects on the river system may come from the following sources:

- **Flooding from inadequate channel capacity**
- **Flooding from levee and levee foundation seepage**
- **Flooding from redirected impacts**
- **Flooding from levee failures due to breaching**
- **Increase of flood risk from scour and erosion on levees**
- **Increase of flood risk from sediment transport and deposition**
- **Increasing the flood risk from antecedent wetting of levees prior to flood**

In order to analyze these potential flood effects, existing hydraulic models of the San Joaquin River was employed. A brief summary of the development of these models is described below.

HYDRAULIC MODELS USED IN THE SEEPAGE ANALYSIS*

The analysis of the potential flood effects was performed using an existing one-dimensional steady-flow model of the San Joaquin River developed by Mussetter Engineering, Inc. in 2002 and updated in 2008. The model, using the HEC-RAS modeling software from the U.S. Army Corps of Engineers (USACE), was developed to evaluate channel capacity, fish passage in channels and at structures, spawning and rearing habitat for fisheries, growth and mortality of riparian vegetation, and sediment transport in the 150-mile reach of the San Joaquin River between Friant Dam and the confluence with the Merced River. The model parameters include flow, topography, channel and floodplain roughness, flow losses, and structures to represent existing channel and floodplain characteristics. A summary of the model development, assumptions, and validation is described below.

Topographic data for the model were derived from topographic and bathymetric surveys developed by Ayres Associates for the Bureau of Reclamation and USACE based on aerial photogrammetry and bathymetric surveys conducted in 1998 and 1999, supplemented with limited amounts of channel cross sections were surveyed by MEI in 1999. In addition, data from a field survey of approximately 1,900 feet of the west levee in the town of Firebaugh were also incorporated into the model. Elevations were subsequently corrected to account for subsidence that occurred in the Mendota Pool area since collection of the survey control data on which the mapping was based. Geometric data for bridges and other hydraulic structures within the project reach were obtained from a variety of sources and assembled in 1999. The resulting model contains approximately 2,160 cross sections for the 150-mile long reach from Friant Dam to the Merced River.

To account for varying roughness across the channel and floodplain for each cross-section, zones within which the hydraulic roughness characteristics are expected to be similar were delineated on the 1998 aerial photography based on the physical appearance of the vegetation and the ground surface. A total of seven distinct zone types were identified, with Manning's roughness coefficients ranging from 0.035 for channel bed and open water to 0.10 for dense trees and brush. The Manning's roughness values where then input into the model for the channel and overbank areas.

Flow profiles were developed for the model to account for historical flow patterns for each reach based on inflows (tributaries and flood–control return flows) and outflows (irrigation and flood control diversion). Due to the effects of channel percolation losses and diversions, flows were further varied along the reach between Friant Dam and the Bifurcation Structure, particularly in the range of flows below about 500 cfs. To quantify these effects, estimated flow-loss relationships were developed for the reach using data collected in the mid- to late-1990s and applied to the Friant Dam releases to estimate the flows at other locations along the reach.

The model includes water surface boundary conditions at the downstream end of the model at the Merced River using the rating curve for the Newman gage. The model also includes internal boundary conditions that depend on the operating rules of specific structures including the Chowchilla Bifurcation structure, Mendota Dam, and San Joaquin River at Sand Slough. These boundary conditions simulate the historical hydrology and operation of each structure.

The model was validated, to the extent possible, using surveyed water-surface elevations and the rating curves for stream gages located along the project reach. The result of the validation illustrated the model can reasonably simulate the existing channel and flow characteristics and can be used to estimate steady-state water-surface profiles and various hydraulic parameters, such as water depth, channel and floodplain velocities, and inundation areas. These outputs were used in this flood analysis to identify existing channel capacities and hydraulic parameters such as flow widths and depths and velocities. Specifically, model results were evaluated for three possible Interim Flows—350 cfs, 700 cfs, and 1300 cfs—in the river. Since inundation data was already available for flows of 350 and 1500 cfs for the bypass portion of the model, these results were used in analyzing the Eastside Bypass. The 1500 cfs results will show slightly greater but similar hydraulic results than that for the maximum first year Interim Flows.

* Resource: Mussetter Engineering, Inc., 2002. Hydraulic and Sediment-Continuity Modeling of the San Joaquin River from Friant Dam to Mendota Dam and Mendota Dam to Merced River

FLOOD EVALUATION

The following summarizes the analysis performed using the hydraulic model results and existing topographic data. Flooding from levee foundation seepage and failure of levees due to levee breaches are beyond the scope of this analysis and are not part of this evaluation. Data currently does not exist that allows a sufficient identification of subsurface seepage from varying subsurface soils or flooding from levee breaches. It also does not allow the evaluation of flood effects from high groundwater areas.

Flooding from inadequate channel capacity—
The one-dimensional HEC-RAS hydraulic model was used to identify the existing channel capacities in the river. The analysis was conducted by Mussetter Engineering, Inc., in 2008. The model was used to estimate water surface elevations over a range of discharges including potential Interim Flows. The analysis determined the non-damaging capacity for each reach assuming 3-feet of freeboard on levees (or adjacent ground in areas of no levees) that protected urban and agricultural lands. This assumed that the existing levees were suitable to handle flows within 3 feet of the top of levee. The analysis did not evaluate levee seepage and stability to determine channel capacity.

The analysis showed that Reach 2A through 5 has sufficient channel capacity to handle flows up to 1300 cfs. The exception is Reach 4B which will not be used to carry first year Interim Flows. A table of the final results is shown in Table 1. Discharges shown in the downstream portions of the river under existing conditions are believed to represent the upper limit of those that are likely to occur since conditions due to seepage, irrigation diversions, and operating procedures at diversion structures were not assumed and will likely alter flows.

Table 1
Summary of estimated flow capacities in Reaches 2A, 2B, 3, 4A, and 4B of the San Joaquin River

Reach	Dominant Levee Freeboard Capacity (cfs)	Interior Levee Freeboard Capacity (cfs)	Approximate Non-Damaging Flow Capacity (cfs)
2A	9,000	8,700	8,700
2B[1]	1,500	3,300	1,500
3	3,400	1,300[2]	1,300[2]
4A	3,900	3,300	3,300
4B	100[3]	<100[3]	<100[3]

[1] Freeboard elevations within Mendota Pool are encroached at all flows based on the assumed normal pool elevation. Estimated levee freeboard capacity does not reflect this condition. Additional analysis should be conducted to assess the levee freeboard for the pool.

[2] Levee freeboard capacity excludes small area of land that may be defined as a damageable surface.

[3] Primarily reflect limited channel capacity of upper portion of reach.

Flooding from levee seepage—
Flooding of adjacent lands from seepage through the levees has been documented throughout the river system from Reach 2A though Reach 4A. However, much of the anecdotal and documented information is based on flows much higher than releases anticipated from Interim Flow releases. Therefore, levee seepage was evaluated by evaluating the flow stage for three possible Interim Flow releases—350 cfs, 700 cfs, and 1300 cfs (the Eastside Bypass model was only run for 350 cfs and 1500 cfs). The HEC-RAS model was run for the these flows and flow stage was then compared to levee toe and adjacent ground elevations (elevations on the outside of the levees) to determine if the flows in the river and Eastside Bypass were high enough to allow levee seepage that would promote surface ponding on adjacent lands. Figures 1 through 5 display the flow stages compared to the levee toe and adjacent ground elevations for each reach. In most all cases, the flow stage in the river from Reach 2B through Reach 4A and the Eastside Bypass was not sufficiently high to cause problems due to flooding from seepage through the levees for flows up to 1300 cfs (1500 cfs for the Eastside Bypass).

In four areas, flow stage rise above the levee toe or adjacent ground and further evaluation was performed as described below and depicted on Figures 6 through 9. In **Reach 2B**, an area about 0.5 miles downstream the San Mateo Avenue crossing (Figure 6) was shown to have flow stage up to 1 foot above adjacent ground elevations at 1300 cfs. Though this area needs to be monitored, the seepage gradient that is expected will likely make the surface flooding effects from levee seepage minor. In **Reach 3**, an area in the City of Firebaugh downstream of Avenue 7 ½ (Figure 7) was also shown to have flow stage above the existing ground. However, in closer analysis, the adjacent ground identified is actually an abandoned pond (or a pond that has not been used for several years) at the wastewater treatment plant and effects to this pond are assumed to be minor. In **Reach 4A**, there appears to be the potential for seepage problems at flow stage above 350 cfs as flows appear to be above adjacent ground elevations (though only 1300 cfs is above the levee toe) near the Sand Slough Control Structure (Figure 8). This area has been reported as a high seepage area during low flows and it appears there is a seepage potential for seepage during Interim Flows. It is recommended that this area have seepage wells installed and monitored.

The **Eastside Bypass** was analyzed with existing data for flows of 350 and 1500 cfs. The results of this analysis showed that the flows mainly stayed within an incised channel except for a 4.5 mile section just downstream of the Sand Slough Control Structure where flows as low as 350 cfs extend to the levees (shown in Figure 9). Figure 5 shows the HEC-RAS model results that compare the flow stage to the levee toe and adjacent ground elevations for specific cross sections to obtain a general idea of the potential for seepage through the levees in the Bypass. The results showed that there is a potential for levee seepage along this section and it is recommended that this area have seepage wells installed and monitored.

In summary, levee seepage resulting in surface flooding to adjacent grounds along the river and bypass are limited. In a few areas it is recommended to install wells and monitor for surface ponding effects. Since this analysis only looked at the potential for surface ponding and will not identify the effects to the inundation of crop root zones or the effect of sand strings that may exist and encourage seepage, slow and incremental ramping of releases and monitoring in locations where historical flooding problems occur are recommended.

Flooding from redirected impacts—
Redirected flood impacts are due to the project moving the risk of flooding from one area to another area. In general, this is due to the improvement of flood protection in one area that would then move the risk of flooding downstream. Since no structural improvements are planned during Interim Flows, there are no redirected flood impacts due to the release of the first year of Interim Flows.

Increase of flood risk from scour and erosion on levees—
The ability to identify the increase of flood risk due to levee failure from scour and erosion requires sufficient soils and construction data on the levees that is currently not available. However, a cursory analysis was made using the 1-D hydraulic models to evaluate the average channel velocities along the river that can be expected in the channels and evaluate the potential for levee erosion. Since levee construction is unknown and levees may be made of sand, the channel velocities along the river were evaluated and compared with the suggested maximum permissible velocity of 2 feet per second (fps) for sand channels. Figures 1 through 5 display the velocities for possible Interim Flows in the river and the Eastside Bypass. In the evaluation, the four critical areas where flow levels were identified above the levee toes were evaluated and flows in these areas illustrated channel velocities below 2 fps. Therefore, the cursory results show that the flood risk from erosion on the levees would not be likely from Interim Flows.

Increase of flood risk from sediment transport and deposition—
The hydraulic modeling results were further evaluated to determine if channel velocities were sufficient to create channel erosion that could cause deposition in the channels,

thereby increasing flood risk. However, the channel velocities in the river are generally below 2 fps, so limited erosion is expected during Interim Flows. Areas that have velocities above 2 fps are limited to single cross-sections and scour, if it occurs, would be limited to isolated areas and not create major sediment deposition areas. Evaluating the full potential of scour and deposition within the channel would require a two-dimensional modeling with data that is not currently available. It is recommended that when future LiDAR and bathymetric data is available, 2-D models be developed to allow a comprehensive analysis of scour and deposition in the channels. Until then, 1-D modeling shows that the effect of sediment transport and deposition on flood risk is not likely in the river during first year Interim Flows.

Increasing the flood risk from antecedent wetting of levees prior to floods— The wetting of levees from Interim Flows would create a saturation zone within the levees. If Interim Flows occurred prior to a flood, the top of the saturation zone—called the phreatic surface—may have a slight effect to the subsequent flood phreatic surface. The higher the phreatic surface, the more likely that levee seepage would have an effect on levee stability from piping and seepage erosion. However, the quantification of the increase in phreatic surface and the effect of this increase on flood risk would require a significant amount of data collection including the height of the flood stage, the geometric properties of the levees, and the permeability of the levee. Furthermore, the increase in phreatic line would only be temporary until the flood phreatic line stabilized and the temporary increase would be considered a minor effect. Therefore, the effect to flooding from antecedent wetting of the levees from Interim Flows is not likely.

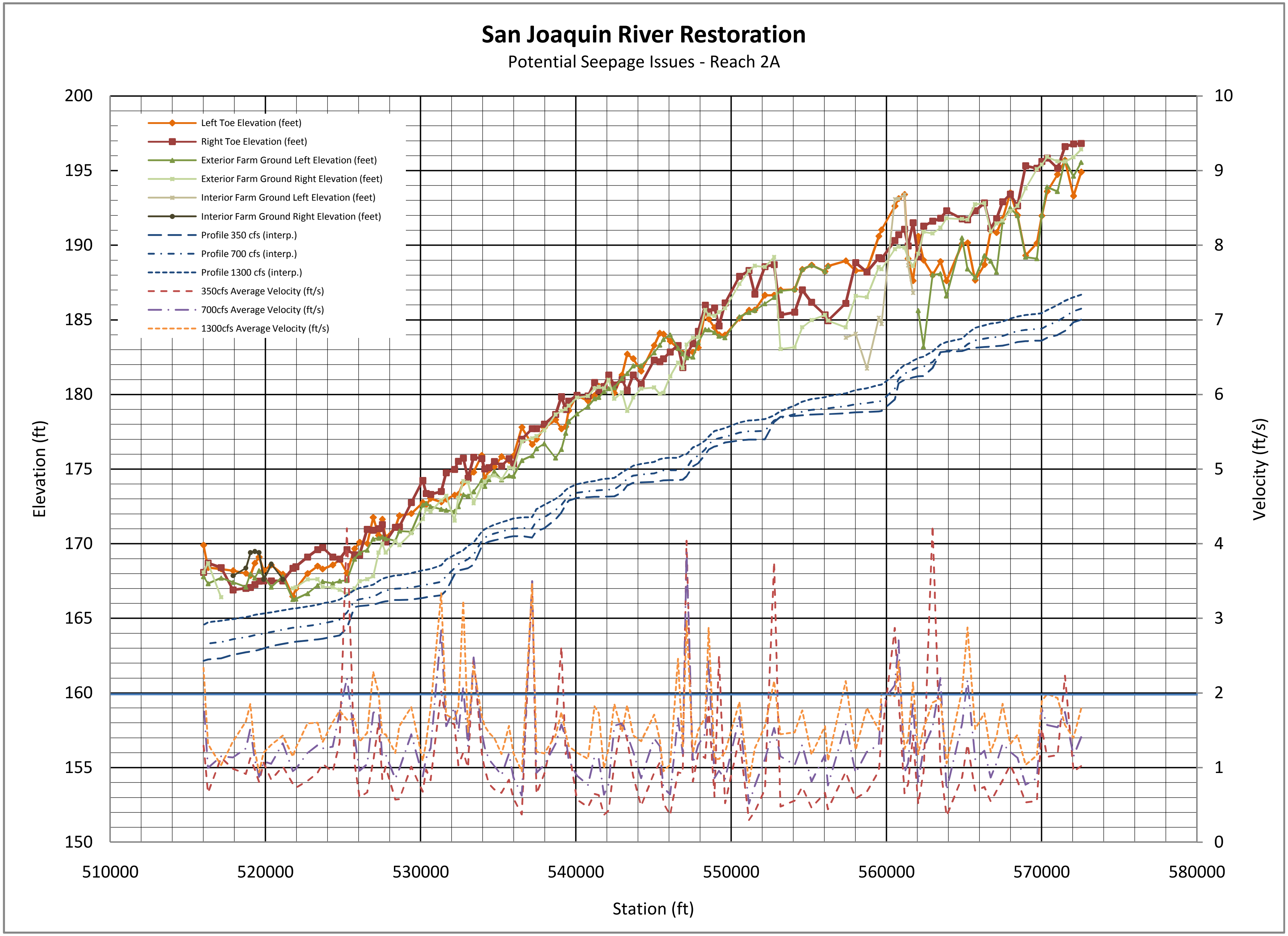
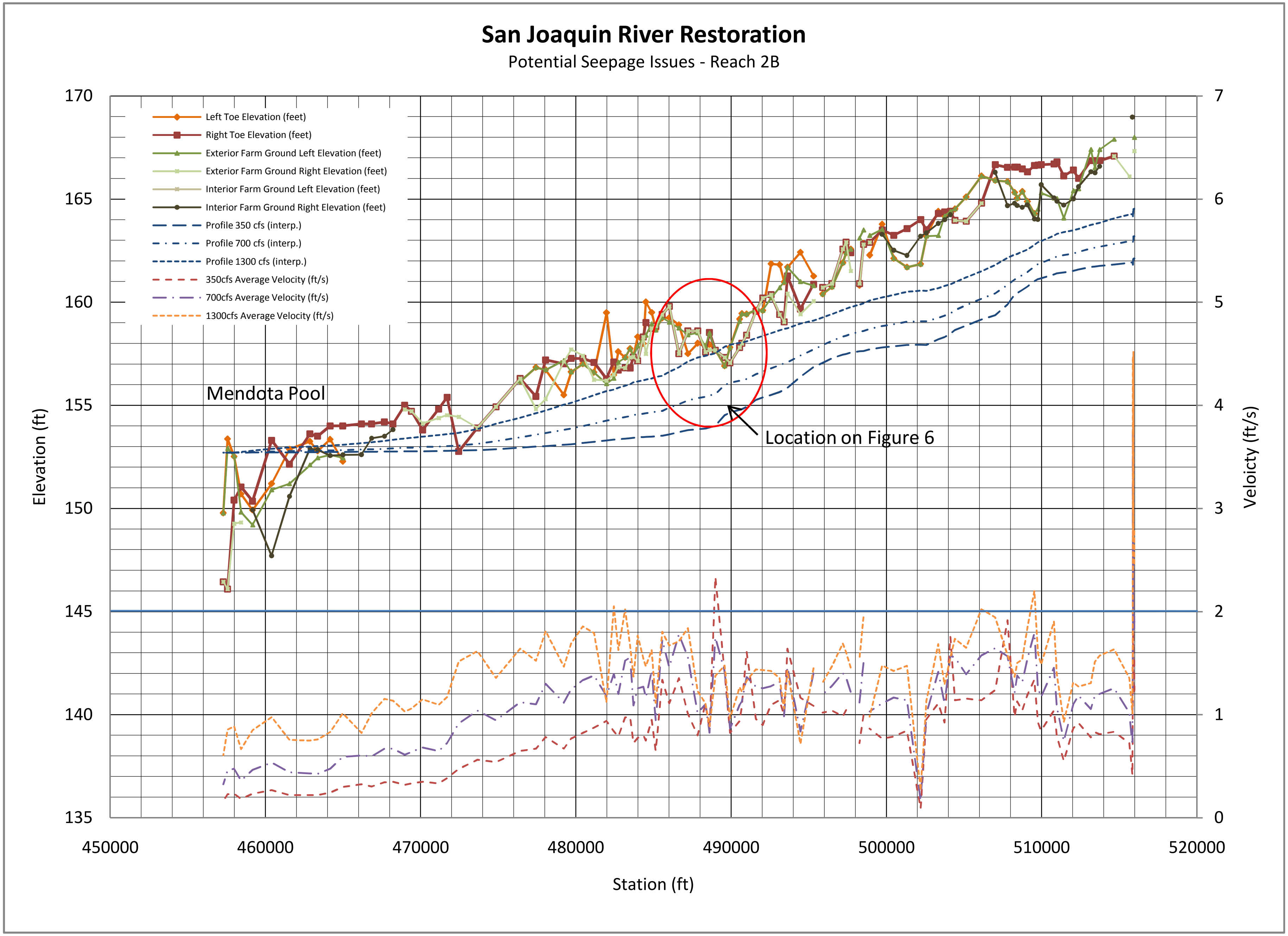

San Joaquin River Restoration
Potential Seepage Issues - Reach 2A
Left Toe Elevation (feet)
Right Toe Elevation (feet)
Exterior Farm Ground Left Elevation (feet)
Exterior Farm Ground Right Elevation (feet)
Interior Farm Ground Left Elevation (feet)
Interior Farm Ground Right Elevation (feet)
Profile 350 cfs (interp.)
Profile 700 cfs (interp.)
Profile 1300 cfs (interp.)
350cfs Average Velocity (ft/s)
700cfs Average Velocity (ft/s)
1300cfs Average Velocity (ft/s)
Elevation (ft)
Velocity (ft/s)
Station (ft)
200
195
190
185
180
175
170
165
160
155
150
10
9
8
7
6
5
4
3
2
1
0
510000
520000
530000
540000
550000
560000
570000
580000

Figure 1



San Joaquin River Restoration
Potential Seepage Issues - Reach 2B
Left Toe Elevation (feet)
Right Toe Elevation (feet)
Exterior Farm Ground Left Elevation (feet)
Exterior Farm Ground Right Elevation (feet)
Interior Farm Ground Left Elevation (feet)
Interior Farm Ground Right Elevation (feet)
Profile 350 cfs (interp.)
Profile 700 cfs (interp.)
Profile 1300 cfs (interp.)
350cfs Average Velocity (ft/s)
700cfs Average Velocity (ft/s)
1300cfs Average Velocity (ft/s)
Mendota Pool
Location on Figure 6
Elevation (ft)
Velocity (ft/s)
Station (ft)
170
165
160
155
150
145
140
135
7
6
5
4
3
2
1
0
450000
460000
470000
480000
490000
500000
510000
520000

Figure 2

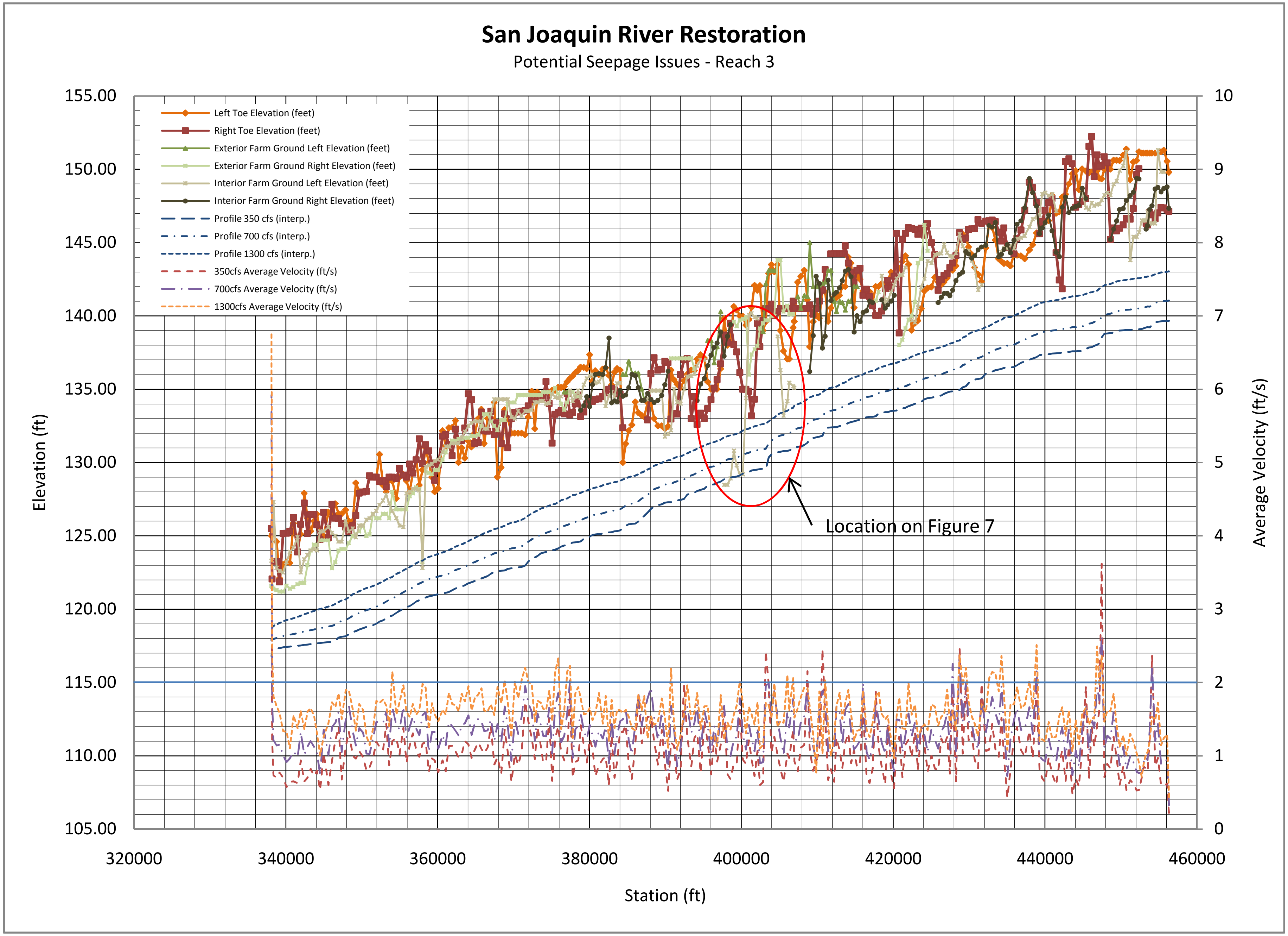
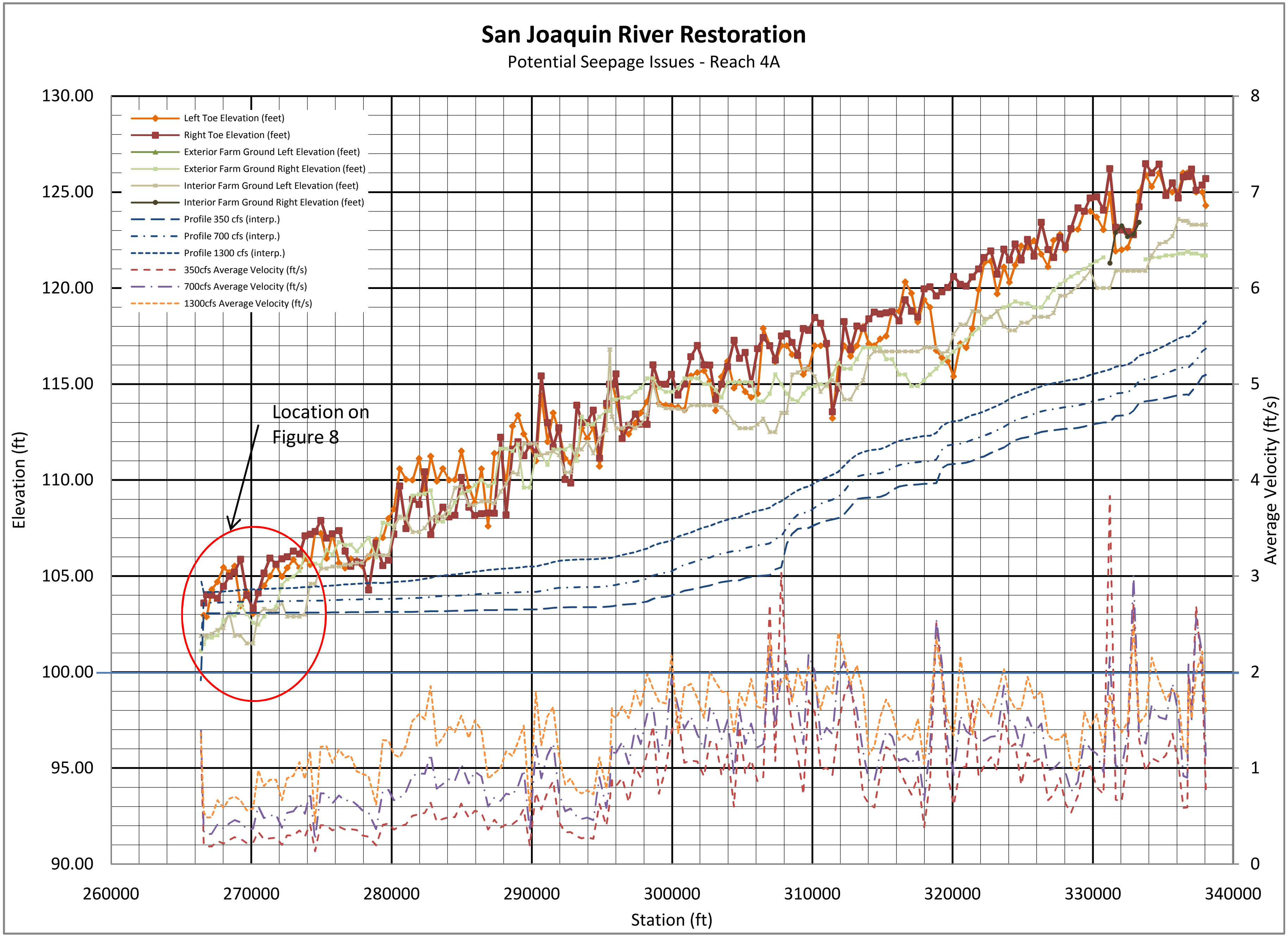

San Joaquin River Restoration
Potential Seepage Issues - Reach 3
Left Toe Elevation (feet)
Right Toe Elevation (feet)
Exterior Farm Ground Left Elevation (feet)
Exterior Farm Ground Right Elevation (feet)
Interior Farm Ground Left Elevation (feet)
Interior Farm Ground Right Elevation (feet)
Profile 350 cfs (interp.)
Profile 700 cfs (interp.)
Profile 1300 cfs (interp.)
350cfs Average Velocity (ft/s)
700cfs Average Velocity (ft/s)
1300cfs Average Velocity (ft/s)
Location on Figure 7
Elevation (ft)
Average Velocity (ft/s)
Station (ft)
155.00
150.00
145.00
140.00
135.00
130.00
125.00
120.00
115.00
110.00
105.00
10
9
8
7
6
5
4
3
2
1
0
320000
340000
360000
380000
400000
420000
440000
460000

Figure 3



San Joaquin River Restoration
Potential Seepage Issues - Reach 4A
Left Toe Elevation (feet)
Right Toe Elevation (feet)
Exterior Farm Ground Left Elevation (feet)
Exterior Farm Ground Right Elevation (feet)
Interior Farm Ground Left Elevation (feet)
Interior Farm Ground Right Elevation (feet)
Profile 350 cfs (interp.)
Profile 700 cfs (interp.)
Profile 1300 cfs (interp.)
350cfs Average Velocity (ft/s)
700cfs Average Velocity (ft/s)
1300cfs Average Velocity (ft/s)
Location on Figure 8
Elevation (ft)
Average Velocity (ft/s)
Station (ft)
130.00
125.00
120.00
115.00
110.00
105.00
100.00
95.00
90.00
8
7
6
5
4
3
2
1
0
260000
270000
280000
290000
300000
310000
320000
330000
340000

Figure 4

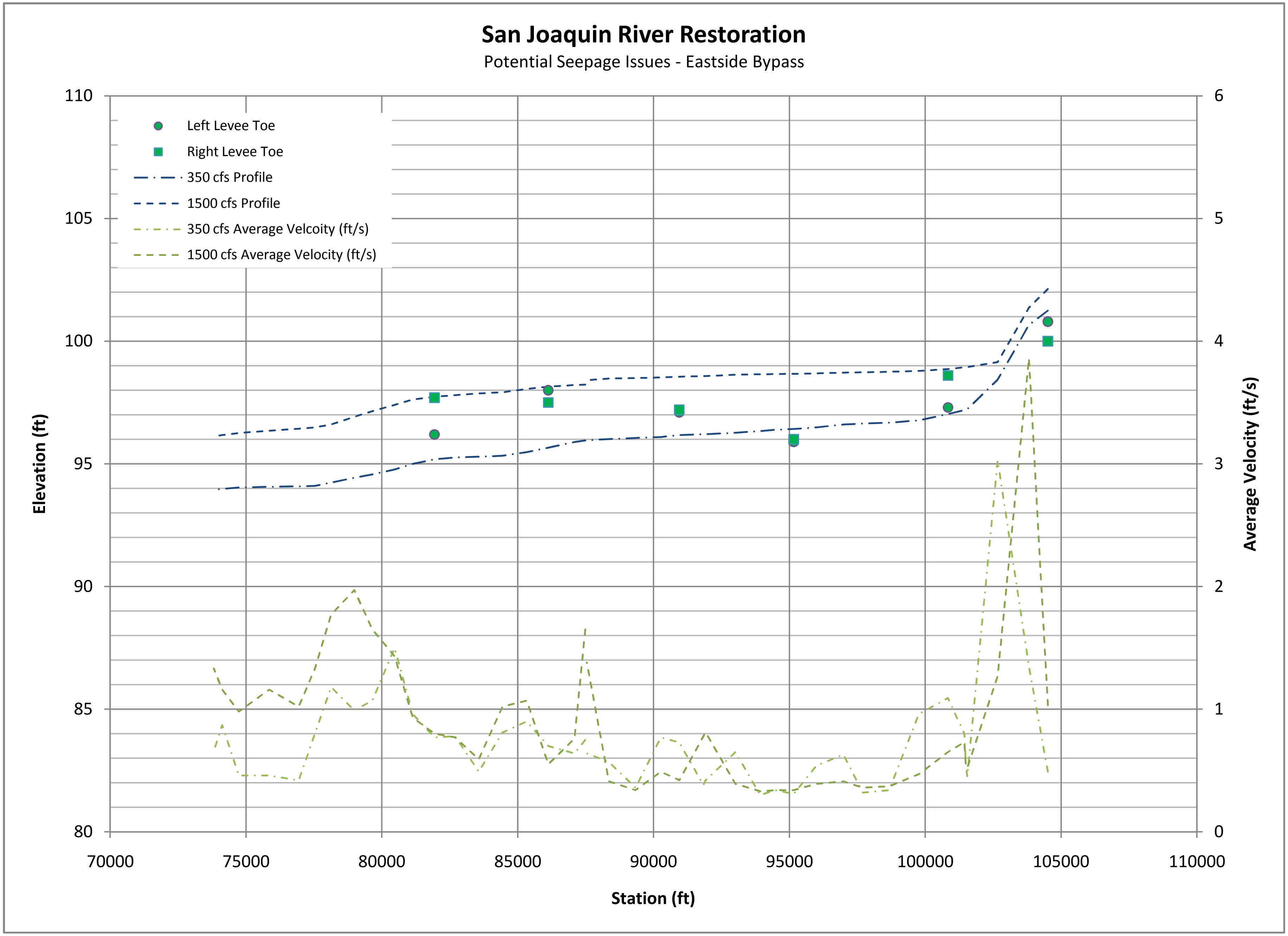

San Joaquin River Restoration
Potential Seepage Issues - Eastside Bypass
Left Levee Toe
Right Levee Toe
350 cfs Profile
1500 cfs Profile
350 cfs Average Velcoity (ft/s)
1500 cfs Average Velocity (ft/s)
Elevation (ft)
Average Velocity (ft/s)
Station (ft)
110
105
100
95
90
85
80
6
5
4
3
2
1
0
70000
75000
80000
85000
90000
95000
100000
105000
110000

Figure 5


XSA35
XSA36
XSA37
XSA38
XSA39
XSA40
XSA41
487500
XSA42
XSA43
XSA43.5
XSA44
XSA45
XSA46
XSA47
XSA47.5
XSA48
490000
Reach 2B
Legend
Selected Cross Sections
Interior Levees
Dominant Levees
350cfs Profile
1500cfs Profile

Figure 6


XS614
XS615
XS616
XS617
XS618
397000
XS619
XS620
XS621
XS622
XS623
XS624
XS625
400000
XS626
XS627
XS628
XS629
XS630
Reach 3
XS631
402500
XS632
XS633
XS634
Legend
Selected Cross Sections
Interior Levees
Dominant Levees
350cfs Profile
1500cfs Profile

Figure 7