TWO-DIMENSIONAL HYDRAULIC MODELING OF RIPARIAN HABITAT RESTORATION FROM COLUSA TO PRINCETON

SACRAMENTO RIVER, RM 142.5 TO RM 164.5
GLENN AND COLUSA COUNTIES, CA

March 28, 2008

Prepared For:

The Nature Conservancy.
Protecting nature. Preserving life.

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Ayres Associates Project No. 33.0551.00

EXECUTIVE SUMMARY

This report provides results from a detailed hydraulic analysis of planned riparian restorations on the Sacramento River between Princeton (RM 164.0) and Colusa (River Mile 144.4). The hydraulic modeling tool was RMA-2V, which is a 2-dimensional model. It was calibrated using the1995 high flow runoff, available1997 river topography and the 1995 surveyed high water marks. The calibrated model was then updated to 2006 LIDAR topography and 2006 land use conditions and then re-run for the 1957 Corps of Engineers design flow. This model was then used as a tool for comparison to the previously published 1957 design profiles and the water surface profiles planned restorations.

Eight parcels within the 20 mile reach of river are proposed for conversion from agricultural use to riparian restoration. The sites range from the Womble property near RM 162 to the Ward parcel near RM 146. While many of the sites are not close to each other, one hydraulic model that covers the entire reach was used to determine if there were cumulative effects from one site to the next. Multiple alternative restoration scenarios were tried until acceptable water surface conditions were finally achieved. The limiting criteria was that the proposed restorations would not create a higher water surface than the existing conditions or the 1957 Corps design profile, whichever was the greater.

The report also summarizes findings from the examination of other issues. Historical thalweg comparisons of the river were plotted and compared, however the results proved to be inconclusive as to an overall trend of aggradation or degradation within this reach of the river.

An inventory of the existing large woody debris within this reach was conducted and the hydraulic model re-run for an increased level of wood in the river system. Results showed little impact primarily because the woody debris occupied such a small portion of the overall flood flow cross section. The report also evaluates impacts to adjacent properties and the levees themselves.

Specific results for each of the planned restorations are included in Section 6 of the report with accompanying plots in the Appendix. In general, the computed water surface elevations for proposed restoration sites are at or below either the existing conditions run or the 1957 design profile with the exception of the Jensen site that has a small area at the downstream edge that is 0.05 ft above existing within the restoration site. This is a small increase and the extent is confined within the floodplain therefore no impact on levee freeboard.

Included in the Appendix are responses to comments by others on the report and a detailed analysis of methods, procedures and results by personnel at DWR.

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1.0 INTRODUCTION

1.1 General

This report summarizes the findings of a hydraulic analysis performed to review the existing floodplain capacity and investigate the effects of proposed restoration of riparian habitat within the Sacramento River floodplain. The Nature Conservancy (TNC) is proposing to restore riparian and savannah habitat on multiple properties within the leveed section of the Sacramento River north of Colusa. A two-dimensional (2D) hydraulic model of the Sacramento River from river mile (RM) 142.5 to 164.5 (Colusa to Princeton) was developed to assist in this analysis. The model was calibrated using recorded high water marks from the 1995 storm event and documented flow splits at the overflow weirs. The 1957 USACE design water surface elevations were used as the maximum water surface elevation for comparing any hydraulic impacts. The project location and model limits are shown in **Figure 1**. The restoration areas are shown in **Figures 2** and **3**.

This hydraulic analysis is in support to the Colusa Subreach Planning Program, which is focused on the Sacramento River floodplain between Princeton and Colusa, an area known as the Colusa Subreach. The scope of this analysis was approved by the Colusa Subreach Planning Advisory Workgroup in response to their identification of specific “Landowner Concerns” regarding wildlife habitat conservation within the floodplain. This analysis will provide specific information regarding the capacity of the floodplain and the effects of restoring native wildlife habitat on eight potential sites within the floodplain. As requested by the Advisory Workgroup, the analysis includes modeling of the entire Colusa Subreach so that cumulative effects are considered.

1.2 Background

The reach of the Sacramento River between RM 142.5 and 164.5 is leveed on both sides, and is a meandering channel with two overflow weirs into the Butte Basin. Upstream of RM 144, the levees are generally setback from the main channel with wide overbanks. From about RM 144 to the downstream end of the model (RM 142.4), the levees are tight against the riverbank. The channel upstream of RM 144 has migrated over the years and is continuing to migrate. **Figure 4** shows the river channel in its various alignments since 1896.

Within this reach of the Sacramento River levee system, the two overflow weirs, Moulton and Colusa, convey excess floodwater into the Butte Basin. The location of these weirs is shown in Figure 1. These weirs are unregulated and free flow when the stage hits the weir crest. For the Moulton Weir, the crest stage is 73.95 ft (NGVD-29) and for the Colusa Weir, the stage for flow to begin is 58.91 ft (NGVD-29). In the early 1990’s, a pilot channel was built next to the Colusa Weir to prevent the weir from being cutoff due to the river channel migrating westward.

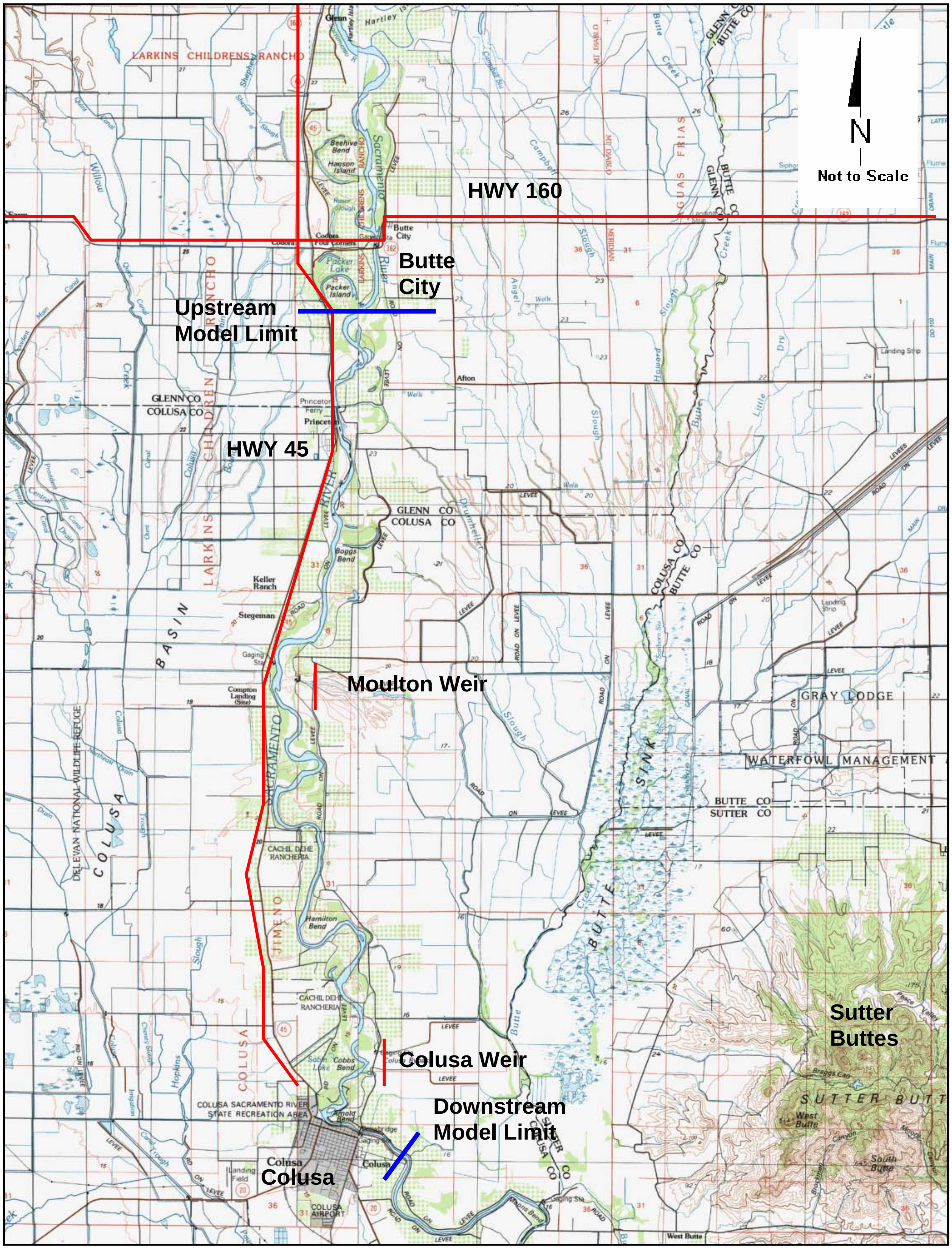


Figure 1. Project Location

Figure 2. Planned Restoration Sites at the Upstream End of the Model

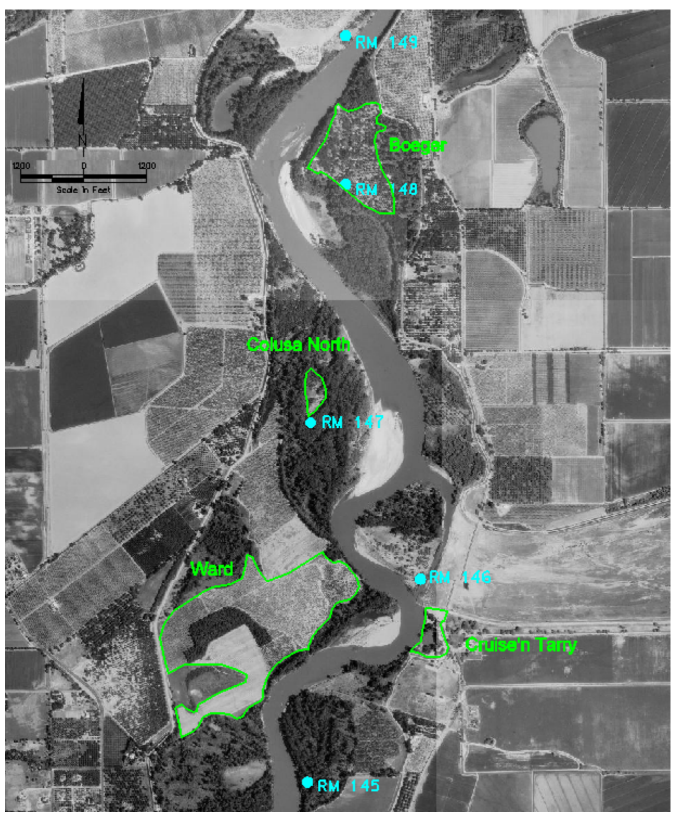


Figure 3. Planned Restoration Sites at the Downstream End of the Model

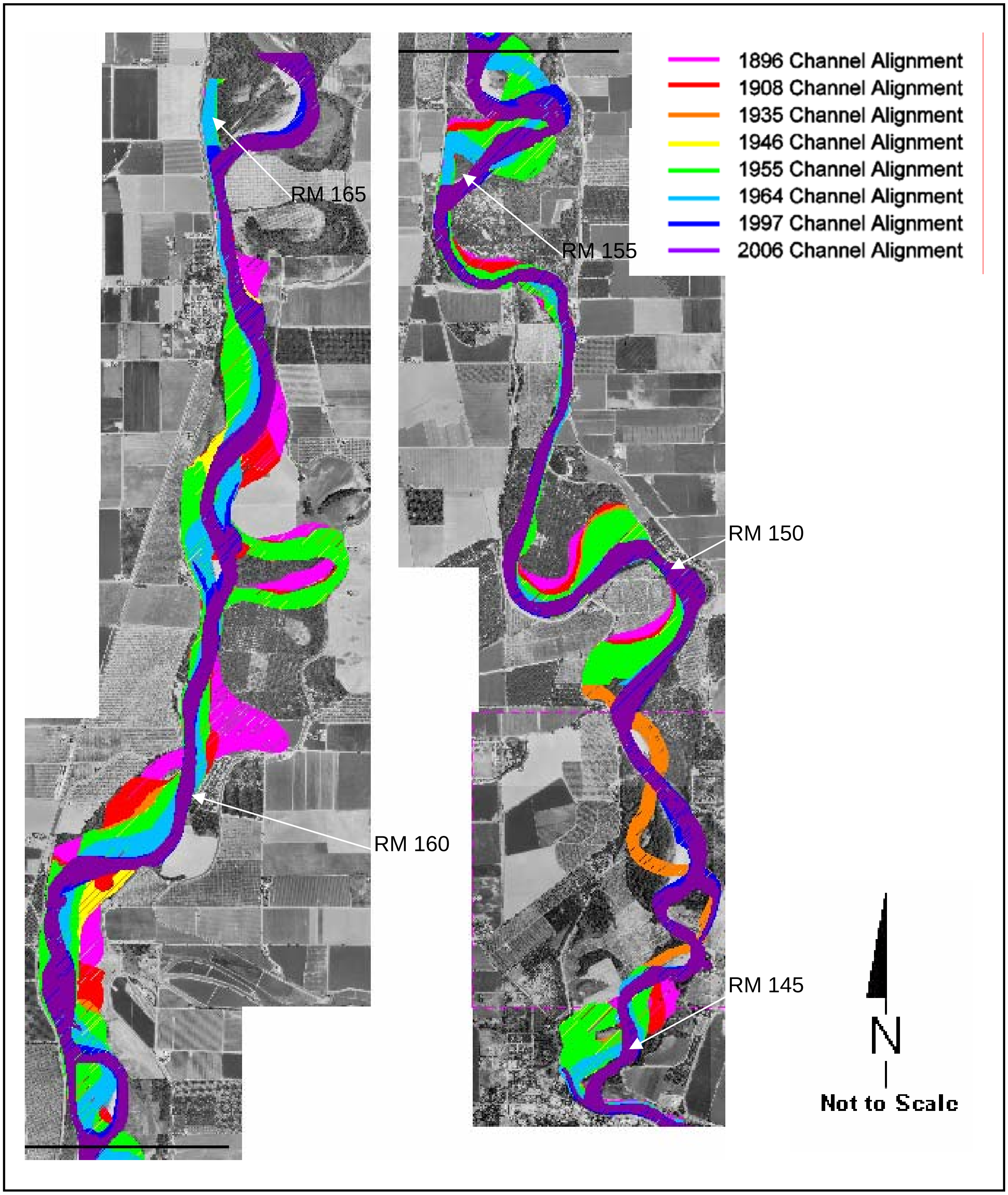


Figure 4. Channel Alignments and Migration Paths

1.3 Purpose and Scope

The purpose of this project is to determine the hydraulic impacts of proposed riparian restorations on the floodplain, the river channel, and levees. To determine these hydraulic impacts, the scope outlines the following tasks:

- Compare channel thalweg profiles from the 1930's, 1957, and 1997.
- Develop an inventory of in-channel, large woody debris.
- Develop and calibrate a base 2D hydraulic model.
- Update model terrain with 2006 LIDAR topography.
- Run an existing conditions hydraulic model using the design flow.
- Re-run the hydraulic model to simulate the effects of large woody debris
- Re-run hydraulic models for the restoration conditions.
- Evaluate the effects of the restoration planting on seepage through the levee.
- Evaluate the hydraulic impacts on the properties adjoining the restoration sites.

1.4 Acknowledgements

This project was scoped by The Nature Conservancy (TNC) and the project manager is Mr. Gregg Werner. The project manager for Ayres Associates is Mr. Thomas W. Smith, PE, GE.

The 1997 river topography was provided by the US Army Corps of Engineers (USACE) and the 2006 LIDAR topography was provided by TNC. Aerial images from 1998 were obtained from Terraserver and images from 2005 were obtained from the Natural Resource Conservation Service.

2.0 CHANNEL THALWEG COMPARISON

The Advisory Workgroup noted that a concern often mentioned by the landowner is that the channel had been aggraded or "silted in" within the Colusa Subreach so that flood-carrying capacity was diminished. To help address this concern, a comparison of available thalweg data was conducted. The thalweg is defined as the deepest part of the river channel bottom. The purpose of the comparison was to determine if the available information would document a general trend in the depth of the channel over time.

Channel thalweg data was collected and recorded in topographic surveys in 1937, 1957, and 1997. The 1937 data came from a survey completed by the USACE, which consisted of measuring a water surface elevation and taking water depths at selected cross sections. The cross sections were taken about every 1/10 of a mile. The 1957 thalweg data came for the USACE design profiles that include the river invert, the method of measurement is not known. The 1997 data was obtained from a detailed bathymetric survey (2-ft contour interval) completed for the USACE and is believed to be the most detailed topography of the 3 surveys.

The channel thalweg profile is shown in **Figure 5**. Upon first glance it appears that the profile shows great variability in the riverbed. Ultimately this profile is inconclusive. Many factors can influence the river thalweg and these factors are not taken into account with a simple profile. The variance in channel width can affect the capacity. Some of the variation in the channel bed could be due to the rock placement on the banks and levees. The different methods of surveying can also be a factor. It is possible that the more detailed survey of 1997 picked up more of the high and low points in the channel that was missed in the previous surveys. Given the channel migration and variance in width and split flows, as seen in Figure 2, this comparison does not contain adequate detail to correctly interpret the results.

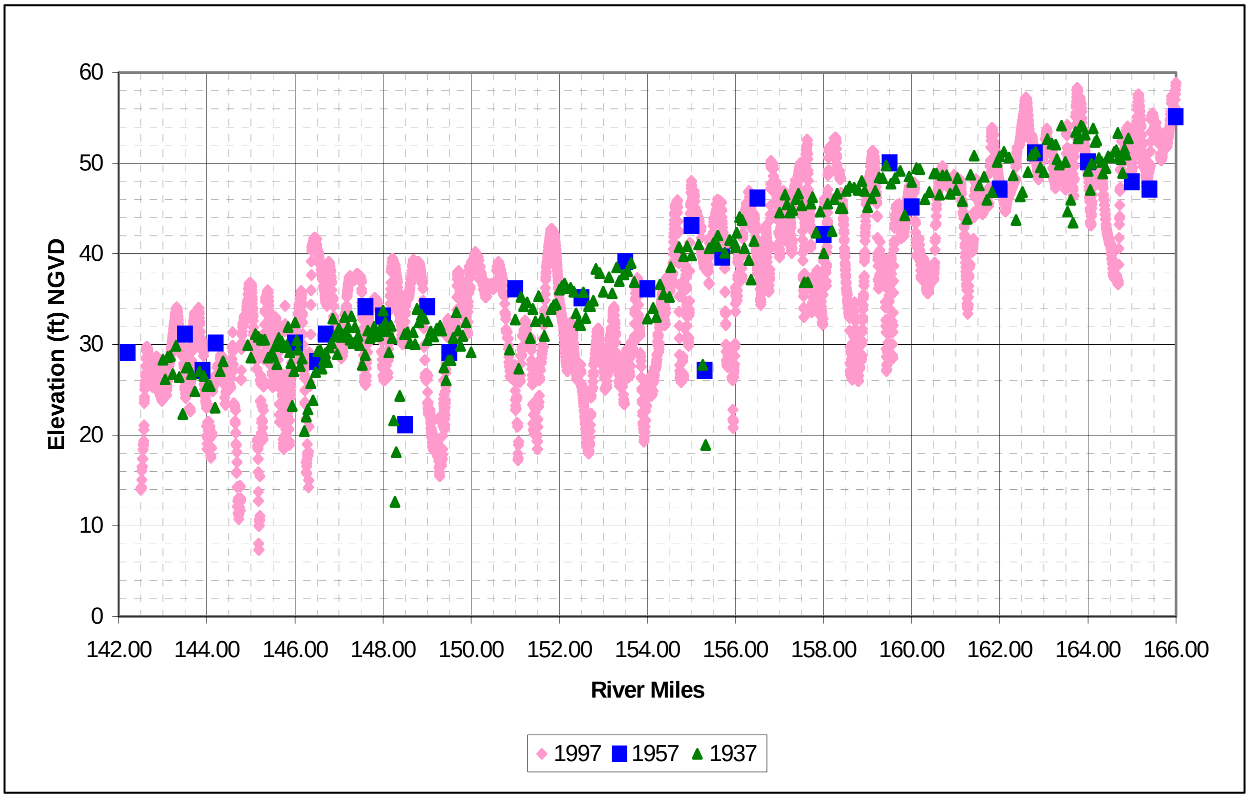


Figure 5. Sacramento River Thalweg, RM 142.5 to 166

3.0 LARGE WOODY DEBRIS INVENTORY

The Advisory Workgroup identified an additional landowner concern that the presence of large woody debris in the channel results in a loss of channel capacity by restricting flow and by increasing the buildup of sediment. To help address this concern, a detailed inventory of large woody debris was conducted for the Colusa Subreach. This inventory was later incorporated into one of the hydraulic model runs to specifically evaluate the effects of this debris on the water surface elevation of this reach of channel. It was reported that in the past, large woody debris was removed from the channel to facilitate commercial navigation but this removal has been discontinued for many years. Reasons for this discontinuance are thought to include lack of commercial navigation, negative impact on fish habitat and lack of funding.

On July 13, 2006, Ayres personnel performed this inventory of in-channel, large woody debris (by boat) through the entire study reach. The flow at the time in the Sacramento River was roughly 10,500 cfs, according to the Butte City gage (BTC). The observed trees were those visible above or just below the water surface on that day. Debris may have moved downstream since then so these numbers can only be assured for that given day. A table showing the inventory of trees, including estimated river mile, waypoint(s), the respective bank location, number of trees at the specific location, and any pertinent notes, is included in **Appendix A**.

Some stretches of the river were fairly barren of tree debris, while others were heavily laden with debris. The approximate location of each observed tree (marked by a red x) and the waypoints are shown on aerial maps, also located in Appendix A. The area of thickest debris density is between RM 156.5 and RM 157.5, this particular stretch of the river is often referred to as "debris alley."

The long duration high flows of early 2006 may have affected debris in two ways. It may have recruited more woody debris through bank erosion and channel migration, or it may have relocated much of the existing debris into lower river reaches.

4.0 HYDRAULIC MODEL RUNS

4.1 Calibration Run

The calibration run consists of performing a simulation of the hydraulic model with known variables to ensure the accuracy of our subsequent model runs. For this project, the model was calibrated to a flood that occurred on January 2, 1995. This was a significant flood flow that has good data available, including surveyed high water marks, gage data, and aerial imagery. The topography used for this run was from the 1997 Sacramento River survey. Aerial imagery from 1998 was used to help identify land uses during the time. Gage data from the Butte City gage, upstream of the site, and the Colusa Bridge gage, near the downstream end of the model, were used for flow data. Stage data from the Department of Water Resources (DWR) and the corresponding rating curve along with historic flow split data were used to determine the flow into the weirs.

4.2 Existing Conditions Run

The existing run simulates present (2006) conditions of the river using the USACE design flow. This run is used as a base for comparison to proposed restoration conditions. The topographic data used in this run was the 1997 survey and was updated with LIDAR topographic data (provided by TNC) for overbanks and any changes to channel alignment. Aerial imagery from 2005 (available from the Natural Resources Conservation Service) was used to establish existing land uses.

4.3 Large Woody Debris Run

The large woody debris run utilizes the existing conditions run as a base model and then incorporates simulated increases in roughness for specific areas of documented large woody debris. Based on the inventory developed in the field, the roughness of specific elements, within the model grid, were increased to account for the documented large woody debris of 2006. The roughness increases were based on the guidance in USGS Water Supply Paper 2339. Adjustments ranged from minor (where the sphere of the influence around one obstruction does not extend to another – increases of 0.005 to 0.015) to appreciable (where the space between obstructions is enough to cause the effect to be additive – increases of 0.02 to 0.03). This run should be looked at as only a "snapshot" in time because debris is somewhat transient in this system. The true purpose of this run was to show how much of an increase large woody debris can make on water surface elevation.

4.4 Restoration Conditions Run

The restoration condition simulates the same flow conditions as the existing conditions model, except the land uses on certain properties were changed to reflect the proposed 8 restoration sites. The sites are referred to as: Womble, Jensen, Stegman, 1000 Acre, Boeger, Colusa North, Cruise'n Tarry, and Ward. The locations of the sites were shown in figures 2 and 3 and the land use plots are shown in **Appendix B** for existing conditions and **Appendix D** for restoration conditions.

The Womble property is situated on the east floodplain near RM 162, in a back-water area. It is approximately 56 acres with a planned conversion from field crops to a scrub and riparian forest.

The Jensen site is just upstream from RM 161 in the east overbank. The property is about 82 acres and the existing land use is orchard. The proposed conversion is to a mix of riparian forest and grassland/shrub mixture.

Stegman is a small restoration site of approximately 7 acres, located adjacent to the river in the west overbank, at RM 160. The current land use is a mixture of scrub and orchard. The restoration is for scrub and riparian forest.

1000 Acres is located just west of Stegman, at RM 160. The 51 acre property is currently orchard, with a planned restoration to riparian forest.

The Boeger property is located in the east floodplain at RM 148. It is about 45 acres and currently field crops. It is proposed to be restored to a combination of riparian forest and scrub.

Colusa North is currently a little orchard (roughly 5 acres) surrounded by riparian habitat. It is in the west overbank at RM 147 with a planned restoration to mixture of savannah, scrub, and riparian forest.

The Cruise'n Tarry property is unique; the upper portion of it is high ground and remains dry for most storm events, while the lower portion remains a reverse current area. It is approximately 8 acres and the planned conversion is from old oxbow/bare earth/some riparian to full riparian.

The Ward property is 142 acres and is located in the west overbank from RM 146 to 145. The current land use is field crops and the proposed restoration is to riparian forest with some savannah and a meadow flow through path. Although the Ward property is being restored by the Department of Water Recourses (DWR), we have included it for cumulative effects and as a courtesy to DWR.

5.0 HYDRAULIC MODELING

5.1 General

The 2-dimensional (2D) hydraulic modeling tool used for this project was the RMA-2V program, version 4.35, maintained and distributed by the USACE and modified by Ayres Associates. The program has been used extensively for similar projects on the Sacramento River and has proven to be an effective model for representing river flow conditions. The Surface-Water Modeling System (SMS) version 9.0 software was used to develop the model geometry file and to view model results.

5.2 Model Development

The geometric definition of the project reach is given in the form of a finite element network of triangular and quadrilateral elements, known as a mesh, a section of the mesh is shown in **Figure 6**. The elements were sized and oriented to represent hydraulic features, breaklines, structures, and topographic changes. Each element contains corner and mid-side nodes, which represent points in space (X, Y, Z) and define the topography of the project reach.

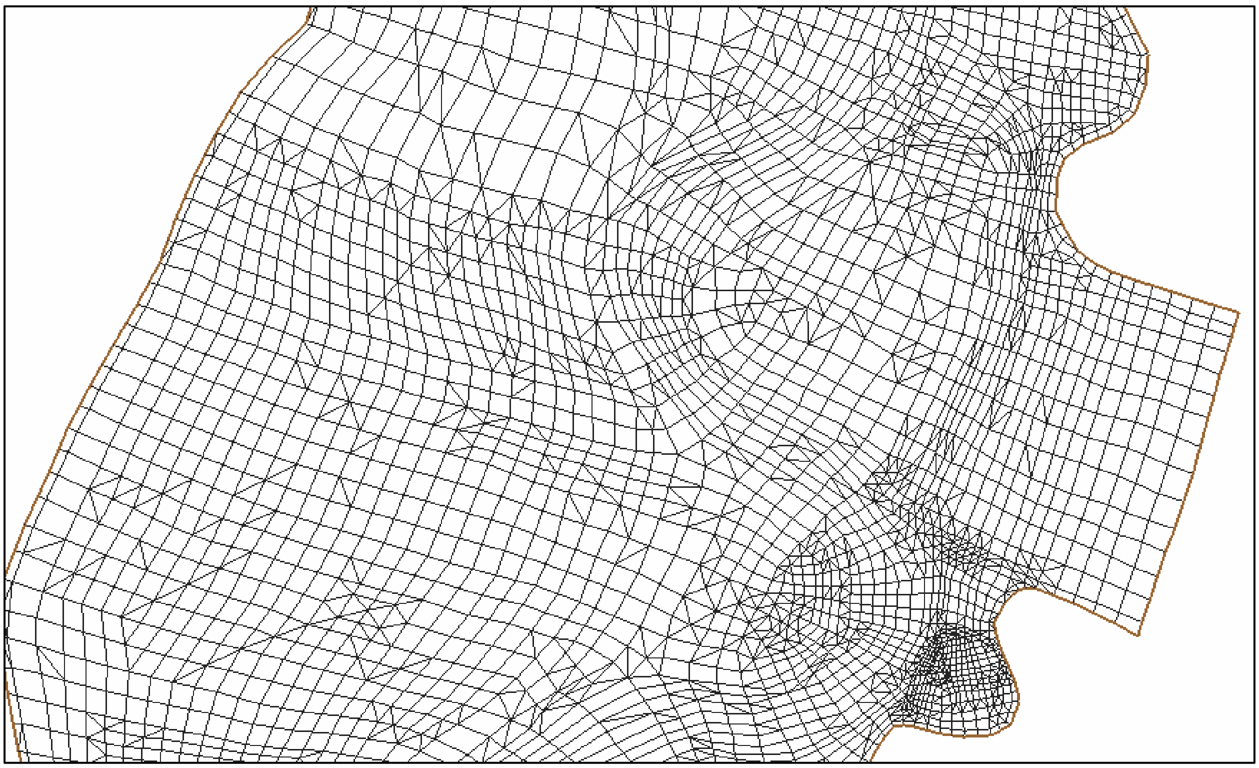


Figure 6. Finite Element Mesh

The topography used to develop the mesh came from a combination of two mapping projects. The initial mesh was developed using the 1997 bathymetric survey completed by Ayres Associates for the USACE. The mesh and channel alignment were updated with the 2006 LIDAR topography provided by TNC. The model mesh coordinates are in NGVD-29, NAD-83, US feet.

5.3 Material Roughness

In the river reach, material types within each element were categorized based on land use and roughness characteristics (dense vegetation, grassland, sandbars, etc.). The material types were assigned to each of the elements in the finite element mesh using aerial photography from the 1998 (USGS) for the calibration model and 2005 aerial imagery developed by the Natural

Resource Conservation Service. A summary of the roughness parameters used for this project is provided below in **Table 2**. The land uses for the existing conditions, debris run, and with-project conditions are shown in **Appendix B, C** and **D**, respectively. These values match closely to a previous hydraulic model performed by Ayres Associates in the early 1990's, adjacent to the Colusa Weir.

Table 2. Material Roughness

Material	Roughness value
Levee	0.03
Scrub	0.04
Orchard	0.075
Sparse Trees	0.06
Light Riparian/Riparian Scrub	0.07
Riparian Forest	0.09
Bare Earth	0.03
Smooth Concrete	0.014
Cobble	0.04
Rock Riprap	0.045
Structure	0.20
Channel	0.028
Grass	0.032
Sandbar	0.02
Oxbow	0.035
Field Crops	0.035
Savannah	0.045
Channel with Minor Debris Effects	0.032 – 0.43
Channel with Appreciable Debris Effects	0.048 – 0.058

5.4 Flow Splits

This reach of the Sacramento River contains two overflow weirs (Moulton and Colusa), which significantly reduce the flow down the main channel by diverting portions of the flow into the Butte Basin. These overflow weirs, shown in Figure 1, start to spill when the flow in the Sacramento River water surface elevation reaches 58.91ft (NGVD) at the Colusa Weir, and 73.95ft (NGVD) at the Moulton Weir.

Our initial model run used the 1957 design capacities for the main river and the weirs. However, after many trials we found that the model would not solve with these flow splits. Upon a further review the historic data for the Sacramento River, Moulton Weir, and the Colusa Weir, some inconsistencies in the flow splits were discovered. The 1957 design capacities of the weirs (25,000 cfs for Moulton and 70,000 cfs for Colusa) are not compatible with recorded historic events (34,000 cfs over Moulton -1970 and 75,300 cfs over Colusa - 1958). The weirs appear to accommodate more overflow than the stated 1957 design flow capacities. Therefore, the historic flow split data was deemed more accurate than the 1957 design flows. Also, we found that the weir rating tables, developed by the Department of Water Resources (DWR), matched very closely to historic stage/flow data and have shown these comparisons in **Figures 7 and 8**.

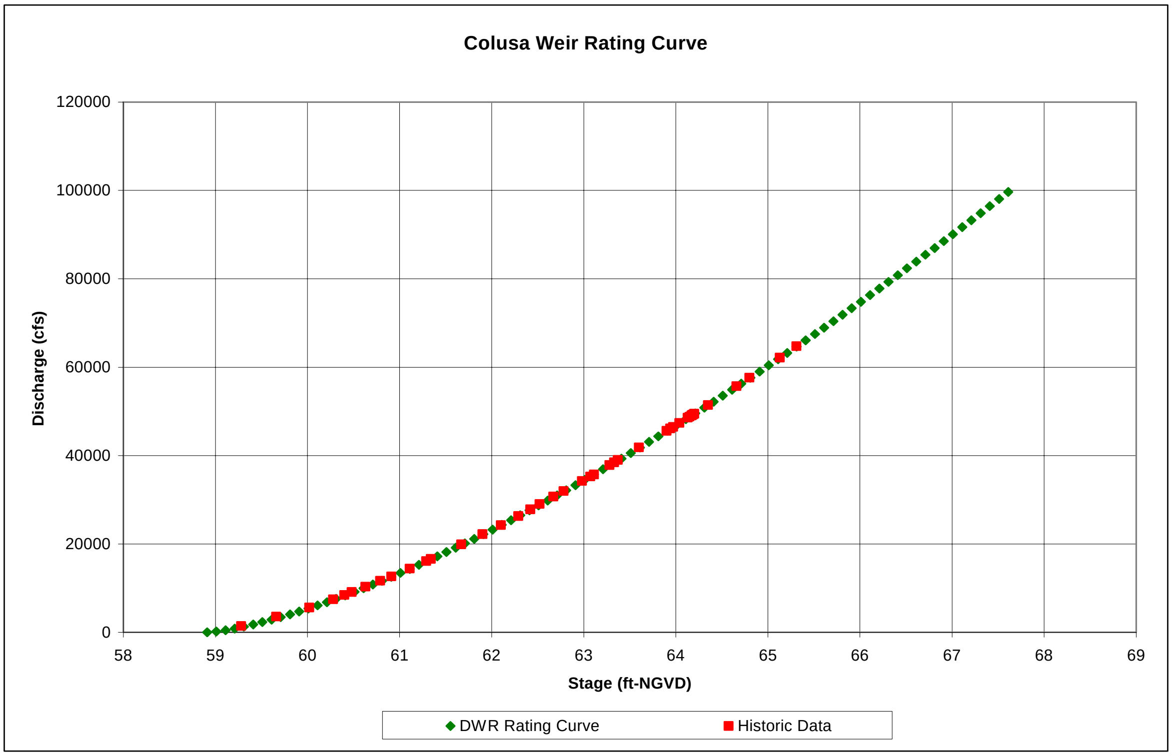


Figure 7. Rating Curve at Colusa Weir

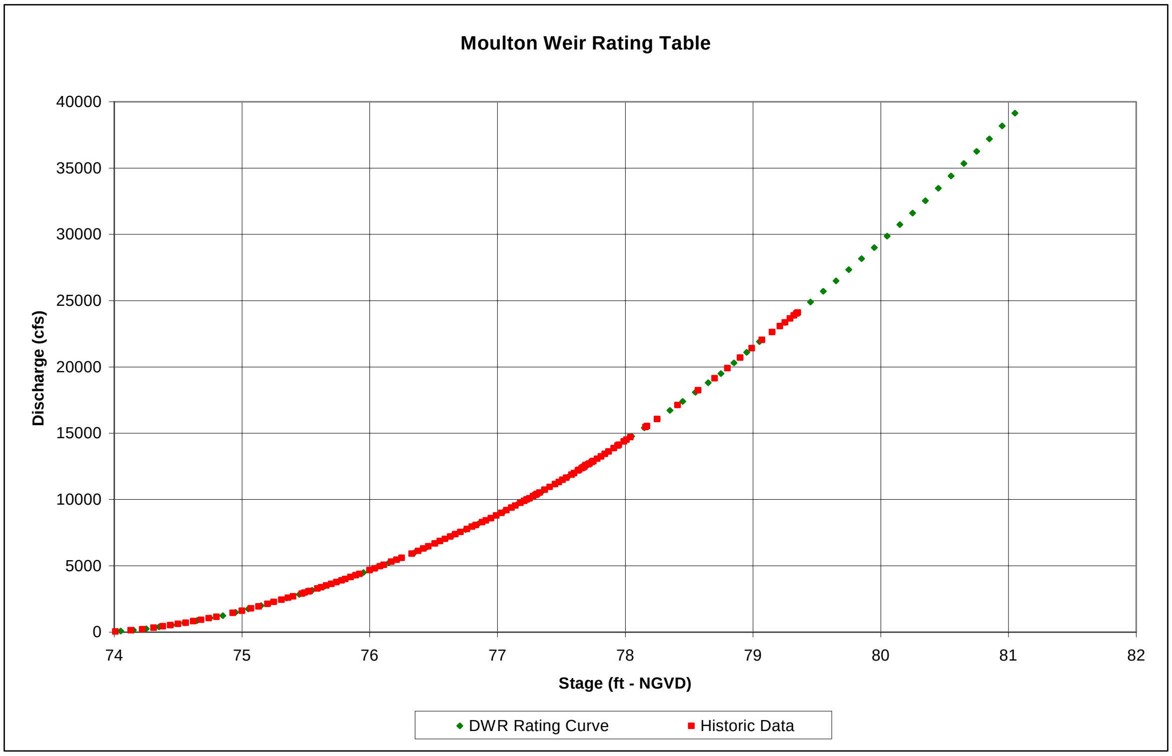


Figure 8. Rating Curve at Moulton Weir

Further, based on the historic data and other available sources, the design capacity in the river, adjacent to the City of Colusa, does not seem correct. The recorded flow at the Colusa bridge gage has never reached the design capacity of 65,000 cfs. The greatest flow of record past the City of Colusa was 51,800 cfs in 1983. In 1958 (one year after the design flows were developed) a flood of 160,000 cfs (design event) passed by Butte City. From this flow only 45,800 cfs passed the City of Colusa. In addition, the DWR rating curve for the Colusa Bridge only extends to 53,000 cfs. A summary of the design and large historic flood events is shown in **Table 3**.

Table 3. Design Flow and Historic Flood Events on the Sacramento River.

Location	USACE Design Flow	1942 Historic Event	1958 Historic Event	1983 Historic Event
Butte City Gage	160,000	170,000	158,000	157,000
Moulton Weir Gage	25,000	N/A	34,700	N/A
Colusa Weir Gage	70,000	N/A	71,200	N/A
Colusa Bridge Gage	65,000	49,000	44,800	51,800

To further document the problems with the design flow capacity numbers, we have provided some graphics. By extending the official Colusa Bridge rating curve (**Figure 9**), the water surface elevation for 65,000 cfs (design flow) would be 71 ft (NGVD). Spot elevations on the east bank are at 71.1, 71.5, and 71.9. There would not be adequate freeboard for a flow of 65,000 cfs. A cross section just upstream of the Colusa Bridge is shown in **Figure 10** with the estimated water surface elevation for 65,000 cfs.

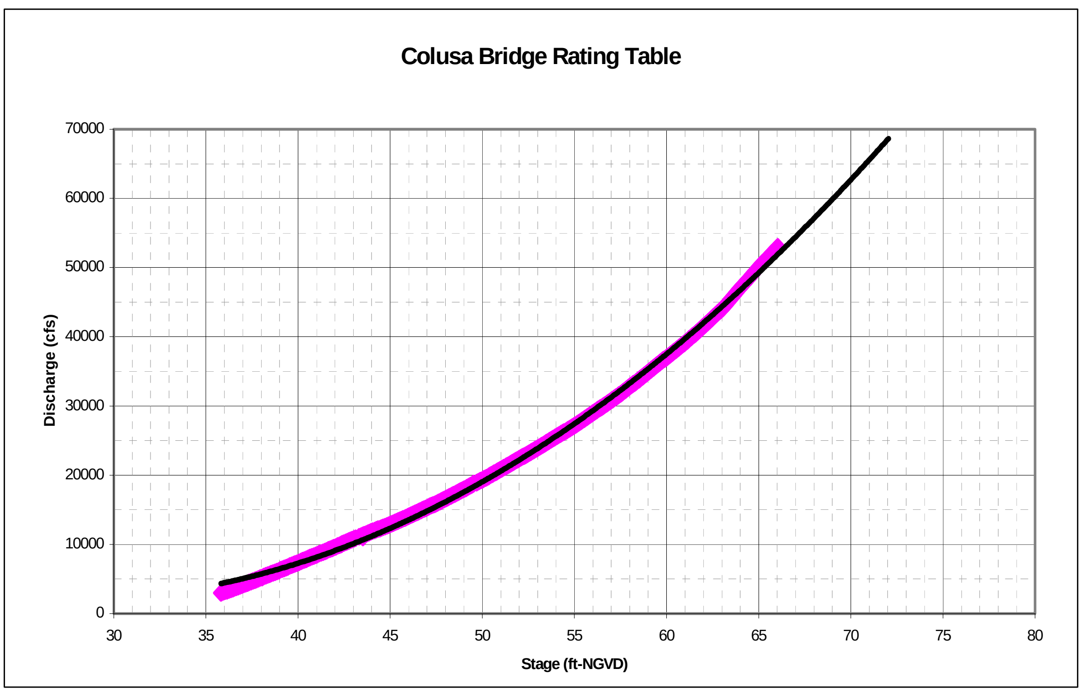


Figure 9. DWR Rating Curve at Colusa Bridge

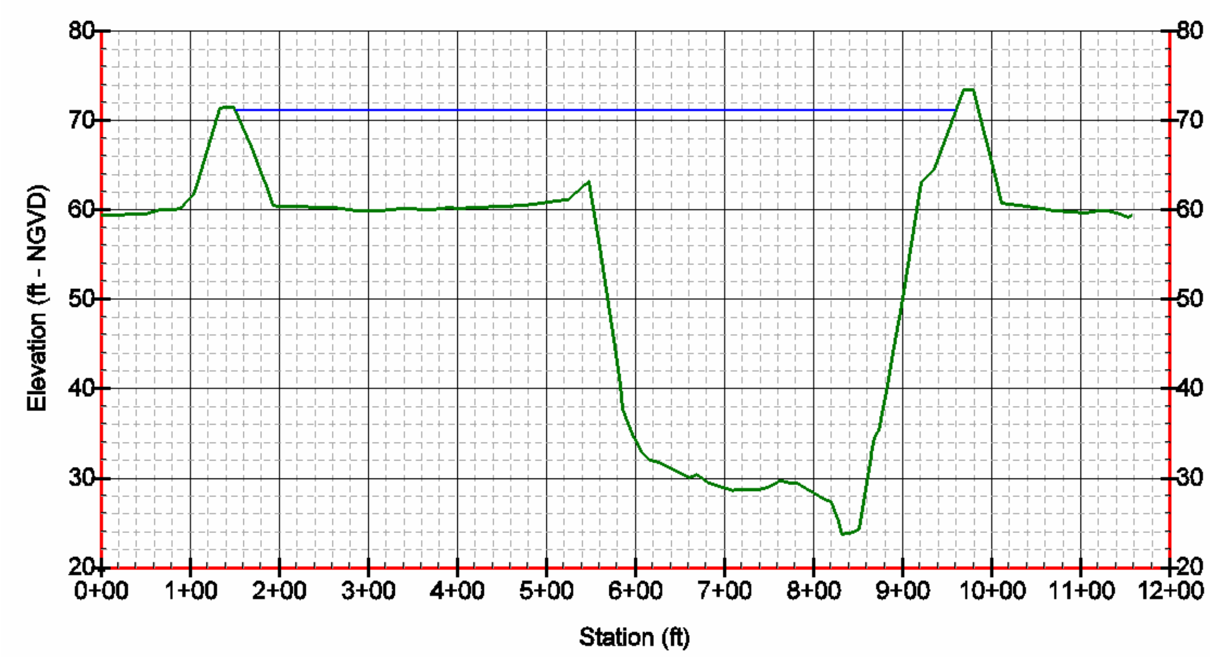


Figure 10. Cross Section of the Sacramento River, just Upstream of Colusa Bridge with Water Surface Elevation Corresponding to a Flow of 65,000 cfs

5.5 Boundary Conditions

The boundary conditions used in the calibration model came from the historic flood event of January 2, 1995. The boundary conditions for the existing conditions model were based on the 1958 historic flow data and slightly increased proportionally to match the upstream flow of 160,000 cfs. The 1958 flow was chosen since it came the closest to the official 1957 USACE design flow (158,000 cfs vs. 160,000 cfs). The boundary conditions for the hydraulic models are summarized in **Table 4**.

Table 4. Boundary Conditions

Boundary	Calibration Model	Existing Conditions/ Developed Models
Upstream Limit (RM 164.5)	143,000 cfs	160,000 cfs
Moulton Weir	24,900 cfs	35,700 cfs
Colusa Weir	69,200 cfs	72,500/73,500 cfs
Downstream Limit (RM 142.5)	48,900 cfs 64 ft (NGVD)	51,800/50,800 cfs 65 ft (NGVD)

5.6 Calibration

Calibration is performed to establish the accuracy of a model, typically by simulating a historic flow with well-established high water marks. This model was calibrated to the January 10, 1995 high flow. Gage data was recorded by USGS at the Colusa gage and Butte City gage. Stage elevations at the Moulton and Colusa weirs were recorded by the DWR's Sutter Maintenance

Yard and rating curves were used to determine the flow. High water marks on the east and west levees were recorded shortly after the flood flow by the DWR's Northern District. Land uses were derived from the 1998 aerial images and altered where known land use changes had occurred after1995.

In our initial run, our model over estimated water surfaces throughout the system. The initial roughness values were overestimated were adjusted accordingly. Further analysis showed specific areas where the water surface was being overestimated. Some investigative work into the land use in these areas was conducted and many areas were found to have different land uses than the 1998 aerial image showed. However, between RM 154 to RM 152, we still had modeled water surfaces of about a foot over the surveyed high water marks. This stretch of the river is narrow and has shown no significant changes throughout the river's recorded history. It is possible that some channel dynamics occurred between 1995 and the survey of 1997 that we cannot account for. Since there are no planned restorations in this stretch of the river, we consider the results in this area to be conservative and adequate for modeling purposes.

A comparison of the surveyed high water marks and the calibrated model water surface is shown in **Table 5**. A profile comparison is shown in **Figure 11** for the East Bank and **Figure 12** for the West Bank.

Based on our professional judgment and experience with previous hydraulic models on the Sacramento River, the overall results show acceptable agreement between the model and the surveyed values. The modeled water surface elevations are all less than 1 foot off from the measured high water marks with only two exceptions. This discrepancy is most likely due to the fact that the river configuration had changed somewhat either during or after the flood event, causing difficulty in recreating the same local topographic and hydraulic conditions. In the locations where the calibration is close to a foot off, there is no restoration planned.

Table 5. Comparison to High Water Marks

River Mile	1995 Surveyed High Water Mark (ft)	Model Elevation (ft)	Difference
East Bank			
165.5	89.4	89.6	0.2
164.7	88.6	89.34	0.74
164.5	87.7	88.62	0.92
164	87.6	88.12	0.52
163.6	86.2	86.48	0.28
162.7	85.3	85.87	0.57
162.5	85	85.39	0.39
162.3	84.8	85.38	0.58
160.5	83.1	83.88	0.78
160.3	83.3	83.86	0.56
160	83.2	82.93	-0.27
159.6	82.6	82.83	0.23
158.3	79.6	79.88	0.28
157.4	79.5	79.14	-0.36
156.1	78.4	77.6	-0.8
150.5	70.9	71.95	1.05
149.5	70	70.17	0.17

River Mile	1995 Surveyed High Water Mark (ft)	Model Elevation (ft)	Difference
East Bank			
147.7	66.8	67.24	0.44
146.8	66	66.76	0.76
145.3	65.8	65.76	-0.04
144.5	64.7	65.15	0.45
143.8	64.5	64.86	0.36
143.1	64.5	64.28	-0.22
West Bank			
164.9	89.4	89.35	-0.05
164.4	87.7	88.13	0.43
163.8	86.5	86.71	0.21
163.3	85.9	86.27	0.37
162.8	85.3	85.88	0.58
161.9	84.9	85.27	0.37
161.6	84.1	84.97	0.87
160.9	83.5	84.06	0.56
160.4	83.1	83.02	-0.08
160.3	82	82.79	0.79
160.2	82.1	82.51	0.41
159.4	81.8	82.25	0.45
158.2	79.9	80.39	0.49
156.9	79.1	79.54	0.44
156.6	79	79.43	0.43
155	77.6	78.29	0.69
154.6	77	78.06	1.06
154.1	76.4	77.58	1.18
153.5	75	76.13	1.13
152.4	74	74.71	0.71
152.1	73.8	73.78	-0.02
151.8	73.2	73.39	0.19
151.4	72.4	72.96	0.56
151	71.8	72.52	0.72
149.2	68.6	68.63	0.03
147.8	67.5	67.62	0.12
147.3	66.8	66.74	-0.06
146	66.1	65.98	-0.12

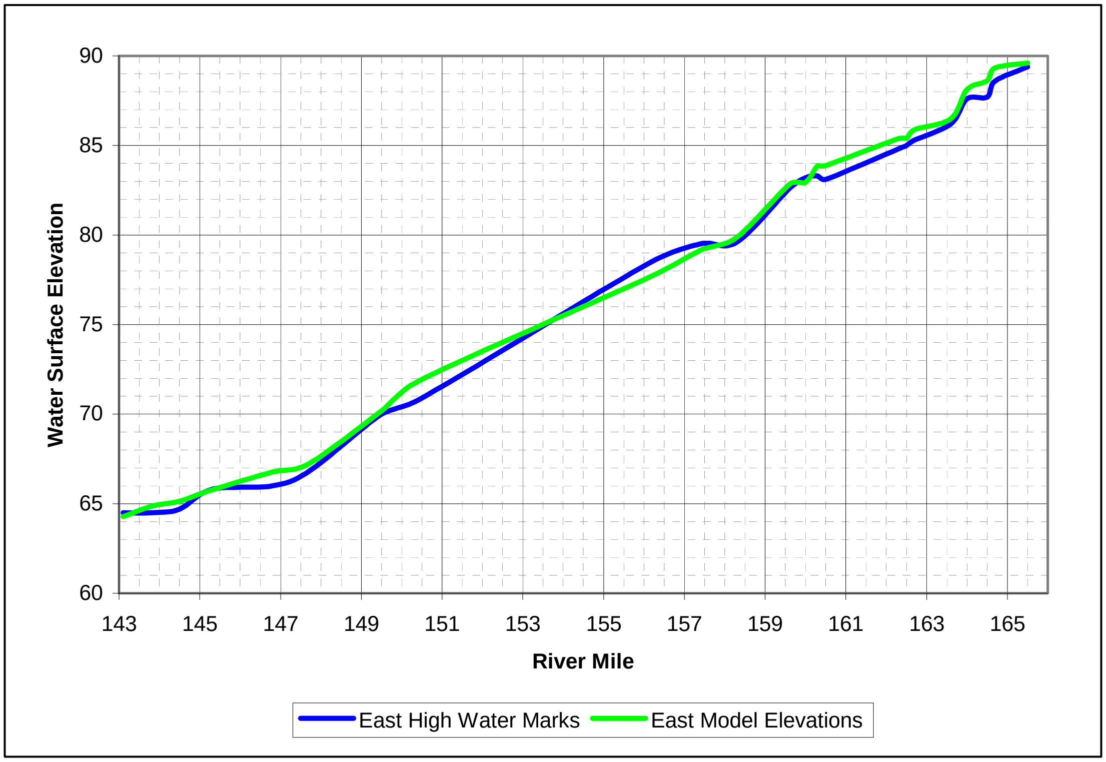


Figure 11. Profile Comparison of High Water Marks on the East Bank

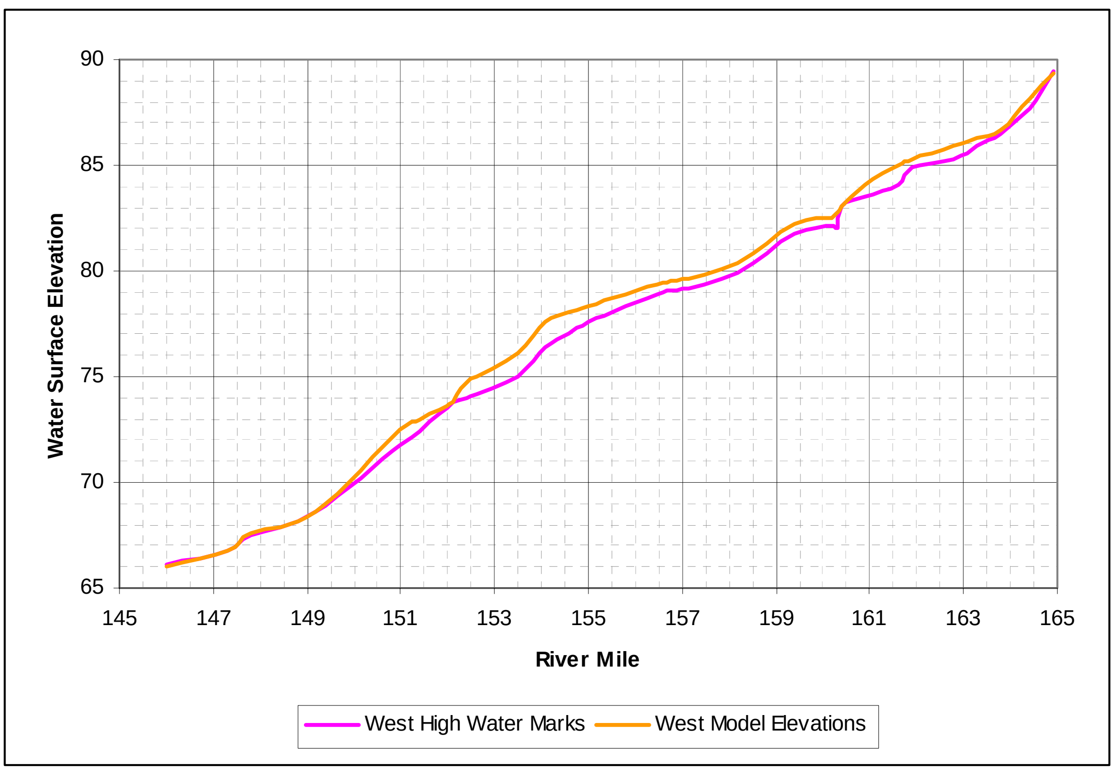


Figure 12. Profile Comparison of High Water Marks on the West Bank

6.0 Results

6.1 Velocity

6.1.1 Existing Conditions Model

The velocity contour plots are overlaid on the 1998 aerial image and are provided in **Appendix E**. The velocity in the channel typically ranges from 3 to 8 fps. Around the sharp bends it gets up to 11 fps. The velocity lowers some after both of the weirs since the weirs are diverting flow. With less flow and roughly the same channel area, the velocity decreases. The overbanks range from less than a foot per second in backwater areas to 3 fps. The velocity in the overbank is greatest in the section where the floodplains are narrowest.

The proposed restoration areas are outlined in white and labeled on the contour plots. The Womble restoration site shows less than 2 fps of velocity, and is essentially a backwater area. The Jensen restoration area shows between 1 and 3 fps and is in the active floodplain. The Stegman restoration has velocities less than 3 fps and is in the active floodplain. The 1000-Acre restoration is less than 2 fps and in a backwater section of the floodplain. The Boeger restoration area is in a narrower section of river and the velocities are between 2 and 3 fps. The Colusa North restoration has velocities below 1 fps and is in a relatively ineffective velocity area. The Cruise'n Tarry restoration area is a backwater section, with a large eddy. The velocities are less than 2 fps. The Ward restoration gets velocities up to 3 fps.

6.1.2 Large Woody Debris Model

The velocity contour plots for the large woody debris run are provided in **Appendix F** and the velocity differential between the debris run and existing conditions is provided in **Appendix G**. The overall velocity and distribution is essentially the same as the existing conditions with some changes within the areas of heavier debris fields. This run does demonstrate that debris fields do have some impact, but it's important to remember that debris is not a static feature of river and the debris fields will change size and locations over time.

None of the impacts shown in this run occur near any of the proposed restoration areas. However, there are two areas that show noticeable changes over the existing conditions model. The cutoff at RM 157, commonly referred to as "debris alley", causes a reduction in velocity of up to 1.0 fps. With a base velocity of 3 to 4 fps, this lowering could potentially create some additional deposition in this area, but that is unlikely in this case because of the increased turbulence created by the heavy debris field. The other area of obvious change is at RM 149 where there is an increase in velocity of up to 1.0 fps in the outer channel that extends partially into the main channel. This increase could cause some erosion on the sandbar island that has formed near the left bank of the channel and the left riverbank.

6.1.3 With-Project Conditions Model

The velocity contour plots for the with-project restoration conditions are provided in **Appendix H** and the velocity differential between the developed conditions and existing conditions is provided in **Appendix I**. The velocity patterns are similar to the existing conditions. The velocity in the channel ranges from 3 to 9 fps, with the velocity in the bends reaching up to 12 fps. The overbank velocities are typically under 4 fps.

On the Womble property, there are velocity decreases of 0.53 fps in the restoration area where the land use roughness increases, which results in up to 0.42 fps of increases adjacent to the property. One of theses increases is adjacent to the levee, where the increase pushes the velocity up to 2.0 fps, which is not high enough to cause erosion. At the Jensen property, the change in land use from orchard (existing) to forest and shrub/grassland (with-project) results in some increases and decreases. In the sections converted to riparian forest, the velocity decreases up to 0.5 fps. There are increases in the scrub/grassland areas and on the west side of the site next to the river. These increases are up to 1.0 fps. This increase puts the maximum velocity at below 3.0 fps, which is not enough to cause erosion on a vegetation bank.

At the 1000-Acre property, the majority of the with-project area has a reduction in velocity and there are no increases. The existing velocity in this area is under 1.0 fps, so any changes should not have any negative effects on the system. The Stegman restoration site has a velocity increase of up to 1.5 fps adjacent to the main channel. This increase brings the velocity on the channel bank to over 4 fps, therefore depending on the cover, erosion may occur.

The Boeger restoration site creates a velocity increase in the main channel of up to 0.3 fps in an already high velocity area. Since the increase is limited to the center of the channel and does not extent to the banks, it should not have any negative impact on the river system. The Colusa North property has a velocity increase of less than 0.22 fps in spots within the restoration. The Cruise'n Tarry restoration site is located in a purely backwater area and the development of this area has no significant impact on the river system.

The Ward property causes decreases upstream, downstream, and within the restoration site from the conversion of open space to riparian habitat. The result of these decreases is increases along the west levee and in the main channel. Along the west levee, the velocity increases by up to 0.78 fps. This increase however does not bring the velocity against the levee past the 1.0 fps mark; therefore it should not have any negative impacts on that levee. Within the main channel, the velocity increases by a maximum of just over 1.0 fps, bringing the main channel velocity to between 3 and 6 fps. An increase adjacent to the east levee, at the southern tip of the Cruise'n Tarry property, brings the velocity up to 4.2 fps over the existing 4.0 fps. Given that the existing conditions velocity is already above the possible erosion threshold, this slight increase should not change the erodibility factor.

6.2 Water Surface Elevation

The water surface elevations for the 1957 design profile, existing conditions land use, and with project land use are shown with cross sections through each restoration site. The cross section locations are shown in **Appendix J** and the cross sections are shown in **Appendix K**. For comparison purposes, we have also included the water surface differential plots between the existing condition run and the 1957 design profile in **Appendix L**. The water surface elevation differential between the existing conditions and the large woody debris run are shown in **Appendix M**. The water surface elevation differential between the existing conditions and the with-project run are shown in **Appendix N**.

6.2.1 Existing Conditions

The plots in Appendix L show the differential water surface between the existing conditions model run and the 1957 design water surface. Of particular interest is that in some reaches (approximately 1/3 of the modeled reach) the existing conditions water surface elevation is higher than the 1957 design profile and particularly in the downstream reaches the existing conditions water surface is lower than the 1957 design profile. We don't have an explanation for this, but obvious reasons include changes in land use within the levees and a greater capacity than the design for both weirs.

The cross section plots in Appendix K show that the existing conditions water surface elevation is lower than the design elevation at the Womble restoration, the Stegman restoration, most of the 1000 Acre restoration, the Boeger restoration, Colusa North restoration, Cruise'n Tarry restoration, and Ward restoration properties. The Jensen restoration site and the southern portion of the 1000-Acre restoration show greater water surface elevation (less than 0.15 ft) in parts and about the same elevation as the design in other parts.

6.2.2 Large Woody Debris Run

This run was completed as a demonstration of the effects on water surface based on mapped debris fields. This run takes the base model and superimposes the debris fields observed and mapping by Ayres in the summer of 2006. Technically, the base model, calibrated to the 1995 high flow event, already includes some effects of debris at that time, but we lack any data from that period so were unable to compare how much different the 1995 debris fields were from those in 2006. However, for demonstration purposes, the roughness associated with the debris fields in 2006 was added to the base model and the model rerun to show how much of an increase in water surface could be associated with just the large woody debris as mapped in 2006.

Figure 13 shows a cross section at RM 157 showing debris within the channel. This was done to show how much of the total flood flow path is impacted by debris. The trees shown are of a 3 ft and 1.5 ft diameter.

The results from this run (Appendix M) show negligible effects throughout most of the entire reach with the exception of Stegman and 1000 Acre parcels, where the water surface is roughly 0.10 ft higher due to the heavy debris load in the area between RM 157 and 158. The results can also be interpreted to mean that if all of this debris were to be removed, the water surface would be reduced by that same amount in these same areas.

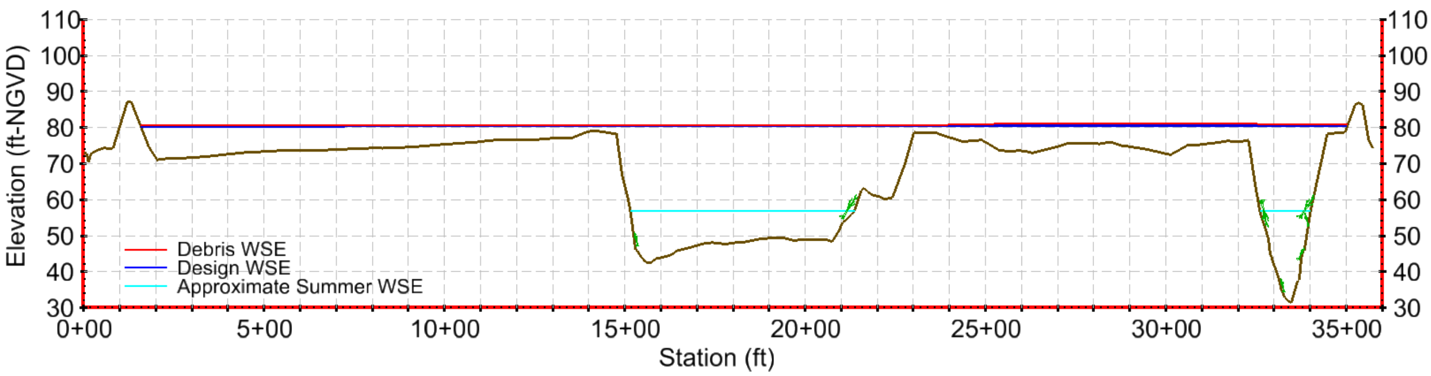


Figure 13. Cross Section at RM 157 Showing Locations of Woody Debris

6.2.3 With-Project Conditions

The with-project conditions water surface elevation is lower than the 1957 design water surface from RM 143 to 154 and from RM 161 to 164. In the remaining areas, the water surface elevation is higher than the 1957 design but at or lower than existing .

At the Womble property, the water surface is more than 0.74 ft below the design elevation and 0.05 ft below the existing conditions at the upstream edge (Figure K-1 in the Appendix) and 0.56 ft below design and 0.11 ft below existing conditions at the downstream edge (Figure K-2 in the Appendix).

On the Jensen property, the with-project condition is slightly less than the existing condition, but greater than the 1957 design by a maximum of 0.36 ft on the upstream edge (Figures K-3 in the Appendix), and on the downstream end it is above the existing and the design conditions elevation by no more than 0.15 ft (Figure K-4), however this increase is confined to the center of the floodplain and does not extend to the levee, so there is no impact on freeboard (Figure N-2 in the Appendix).

On the Stegman property, the with-project water surface is below the 1957 design and 0.1 ft above the existing conditions (Figure K-5 in the Appendix). The upstream end of 1000-Acre is below the 1957 design, however the downstream end is 0.16 ft above it. When compared to the existing conditions, there is a maximum increase of 0.02 ft on the northern portion of the site, which is considered negligible. There is no increase over existing conditions on the southern portion of the 1000 Acre restoration site.

For the Boeger property, the water surface is below the 1957 design and maximum of 0.25 ft above the existing conditions.

On the Colusa North property, the with-project water surface elevation is below the 1957 design and roughly 0.05 ft higher than the existing conditions water surface elevation.

At Cruise'n Tarry the water surface elevation is below the 1957 design and roughly the same as the existing conditions.

For the restoration site on the Ward property, the with-project water surface elevation is below the 1957 design. When compared to the existing conditions water surface elevation, the with-project elevation ranges from the same elevation to 0.1 ft higher.

6.3 Effects of Restorations on Seepage through and under the Levees

Possible effects on seepage though or under the levees is directly related to **1)** increases in water surface which would produce a higher driving force for seepage and **2)** to longer durations of flood events as a result of the restorations. A review of the differential water surface plot information shows that the water surfaces at the proposed restoration sites are all either roughly at or below either existing conditions and below the 1957 design profile.

As for any increase in flood duration, there are no features that will be incorporated that will change the volume of floodplain storage and therefore no change will occur in the runoff hydrograph for this reach of river as a result of the proposed project. For the project to impact flood duration, it would have to include features that store water and released it at a later time during the runoff hydrograph. Since the water surfaces remain virtually unchanged, the volume of existing storage within the river and floodplain remain unchanged for this proposed project.

The other possible cause of increased seepage potential could be in the seepage path was shortened by erosion of the levee surface. A review of changes in velocity as a result of the restorations did not show any areas where levee erosion would increase enough to cause a shortened seepage path.

6.4 Impacts to Properties Adjoining Restoration Sites

Impacts to adjoining properties were analyzed in terms of both higher water surfaces during overbank flow events and velocity. In general the differences in water surface for the model runs performed were very small over the existing conditions model and any associated impact is negligible.

Changes in velocity could be of more significance in that it could affect the patterns of overbank erosion or deposition. The area adjacent to each proposed restoration was reviewed and summarized as follows.

Womble; near RM 162: The water surface plot in Appendix K (K-1 and K-2) shows the with-project condition to be a slightly lower water which will have no impact on adjacent properties. In regards to changes in velocity, the first plot in Appendix I (I-1) shows that most of the change is contained within the Womble property itself and in general is a reduction of 0.1 fps to 0. 5 fps. On the property directly to the west of Womble, there is a small area of velocity increase of maximum 0.43 fps, which brings the with-project velocity up into the range of 1.5 to 2.0 fps. Since 2.0 fps is still below the range where erosion would occur for bare soil, we see no impacts related to new soil erosion. If deposition were occurring now, it would be slightly reduced.

Jensen; near RM 161: The water surface plot in Appendix K (K-3 and K-4) shows the with-project condition for the Jensen plot to be the same as the existing condition which will have no impact on adjacent properties. The velocity plot included in Appendix I (I-2), shows increased velocities for shrub/grass corridors and just west of the site, up to 1.0 fps for a resultant velocity of 4 fps. Increases of a smaller magnitude on the downstream property are in the 0.10 to 0.30 fps range. Since the velocities with-project are still less than 2 fps, no induced erosion on these properties is expected. Correspondingly lower velocities are shown in the restoration site and on the property to the east of Jensen. No impacts are expected on the property to the east of Jensen.

Stegman; near RM 160: The water surface plot in Appendix K (K-5) shows the with-project condition to be very close to the existing condition which will have no impact on adjacent properties. The velocity plot in Appendix I (I-2) shows considerable change at the site and a smaller increase immediately west of the site. The new velocity at this location is now up to 1.5 fps, however still below the potential to induce erosion on bare soil (2 fps). There is also an increase of up to 1.5 fps along the west riverbank. With project velocities at design flow are now in the range of 5 to 7 fps and this will increase the potential for bank erosion in the area downstream of the armored section (the armored section ends at the upstream end of the site).

1000-Acre; near RM 160: The water surface plot in Appendix K (K-5 and K-6) shows the with-project condition to be very close to the existing condition which will result no impact on adjacent properties. The velocity differential plot in Appendix I (I-2) for this site shows a slight decrease in velocity for the property immediately downstream of 1000-Acre, which should not have any impacts on the adjacent property.

Boeger; near RM 148: The water surface plot in Appendix K (K-7 and K-8) shows the with-project condition to be very close to the existing condition (and about 1.5 feet below the 1957 design water surface) which will have no impact on adjacent properties. The velocity differential plot in Appendix I (I-4) shows lower velocities on and immediately adjacent to the Boeger site with some small pockets of increased velocity that are considered to be less than significant. Velocities increase within the river proper by about 0.2 fps. Base velocities are already high in this area (6 to 9 fps) and sediment transport capacity in the river may increase. The opposite riverbank is currently armored and this armor should adequate handle the 0.20 fps increase in bank velocity.

Colusa North; near RM 147: The water surface plot in Appendix K (K-9) shows the with-project condition to be very close to the existing condition which will have no impact on adjacent properties. The differential velocity plot in Appendix I (I-5) shows only a minor change to adjacent property (immediately east of Colusa North) and is considered to be less than significant. This adjacent property is owned by the Department of Fish and Game, so it should not be an issue.

Cruise'n Tarry; near RM 146: Both the differential velocity (I-5) plot and the water surface plot (K-10) show very little change that can be attributed to the proposed project. This site is very small and any impacts near this small site are overwhelmed by the influence of the Ward site across the river.

Ward; near RM 146: The water surface plot in Appendix K (K-11, K-12, and K-13) shows the with-project condition to be very close to the existing condition which will have no impact on adjacent properties. There are both some increases and decreases in floodplain velocities adjacent to the Ward site as can be seen in Appendix I (I-5). A review of the actual with-project velocities in Appendix H (H-5) shows that all overbank velocities are less than 2 fps and below the threshold for initiating erosion. Some new deposition may be possible in the areas of reduced velocity. The differential velocity plot also shows some velocity increases in the main river channel ranging from 0.10 fps to 1.0 fps. However most of these increases are away from the levee and in general will increase transport capacity in this reach. In the two areas where the river is close to the levee, immediately downstream of Cruise'n Tarry's and at RM 144.6L the increases are less than 0.2 fps. The upstream site was a repaired critical erosion site (set back levee) and the downstream site is armored.

7.0 CONCLUSIONS

Based upon our stated analyses of the Colusa to Princeton Subreach of the Sacramento River, we offer the following conclusions:

1. While the report was scoped to include a comparison of the three historic thalweg surveys (Figure 5) for this reach of the river, the results appear inconclusive in demonstrating overall trends of regional aggradation or degradation as they relate to river capacity. While the 1997 data shows a greater range of high and low points along the entire length of the profile, it is quite possible that this is because the newer data set has closer spaced cross sections and shows more detail over the 1937 values. Also the other element that was not considered in looking at changes in capacity, is the width of the existing channel over what existed in 1937. Overall changes in river and floodplain capacity are better demonstrated by the plots in Appendix L – Water Surface Elevation Differential, Design to Existing Conditions, which show which areas now have more freeboard than in 1957 and which reaches have less.

2. The hydraulic run with large woody debris added to the model is a "snapshot" in time and was performed to demonstrate how much a documented amount of woody debris in the river can affect water surface elevations. The 2006 inventory of large woody debris

was used for this run because it was a real situation and followed a large runoff event that most likely caused higher levels of accumulated debris. This run showed only minimal increases in selected areas (maximum of 0.1 foot) and also goes to show that the opposite would occur (0.1 ft of lowering) if the woody debris was removed.

3. The hydraulic model would not calibrate using the published design flows (1957) at the boundary conditions (Moulton Weir, Colusa Weir and Sacramento River at Colusa). Historic flow records from stream gage data were found to be a more accurate representation of the actual flow splits at the weirs and were used to calibrate the hydraulic model.

4. The computed water surface elevations for proposed restoration sites are at or below either the existing conditions run or the 1957 design profile with the exception of the Jensen site that has a small area at the downstream edge of the site that is 0.05 ft above existing within the restoration site. While 0.05 ft is considered to be insignificant, it is still an increase, however the location of this increase is limited to within the floodplain and does not impact the adjacent levee.

5. The proposed restoration will have no effect on the seepage potential either through or under the levees both on the proposed restoration sites and on any adjacent sites.

6. While the changes in floodplain velocities will have some effect on adjacent properties, in general, they were considered to be less than significant. Some small changes in deposition and erosion patterns may be seen for the design flow event.

Appendix A -
Woody Debris Inventory Locations

Approximate River Mile	Waypoint	Upstream Waypoint	Downstream Waypoint	Number of Trees	Location	Notes
164		WD01	WD02	7	right bank	All trees are within 50 ft of the bank and evenly spaced. The downstream most tree is sticking out of the water, and the rest only the tops are sticking out. Picture is taken looking upstream.
164	WD03			1	left bank	Picture taken looking at left bank.
163.7		WD04	WD05	5	right bank	The upstream most tree, the top of the tree is on the bank and the lower portion is submerged. Pictures a,b, and c were taking looking upstream, picture d is looking at the right bank.
163.5	WD06				right center	Tree is located in the center of the main channel, just west of a sandbar. Picture taken looking east.
163.5		WD07	WD08	8	left and right bank of side channel	Trees are located in a small side channel east of a sandbar. Most of the trees are on the left bank with a couple on the right. Pictures a and c are lookingat the left bank, picture b is of the right bank of the side channel and the sandbar, picture d is looking downstream.
163	WD10	WD09	WD11	21	left bank	This reach had multiple trees and snags. 20 of the trees were on the left bank and 1 was in the center of the channel. Pictures are taken looking upstream at left bank.
162.8	WD12			6	left bank	The trees are in a cluster on the left bank. Picture taken looking upstream.
162.5	WD13			1	middle	Top of tree sticking out, causing a major riffle.
162.3	WD14			1	left center	Tree barely visible at that day's flow, riffle was observed.
161.9	WD15			4	right bank	Large percentage of the trees are sticking out above the water line.
161.6	WD16			2	right bank	Two trees with lots of brach debris on the right bank.
161.5		WD17	WD18	9	right bank	Pictures a, b, c, and d are looking at the right bank, pictures e and f are looking upstream.
161.5	WD19			4	right bank	Trees on right bank at upstream end of a sandbar. Picture looking upstream.
161.5	WD20			8	left and center	7 trees on left bank, 1 in center. Picture looking upstream.
161.3	WD21			5	left to middle	Trees spread out from center of channle to the left bank.
161.1	WD22			6	left to center	A cluster of 2 trees in the middle of the river and approximately 4 trees on the left bank. The left bank trees had lots of branches tied up in them.

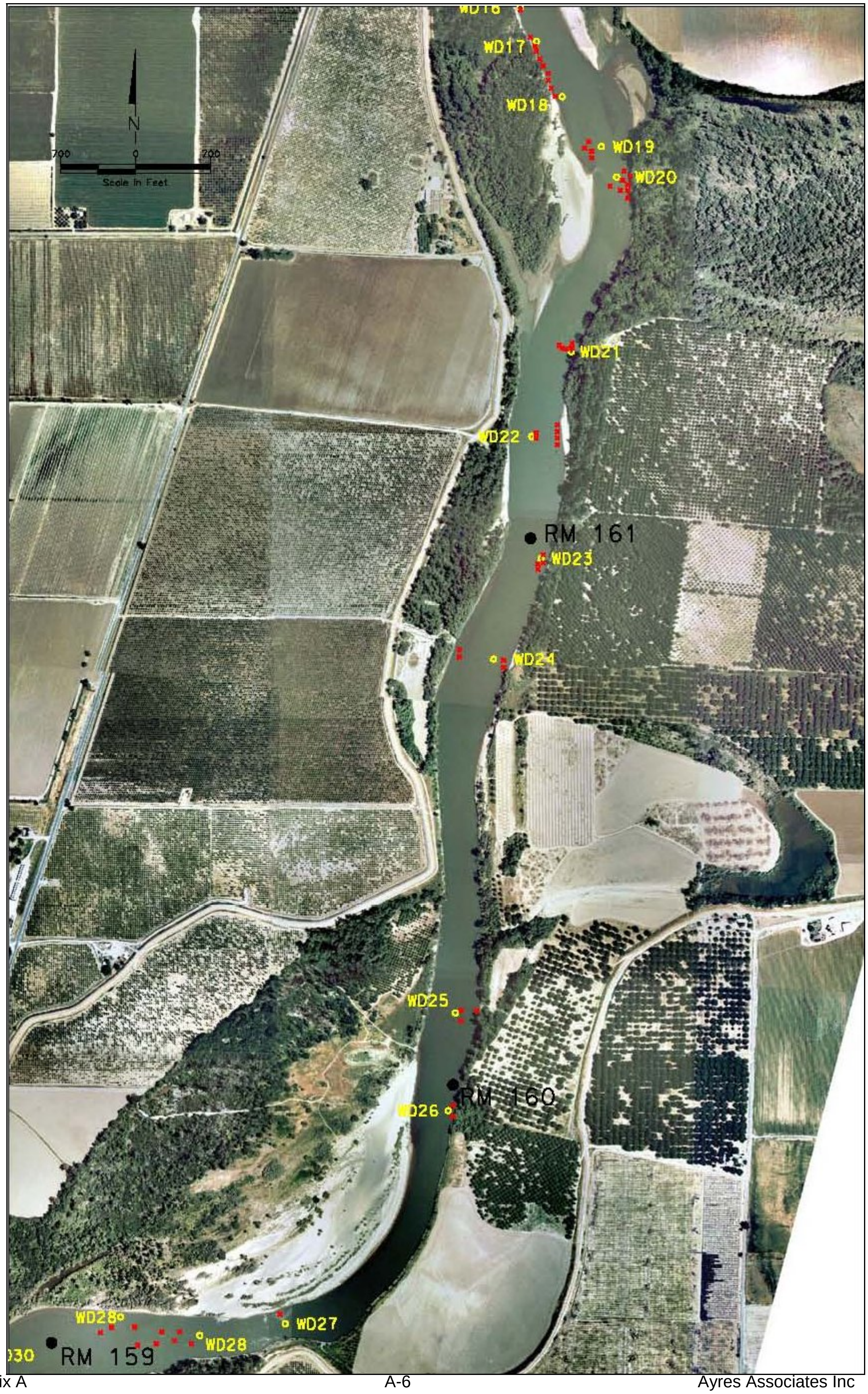
Woody Debris Inventory

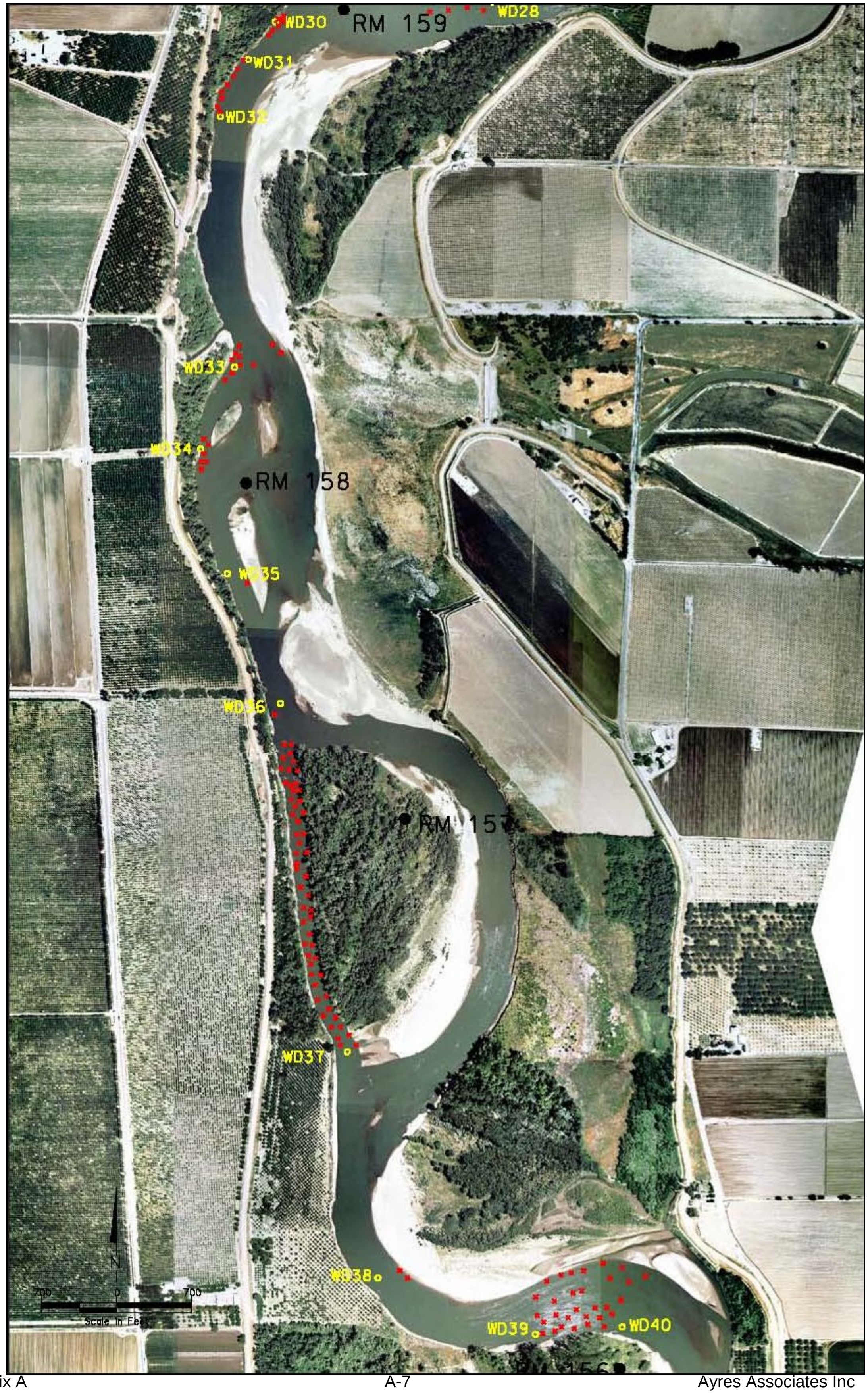
Approximate River Mile	Waypoint	Upstream Waypoint	Downstream Waypoint	Number of Trees	Location	Notes
161	WD23			4	left bank	Approximately 20 to 40 feet from the left bank, 2 barely sticking above the water level.
160.6	WD24			4	left and right	2 trees were on the left bank and 2 on the right bank.
160.2	WD25			3	left and middle	2 trees in the middle of the channel, 1 on the east bank.
159.8	WD26			2	left bank	
159.7	WD27			1	right bank	Tree protrudes out from the bank into the river.
159.4		WD28	WD29	9	middle	Trees are located in the middle of the channel with 8 exposed and 1 just underwater.
158.8	WD30			6	right bank	Cluster of multiple trees, may be more or less trees, water too high to distinguish.
158.6		WD31	WD32	8	right bank	8 trees were observed on the right bank, with the potential for more underwater. Lots of debris on the banks.
158.1	WD33			10	right, middle and left	7 trees on the right bank, 1 in the middle, and 2 on the left bank.
157.7	WD34			6	right bank	Multiple branches still attached to tree trunks.
157.4	WD35			1	left bank	Lone tree adjacent to large sandbar on the left bank.
157.1 - 156.6		WD36	WD37	54	throughout	This stretch of the river is commonly refered to as "debris alley" and is the right channel of the river Trees are located throught the section with some only slightly sticking out above the water. Picture a is taken from the upstream of the section and picture b is about halfway through the river section.
156.4	WD38			2	middle	2 trees in the middle of the river with multiple snags.
156.2		WD39	WD40	30	throughout	The river widens out at this location, trees are observed throught the channel and there is lots of debris is on the right bank.
155.8	WD41			4	right bank	Trees located adjacent to a sandbar. Picture taken looking upstream.
155.5 - 154.8		WD42	WD43	46	throughout	The majority of the trees are on the right bank with some in the middle and on the left. Some are just under the water.
154.5	WD44			3	right bank	Picture taken looking downstream.
154.4	WD45			1	left bank	Large tree with multiple large branches sticking out.
154.2	WD46			1	left bank	
154	WD47			4	left bank	Majority of trees are underwater.

Approximate River Mile	Waypoint	Upstream Waypoint	Downstream Waypoint	Number of Trees	Location	Notes
153.2		WD48	WD49	6	right bank	Picture not great, trees are in the shadows.
152.8		WD50	WD51	14	right bank	Trees have multiple piles of branches and snags caught on them. Some of the trees are half in the water half on the bank.
152.5	WD52			3	right bank	Trees are located very close to the right bank. Pictures taken looking upstream.
152.1	WD53			4	right bank	Trees are clustered, estimated 4 but possible more or less.
152		WD54	WD55	9	right bank	Cluster of trees at the upstream end.
151.4	WD56			1	left bank	On tree close to the left bank.
150.8		WD57	WD58	7	right bank	4 trees are clumped together at the downstream end. Picture a looking downstream, pictures b and c are looking upstream.
149.5	WD59			3	right bank	Trees are caught up on each other and located on the right bank of the right river channel.
149.3	WD60			1	right bank	Lone tree (with 2 branches sticking out) near sandbar on right bank.
149.1		WD61	WD62	4	right bank	The 4 trees are clustered together.
148	WD63			1	middle	About 2 ft of tree sticking out above the water in the center of the channel.
147.6	WD64			1	middle	Single tree in center of river.
147.2	WD65			1	middle	A portion of the tree is visible in the center of the river and causing a noticable riffle.
147.1	WD66			1	left bank	
146.5		WD67	WD68	24	throughout	Trees are scattered throughout the channel. Picture a is at the upstream end looking donstream and picture b is at the downstream end looking upstream.
146	WD69			1	left bank	Picture taken looking downstream.
145.9	WD70			1	middle	Picture taken looking downstream.
145.8	WD71			2	middle	Picture taken looking downstream.
145.7	WD72			1	right center	Picture taken looking downstream.
145.5		WD73	WD74	18	right and center	Picture of upstream most trees on the right bank.
145.2	WD75			2	middle	Picture taken looking downstream.
145	WD76			1	right	Tree close to right bank, with lots of debris on the bank.

Approximate River Mile	Waypoint	Upstream Waypoint	Downstream Waypoint	Number of Trees	Location	Notes
144		WD77	WD78	10	left	Picture taken from the upstream end of the river section.
143.4 Colusa Bridge	WD79			6	both piers	On the east pier, 2 trees are stuck above the water line and 2 trees are around the pier at the water line. The west pier has about 2 (maybe more) trees with lots of debris.
143.3 Pump				numerous	Abandoned pump structure	An abandonded pump structure, about 10 ft tall and 5 ft wide is covered in trees, on the top, side, and front. Too numerous to count, over 20.


WD01
WD03
WD02
RM 164
WD04
WD05
WD07
WD06
WD08
WD09
WD10
RM 163
WD11
WD12
WD13
WD14
RM 162
WD15
WD16
N
0
700
Scale in Feet


N
700
0
700
Scale in Feet
WD17
WD18
WD19
WD20
WD21
WD22
RM 161
WD23
WD24
WD25
RM 160
WD26
WD27
WD28
WD28
RM 159

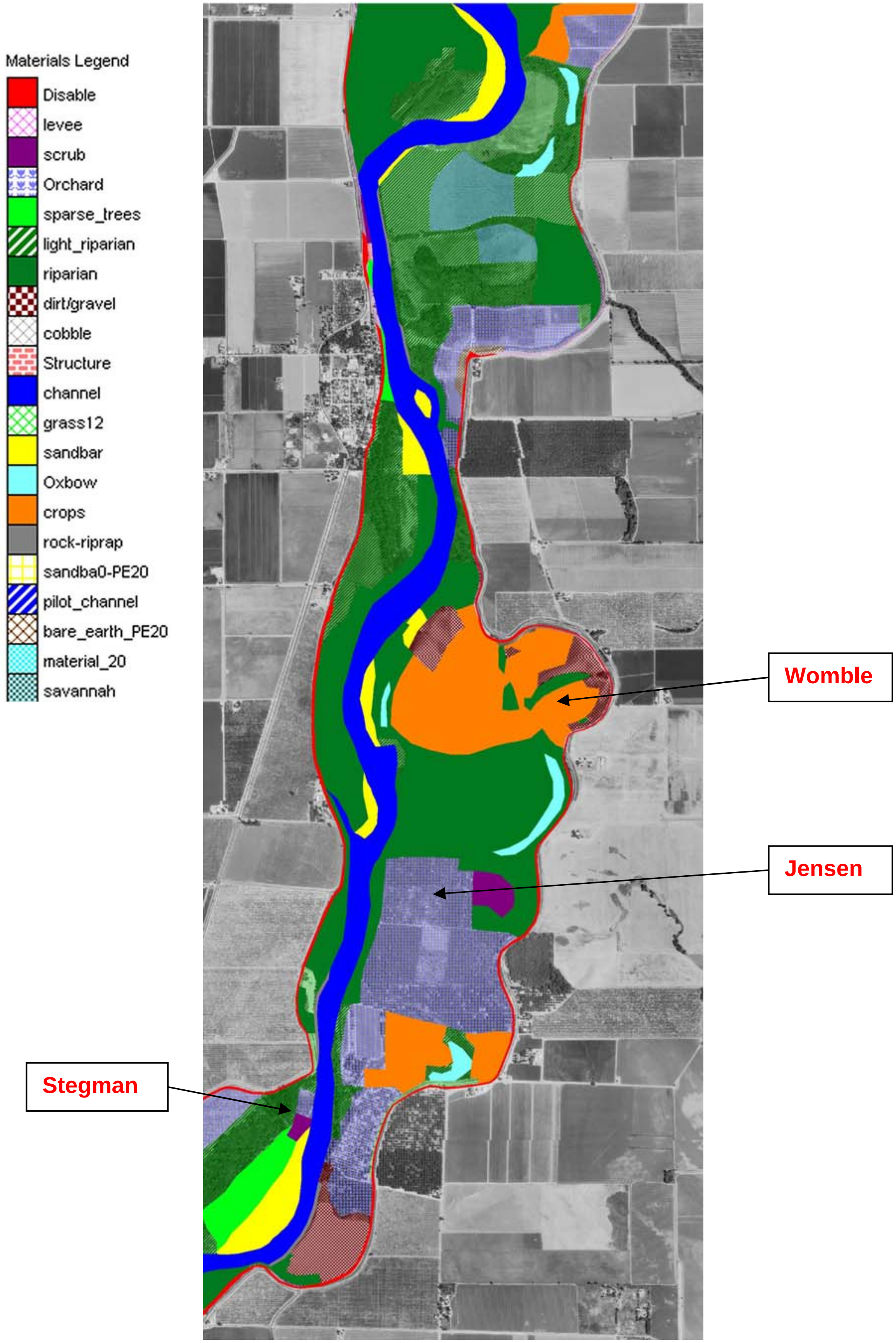

WD28
WD30
RM 159
WD31
WD32
WD33
WD34
RM 158
WD35
WD36
RM 157
WD37
WD38
WD39
WD40
N
700
0
700
Scale in Feet


RM 156
WD41
WD42
RM 155
WD43
WD44
WD45
RM 154
WD46
WD47
WD48
WD49
RM 153
WD50
WD51
WD52
N
700
0
700
Scale in Feet

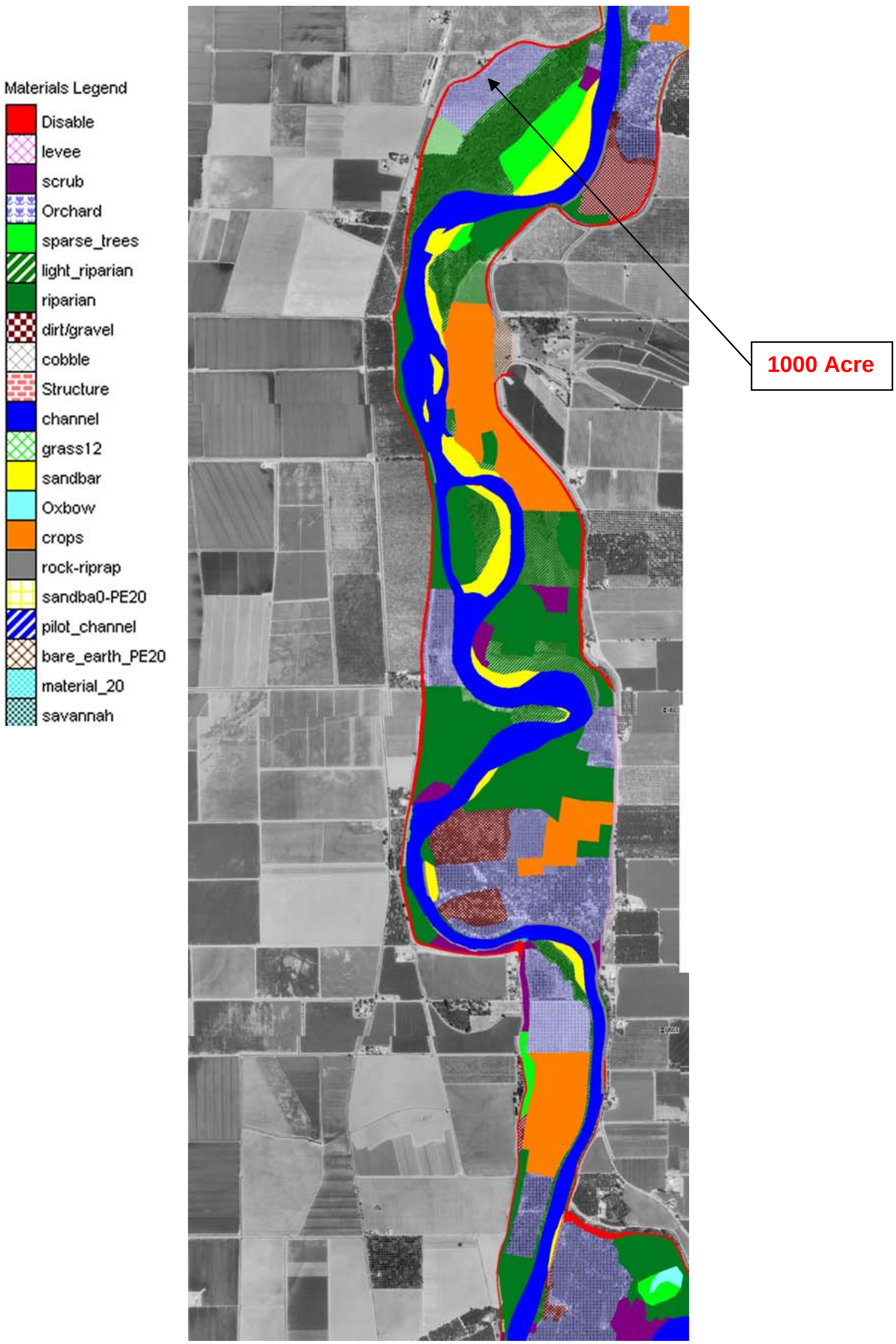

N
700
0
700
WD52
WD53
RM 152
WD54
RM 150
WD55
WD58
WD56
RM 151
WD57
WD59
WD60
WD61
RM 149
WD62
RM 148
WD63
WD64

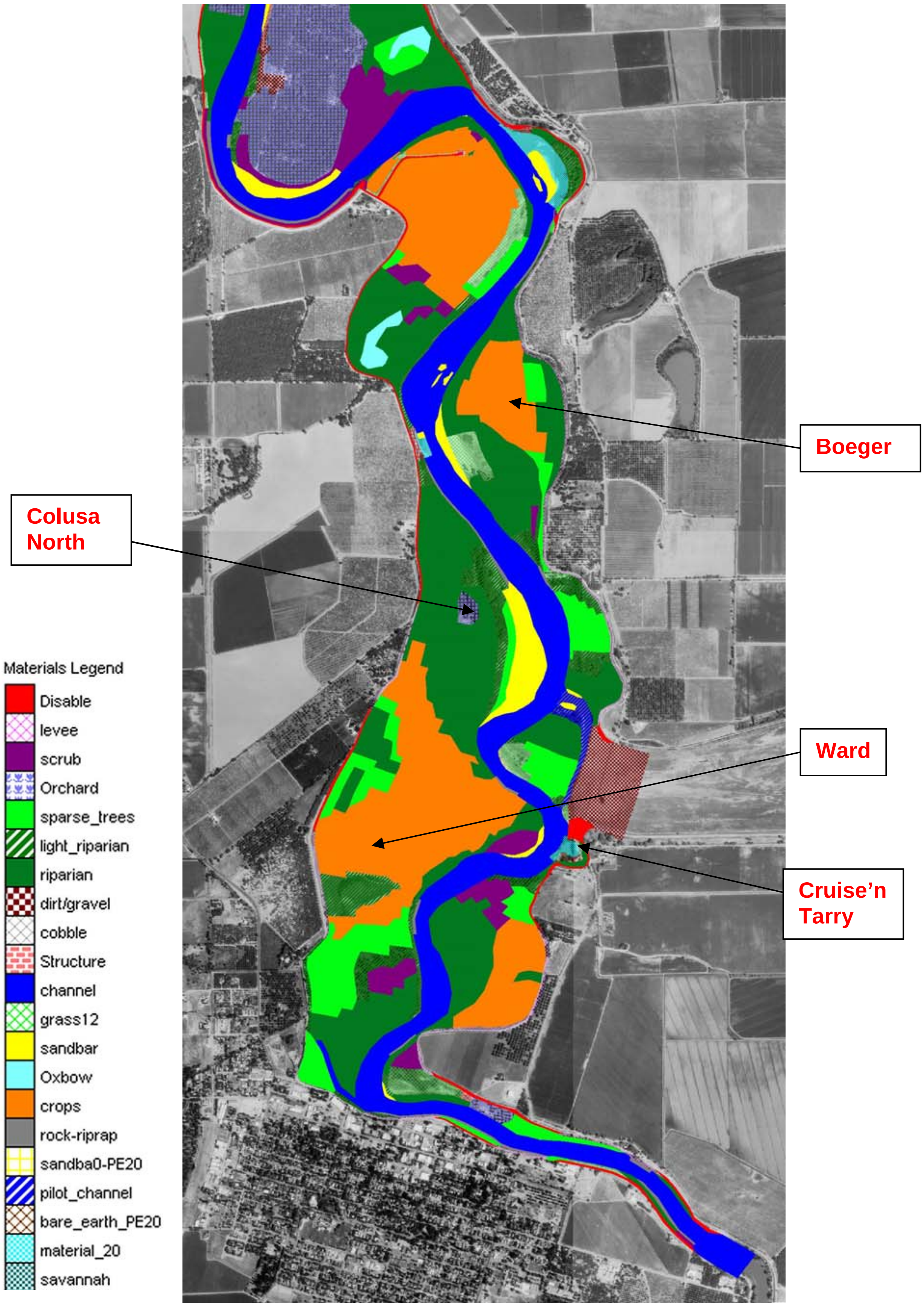

WD65
WD66
RM 147
WD67
WD68
RM 146
WD69
WD70
WD71
WD73
WD72
WD74
WD75
RM 145
WD76
WD77
WD78
RM 144
WD79
RM 143
N
Scale in Feet

Appendix B – Land Use Figures
Existing Conditions

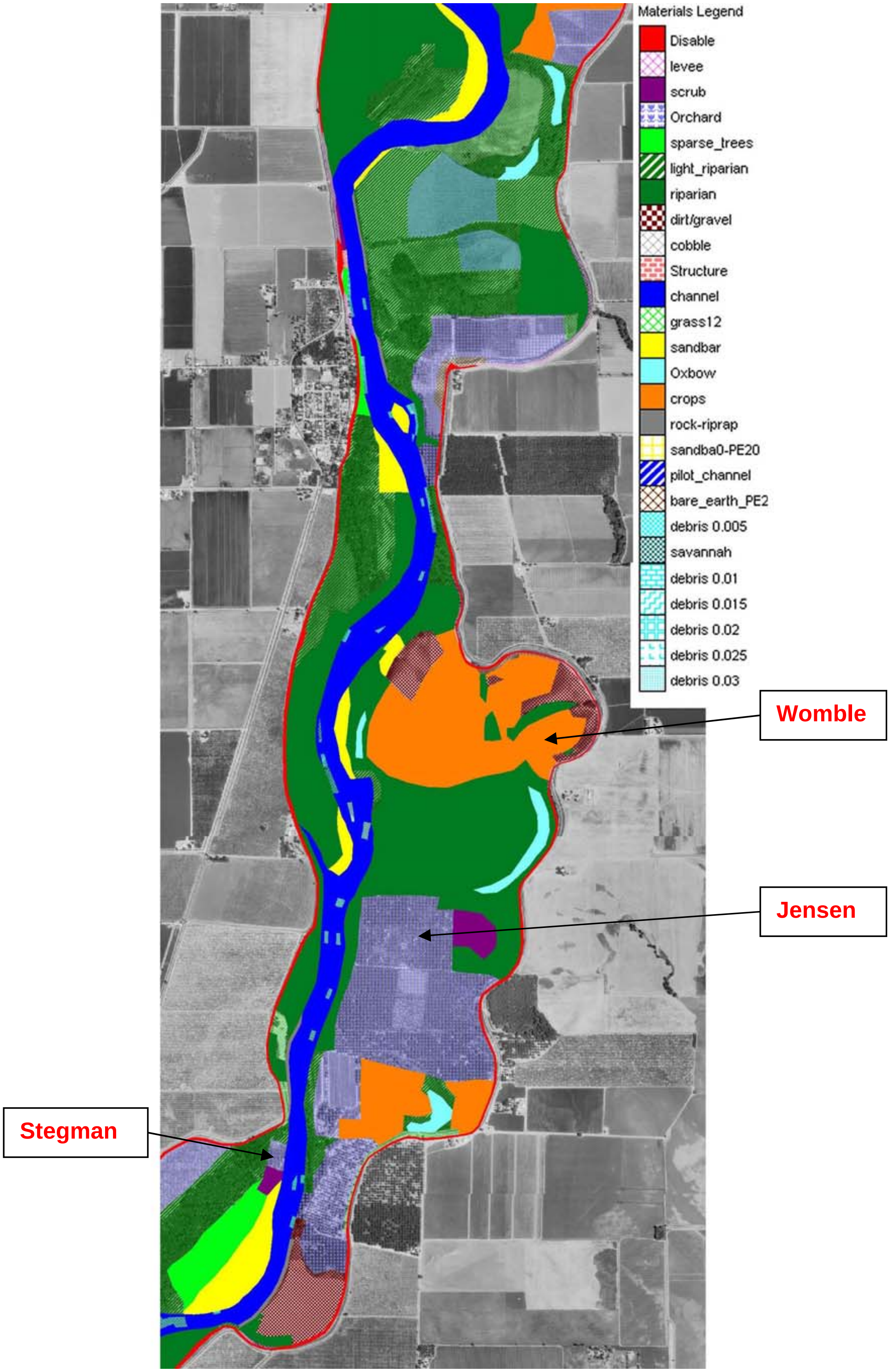


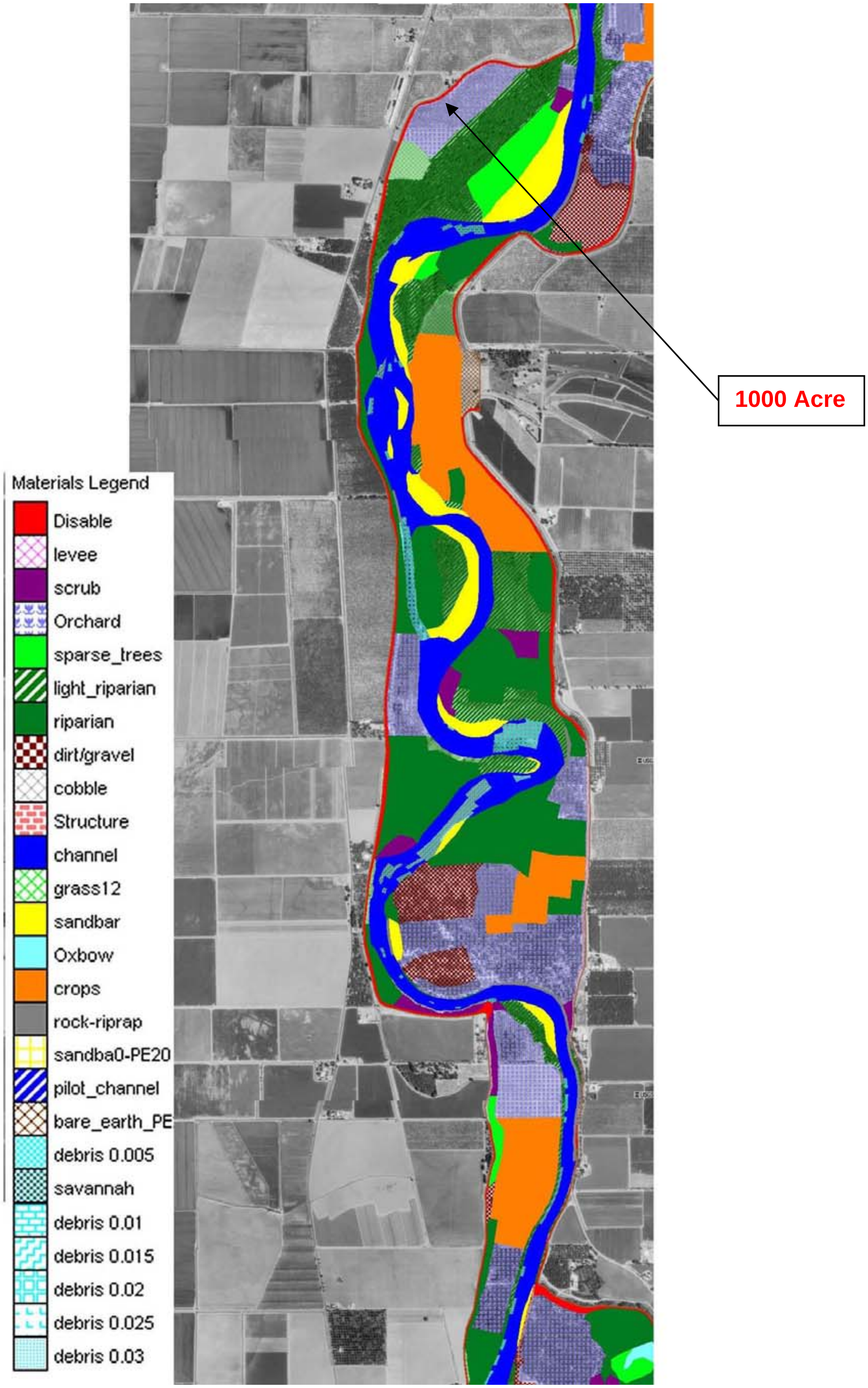
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE20
material_20
savannah
Womble
Jensen
Stegman


Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE20
material_20
savannah
1000 Acre

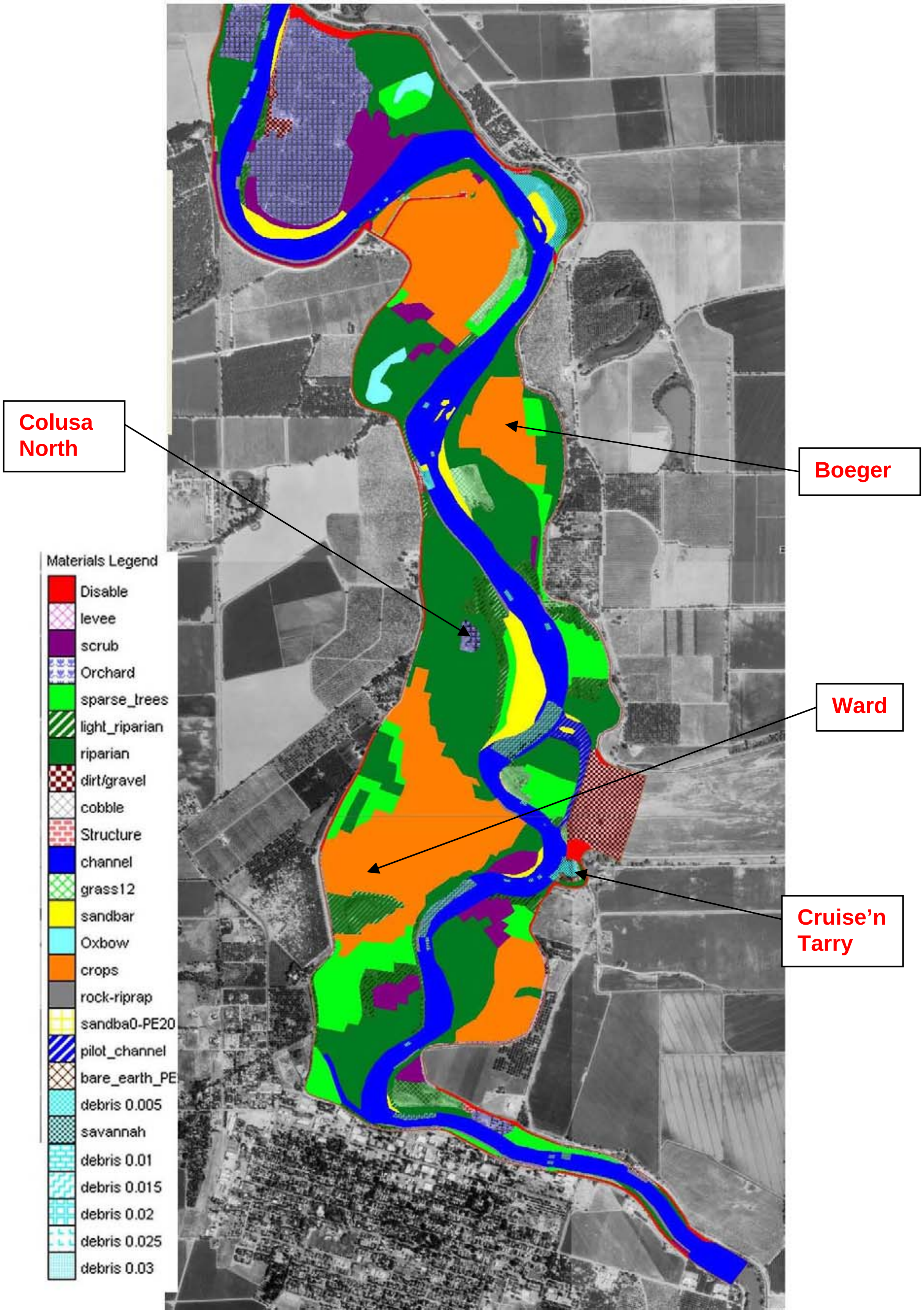

Boeger
Colusa North
Ward
Cruise'n Tarry
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE20
material_20
savannah

Appendix C – Land Use Figures
Debris Conditions

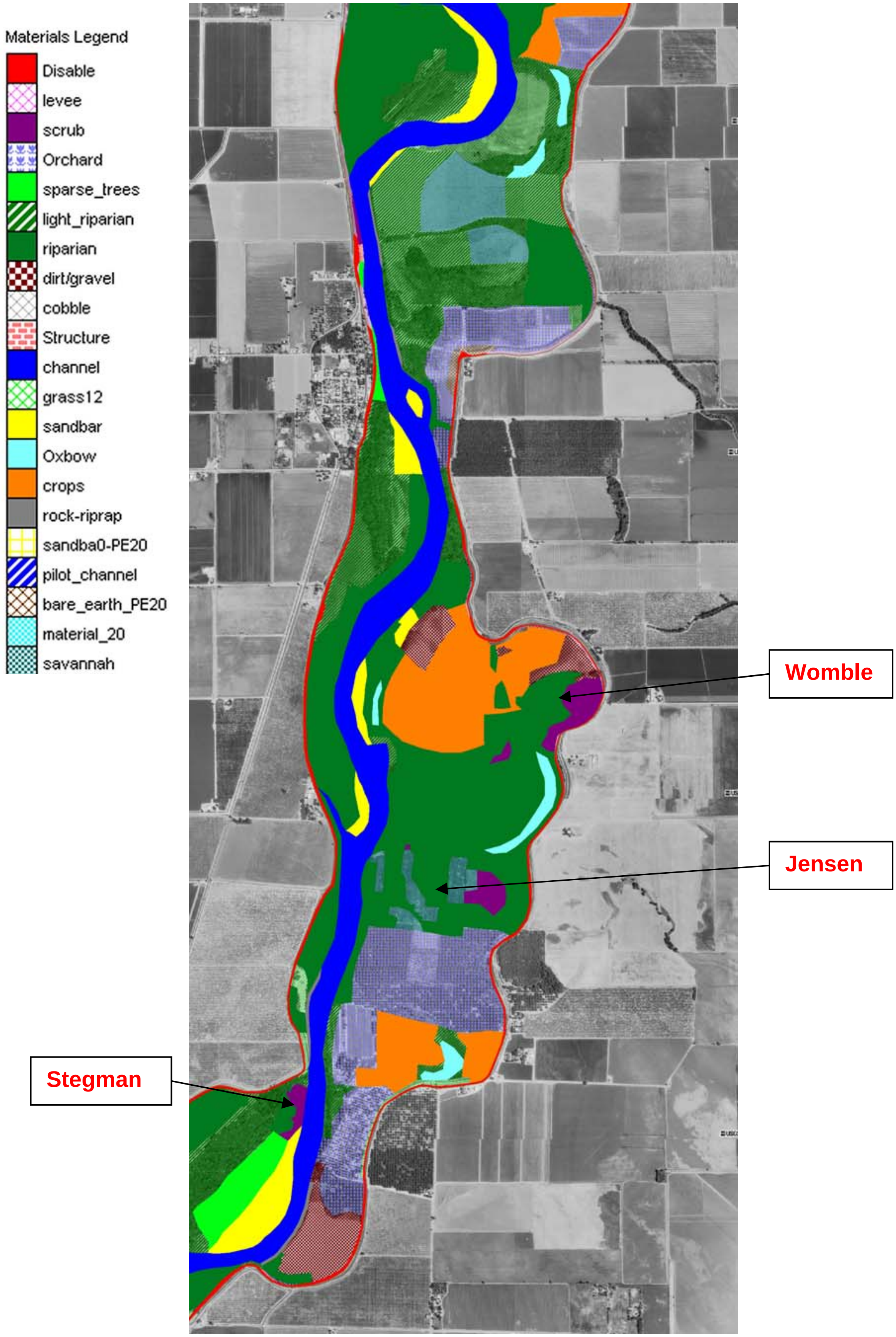

Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE2
debris 0.005
savannah
debris 0.01
debris 0.015
debris 0.02
debris 0.025
debris 0.03
Womble
Jensen
Stegman



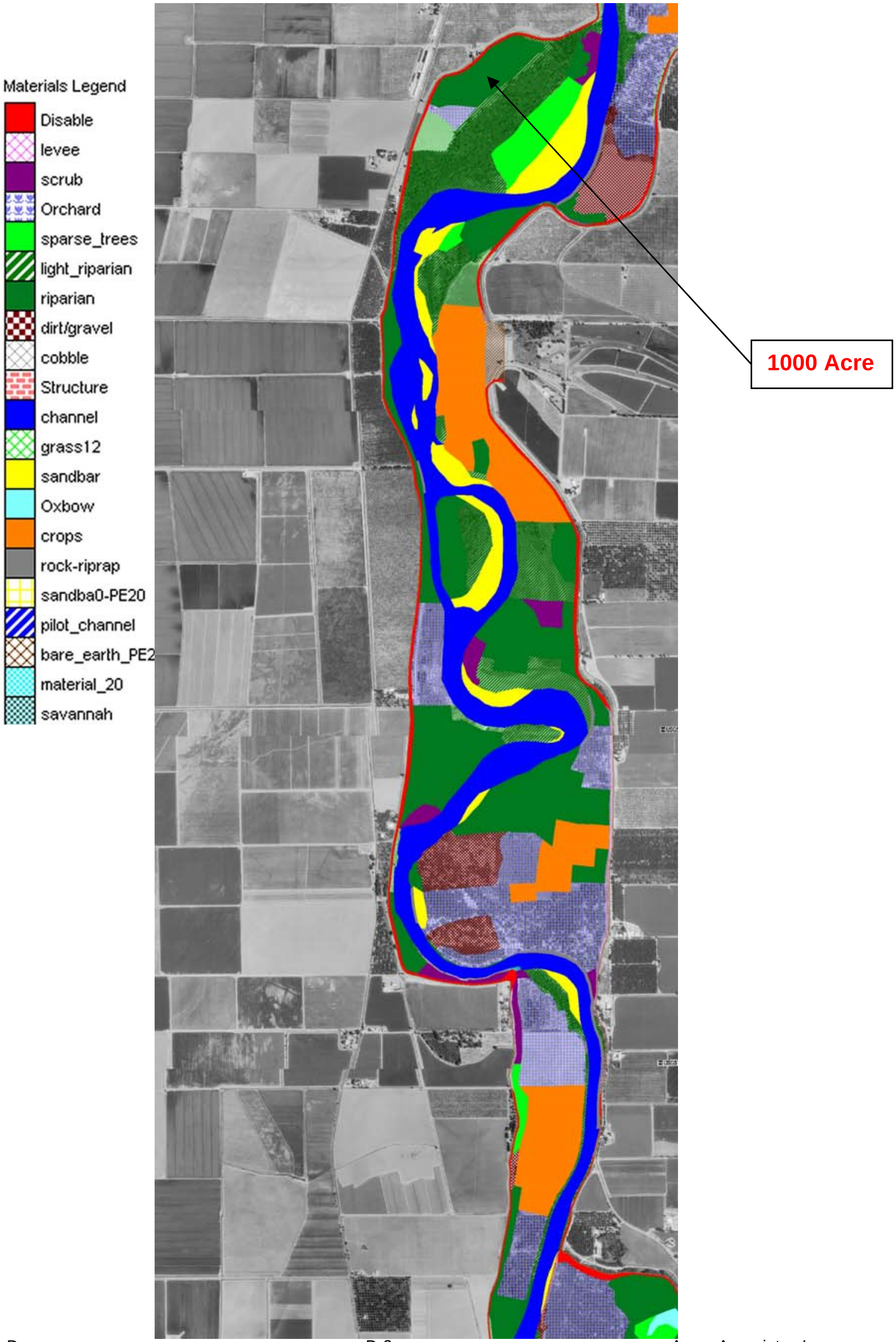
1000 Acre
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE
debris 0.005
savannah
debris 0.01
debris 0.015
debris 0.02
debris 0.025
debris 0.03

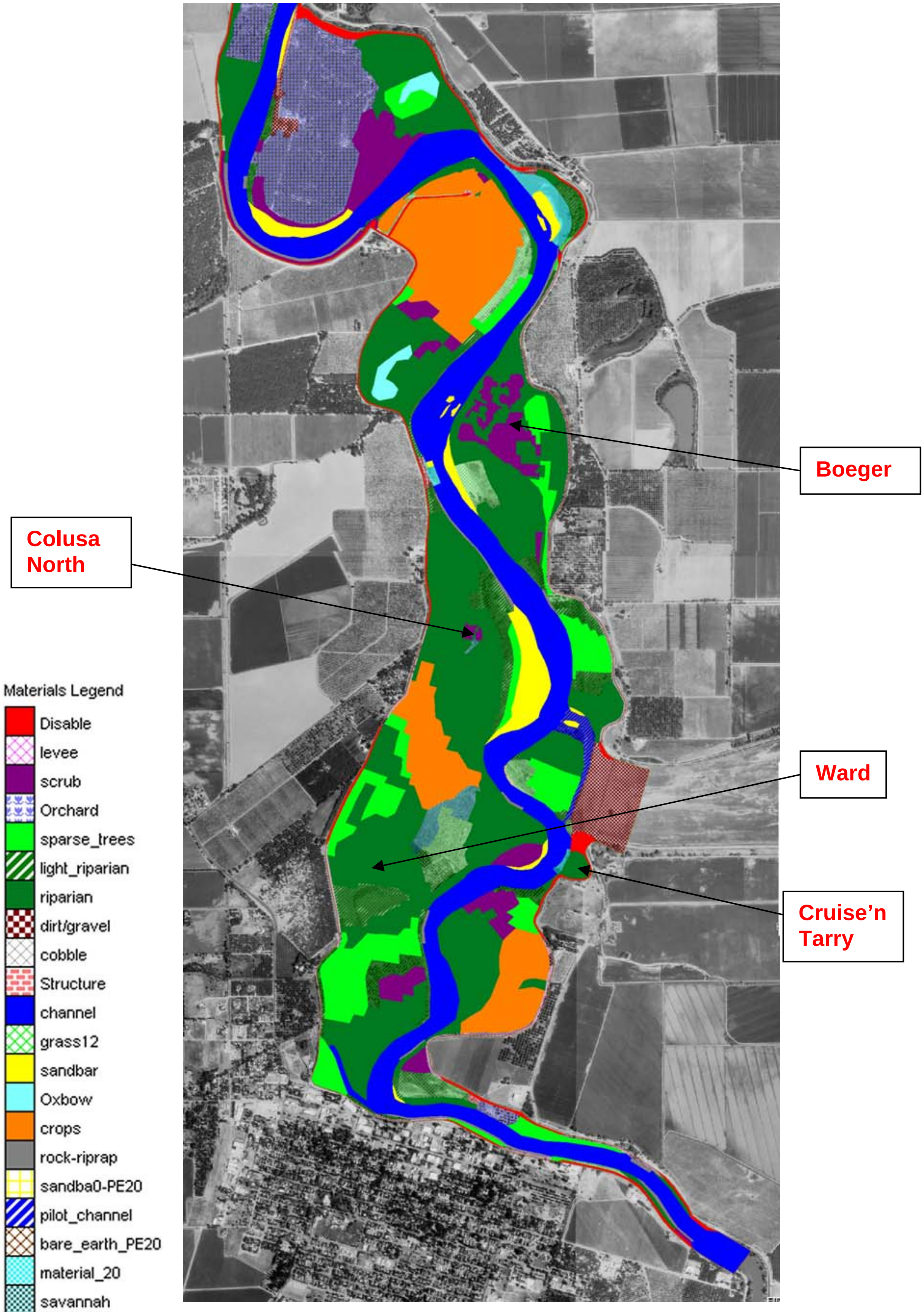

Colusa North
Boeger
Ward
Cruise'n Tarry
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE
debris 0.005
savannah
debris 0.01
debris 0.015
debris 0.02
debris 0.025
debris 0.03

Appendix D – Land Use Figures
Restoration Conditions

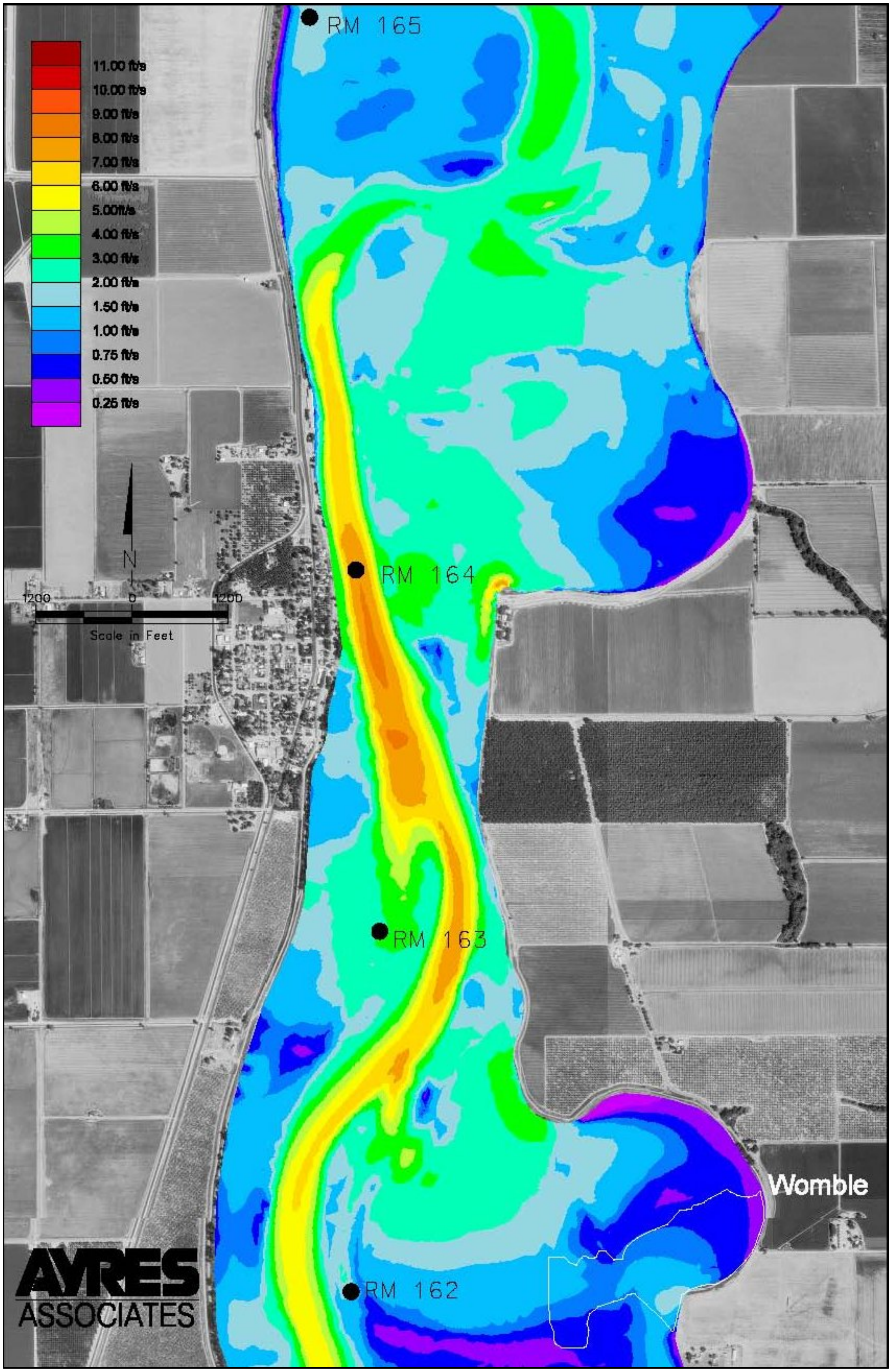


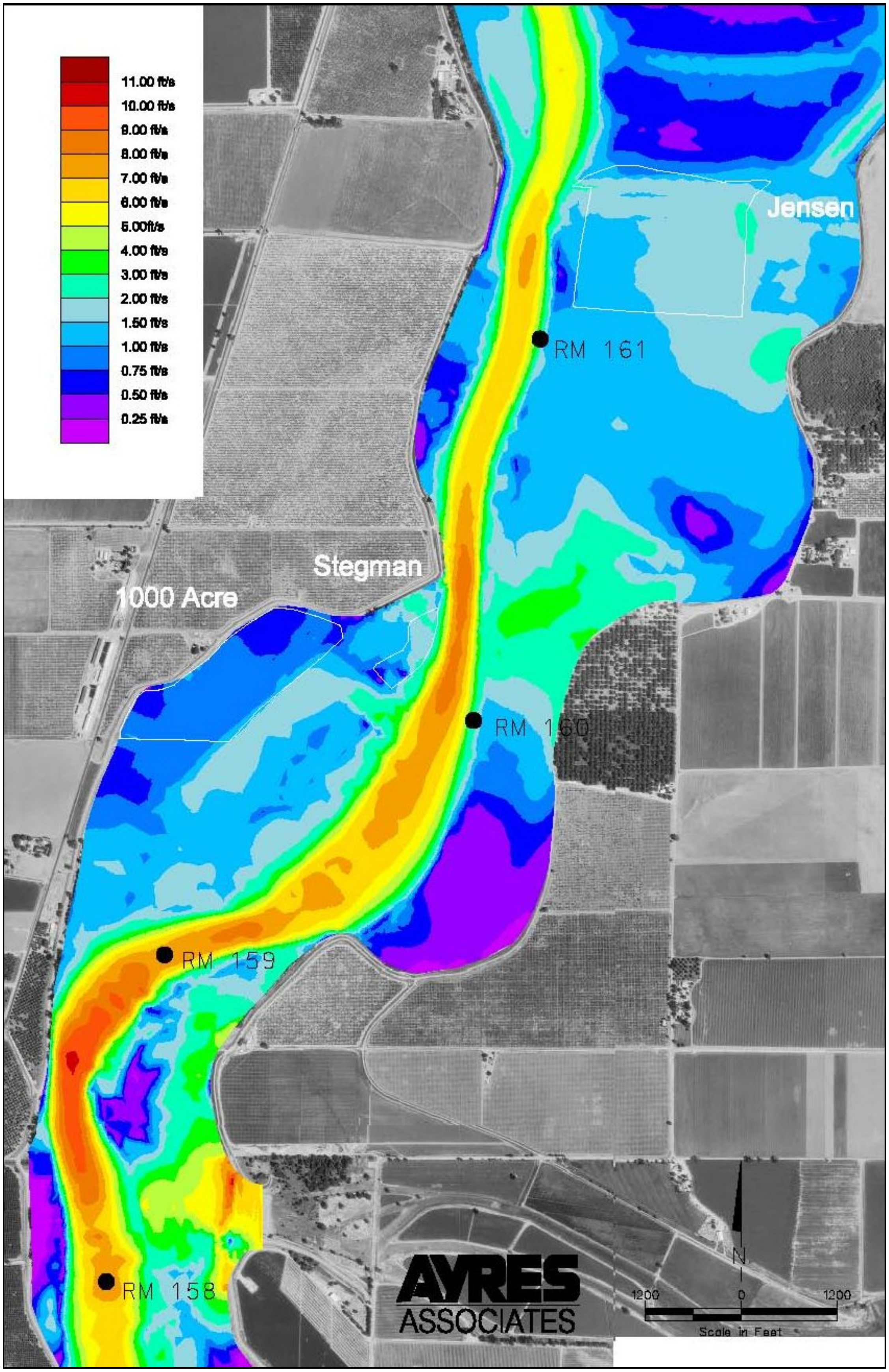
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE20
material_20
savannah
Womble
Jensen
Stegman

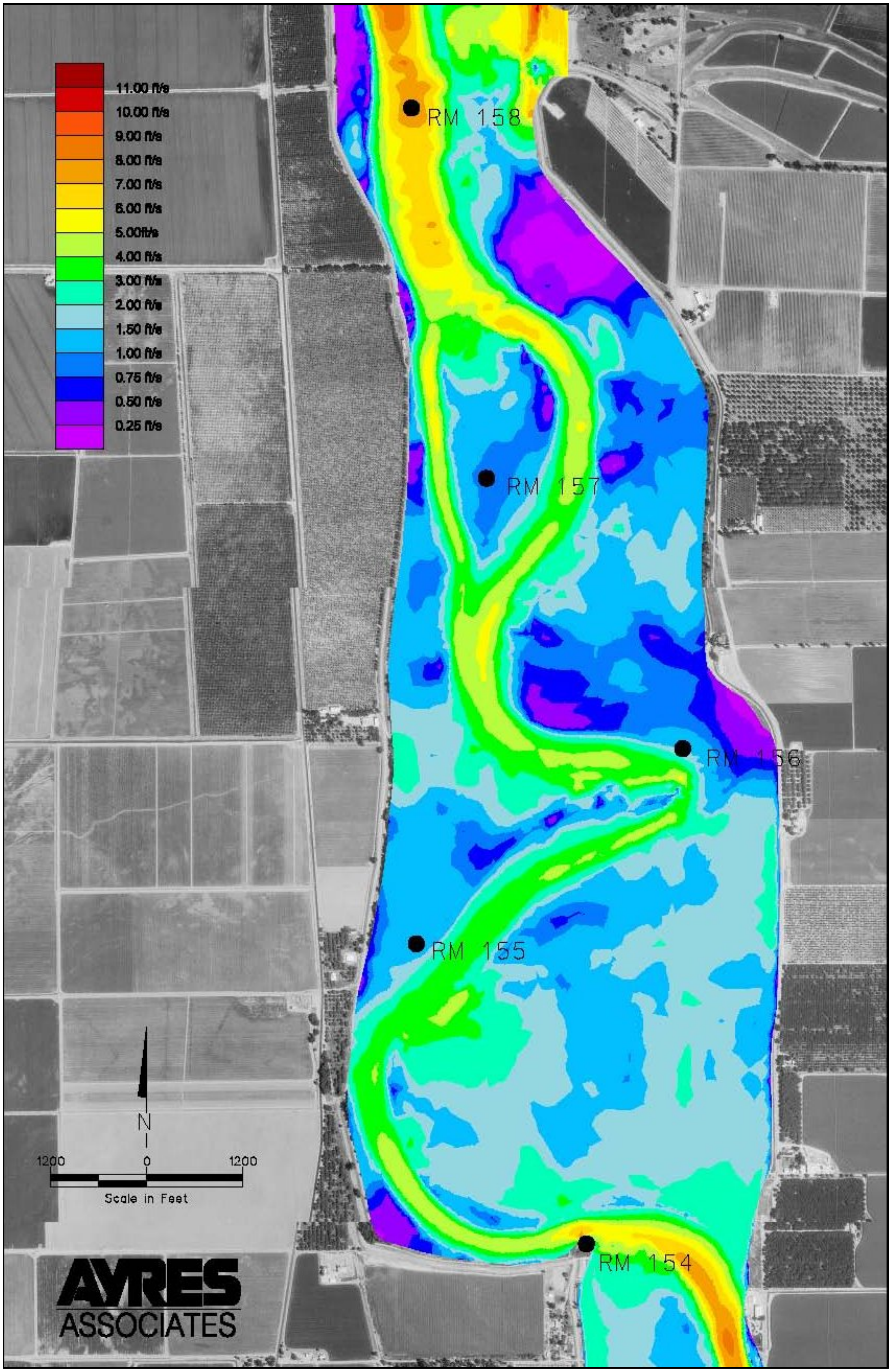

Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE2
material_20
savannah
1000 Acre


Boeger
Colusa North
Ward
Cruise'n Tarry
Materials Legend
Disable
levee
scrub
Orchard
sparse_trees
light_riparian
riparian
dirt/gravel
cobble
Structure
channel
grass12
sandbar
Oxbow
crops
rock-riprap
sandba0-PE20
pilot_channel
bare_earth_PE20
material_20
savannah

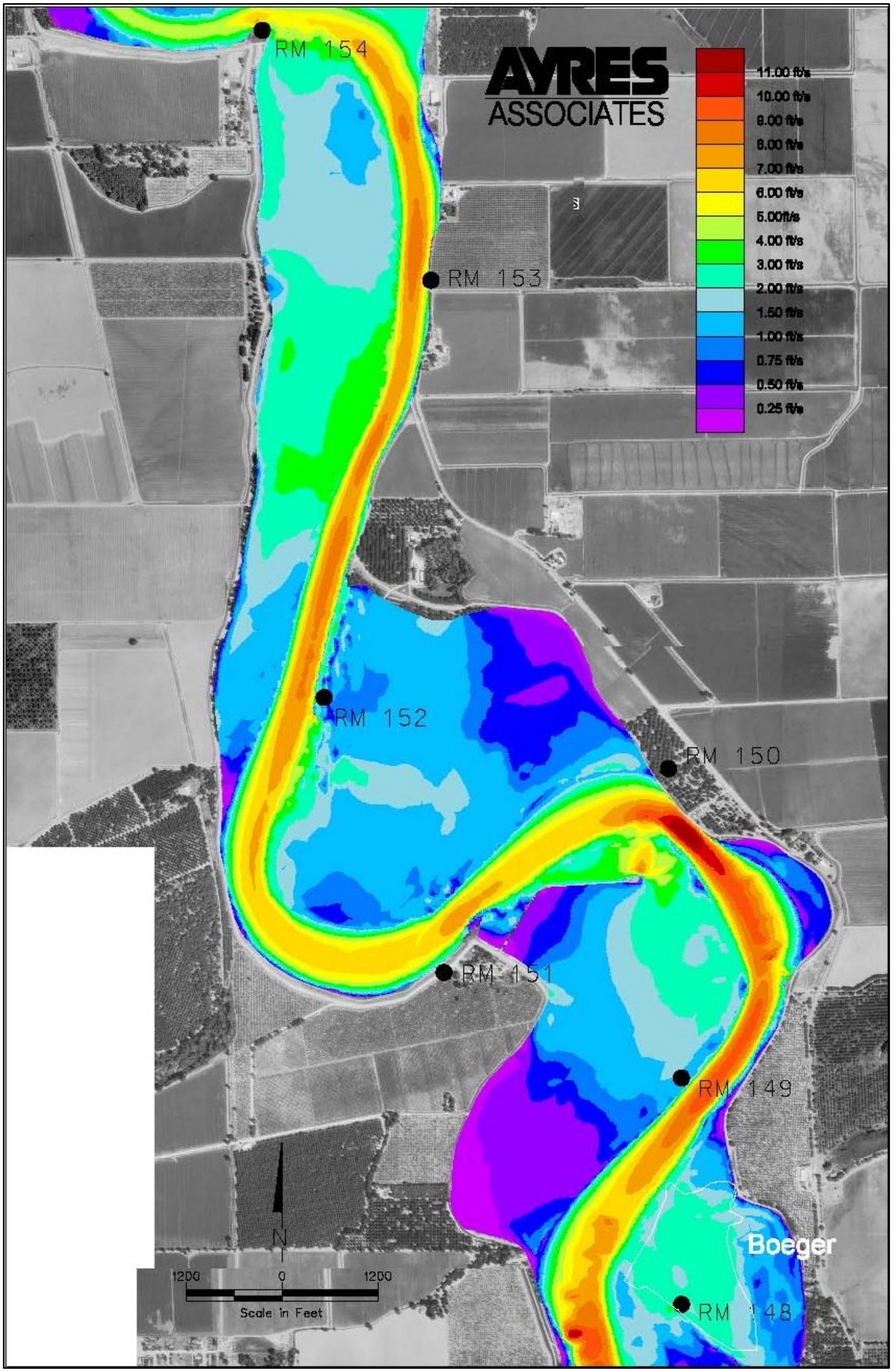
Appendix E – Velocity Plots
Existing Conditions

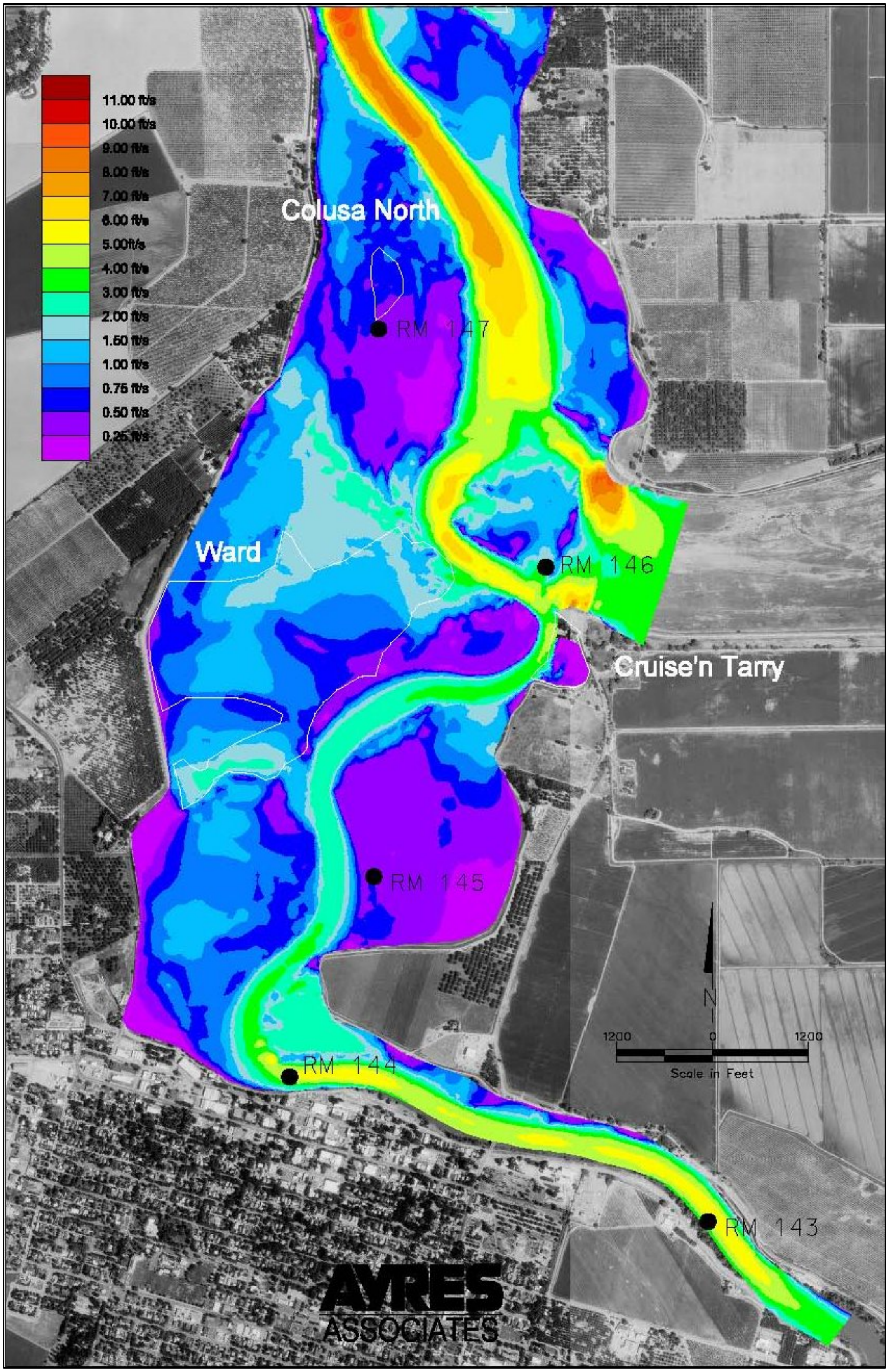

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
RM 165
RM 164
RM 163
RM 162
N
1200
0
1200
Scale in Feet
Womble
AYRES
ASSOCIATES


11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES ASSOCIATES
N
1200
0
1200
Scale in Feet

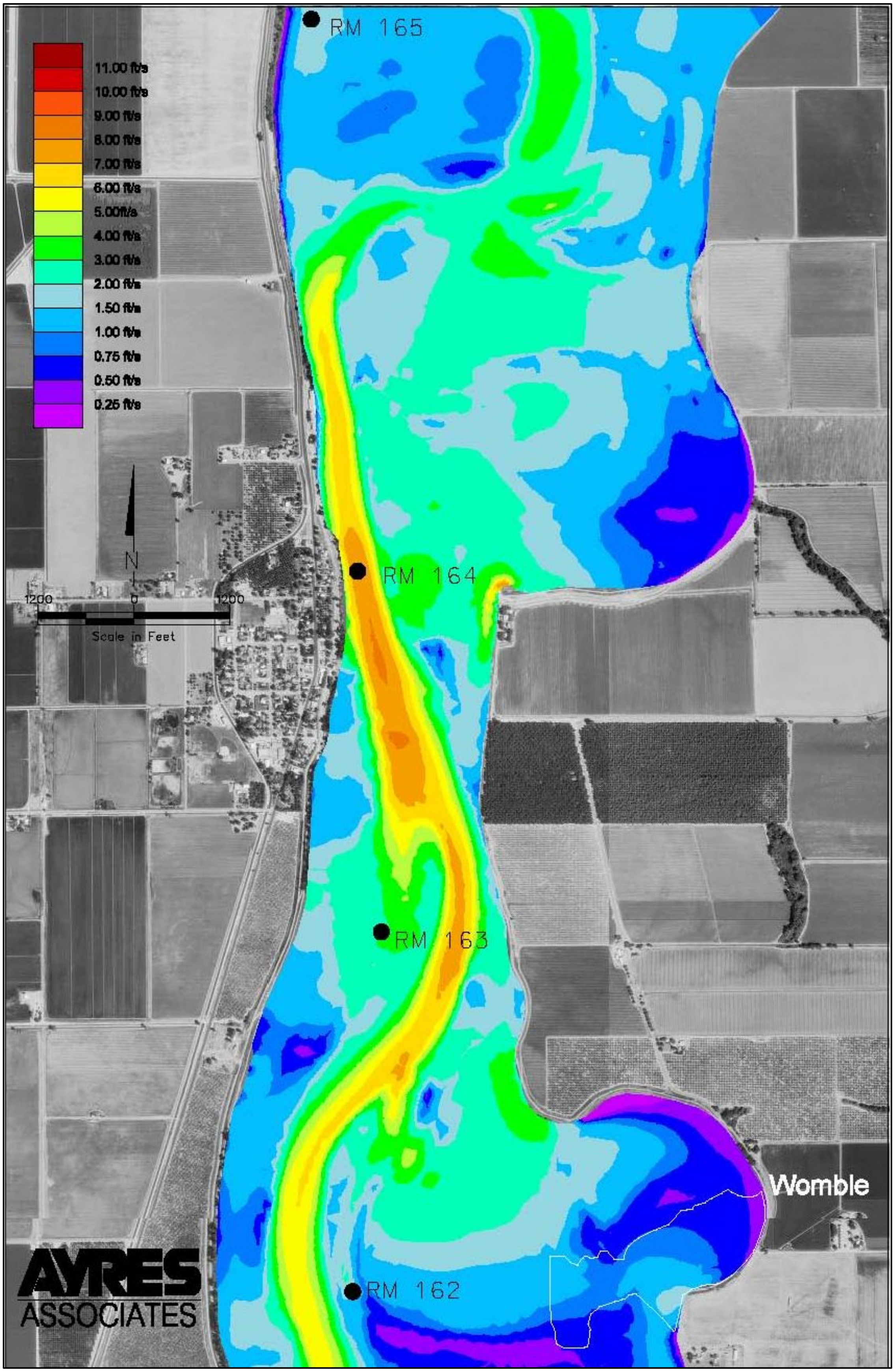


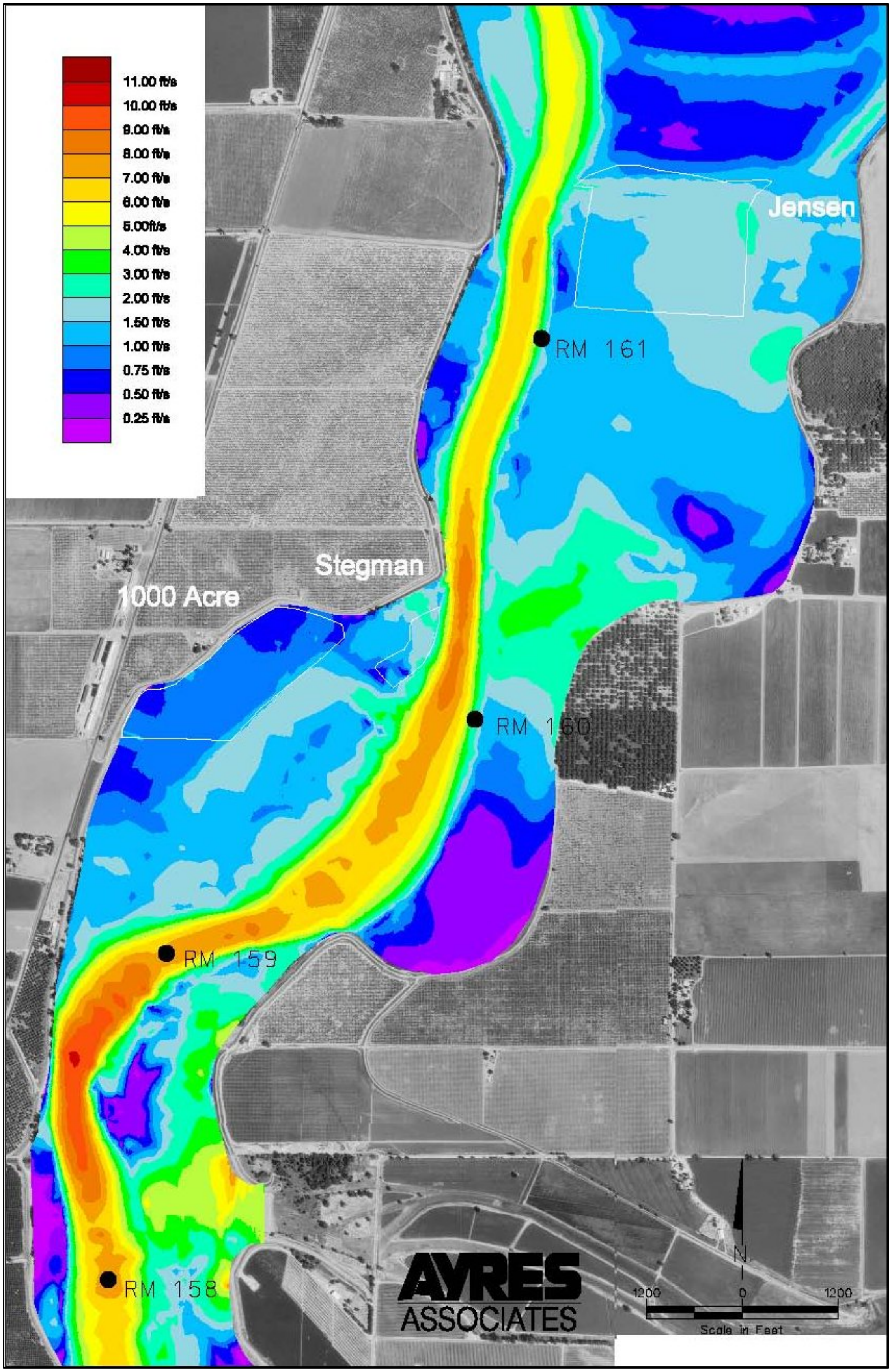
11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
RM 158
RM 157
RM 156
RM 155
RM 154
N
1200
0
1200
Scale in Feet
AYRES ASSOCIATES

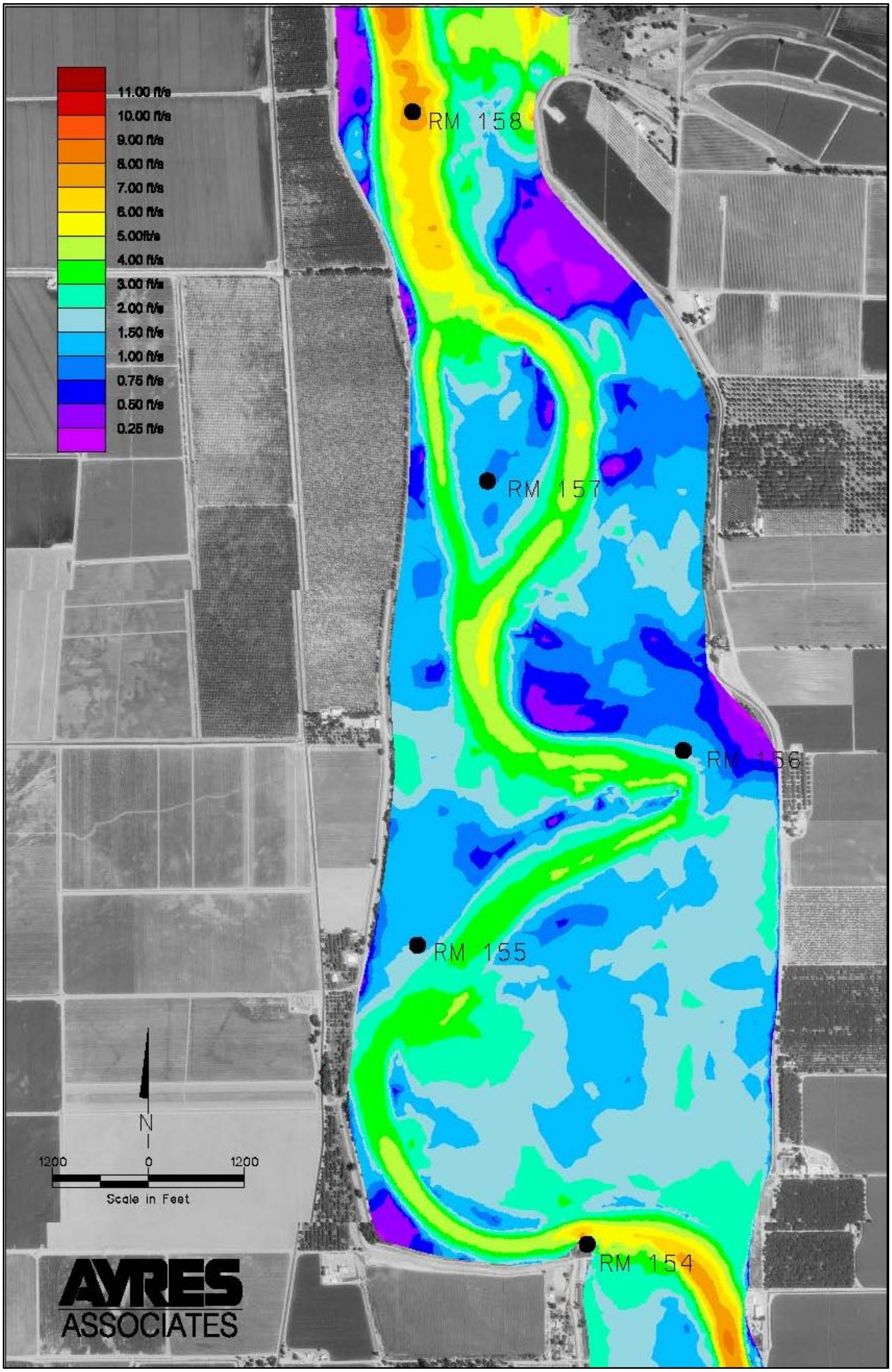

RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
AYRES ASSOCIATES
11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Boeger
N
1200
0
1200
Scale in Feet

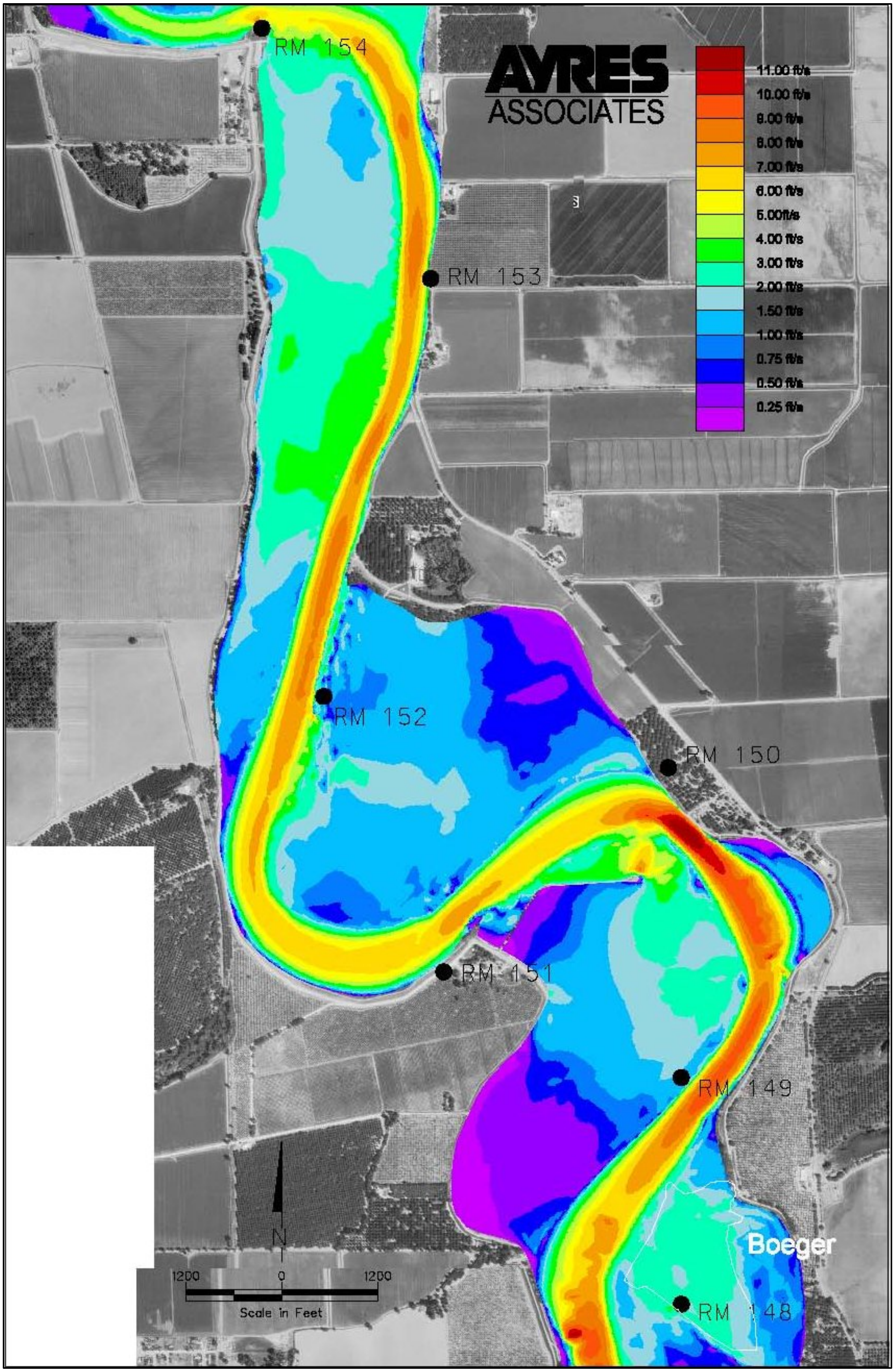

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Colusa North
RM 147
Ward
RM 146
Cruise'n Tarry
RM 145
N
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

Appendix F – Velocity Plots
Debris Conditions

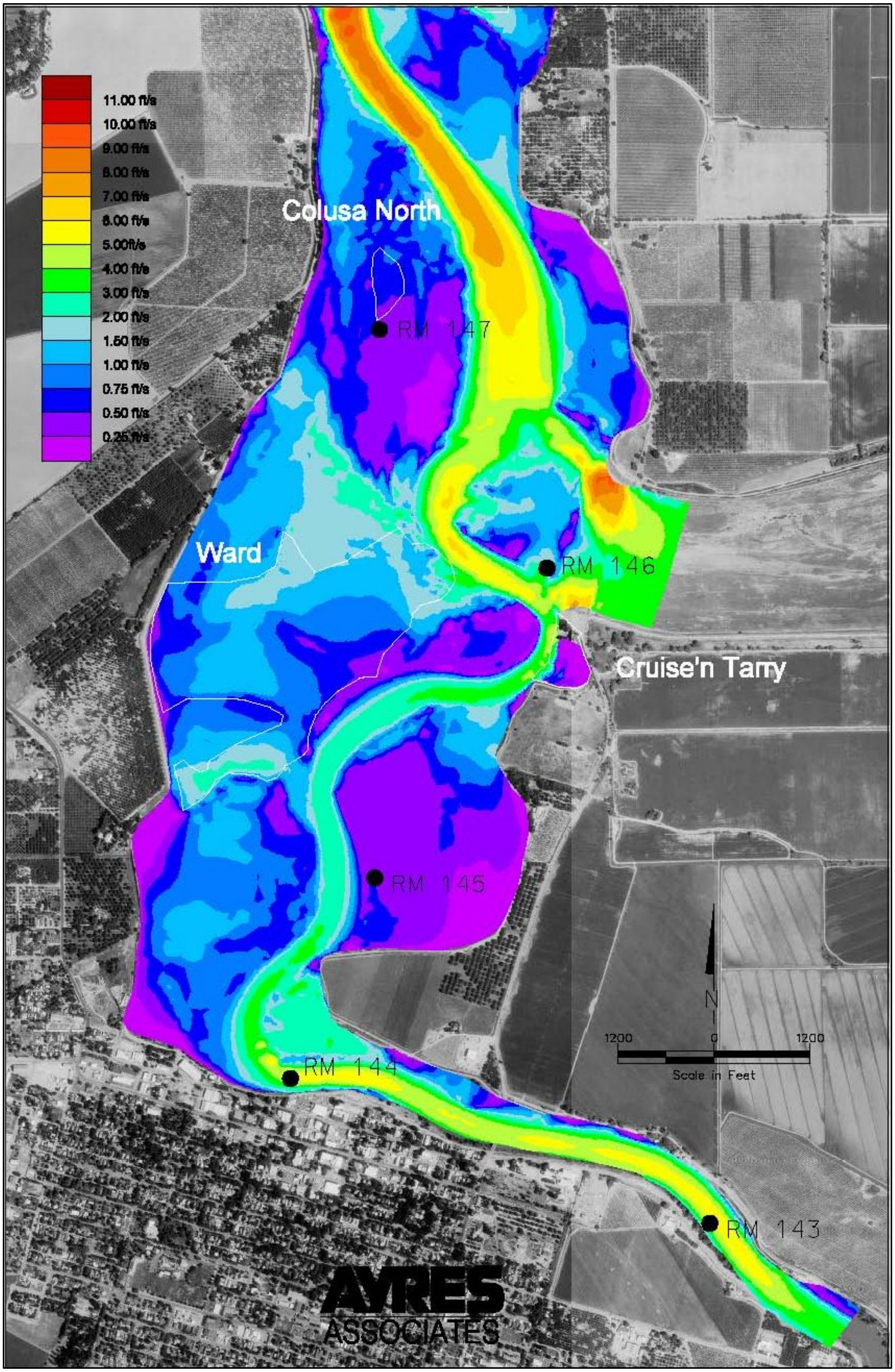

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
N
1200
0
1200
Scale in Feet
RM 165
RM 164
RM 163
RM 162
Womble
AYRES ASSOCIATES


11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES
ASSOCIATES
N
1200
0
1200
Scale in Feet

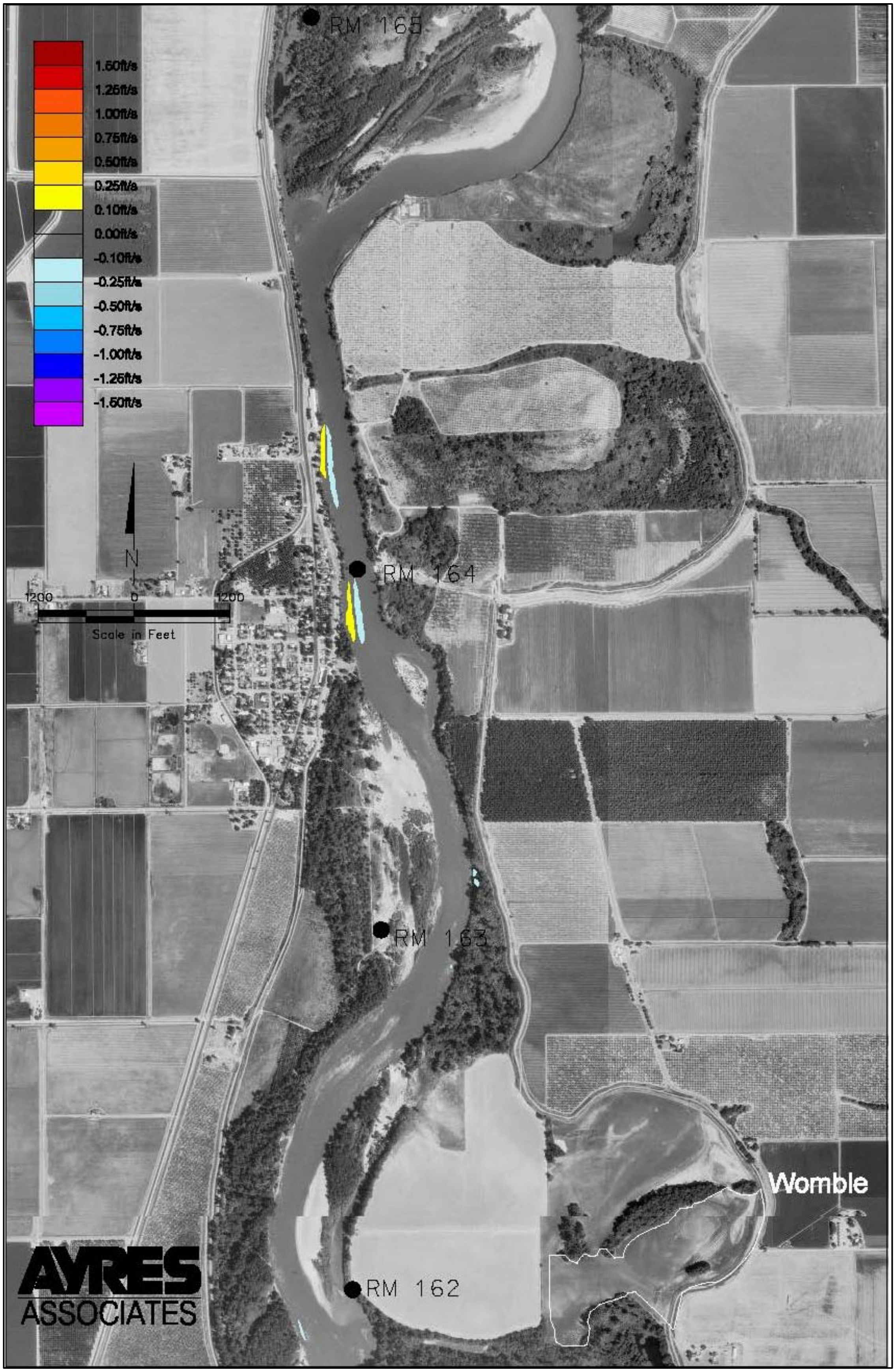

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
RM 158
RM 157
RM 156
RM 155
RM 154
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

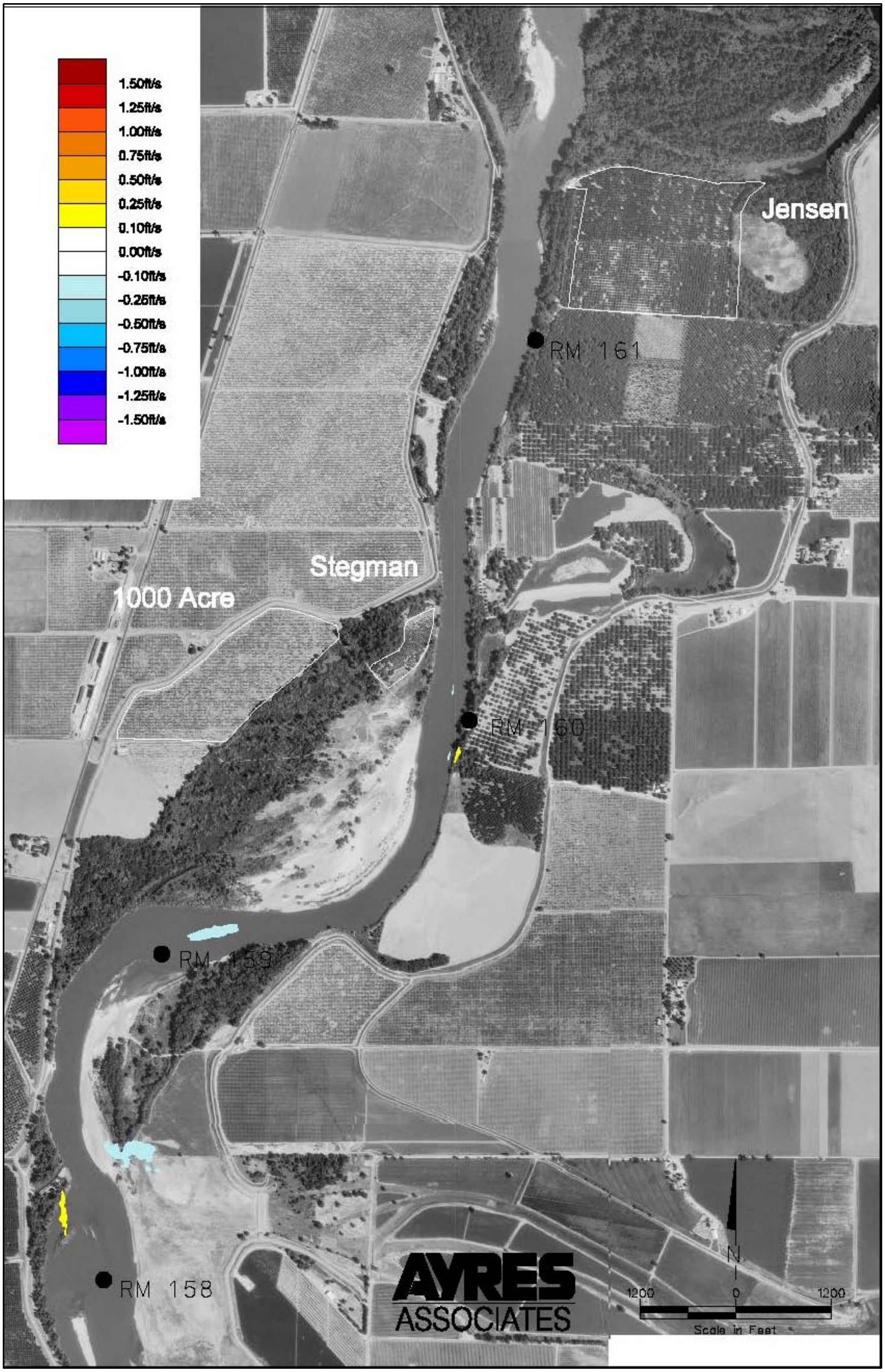


RM 154
AYRES ASSOCIATES
11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
RM 153
RM 152
RM 150
RM 151
RM 149
Boeger
RM 148
N
1200
0
1200
Scale in Feet

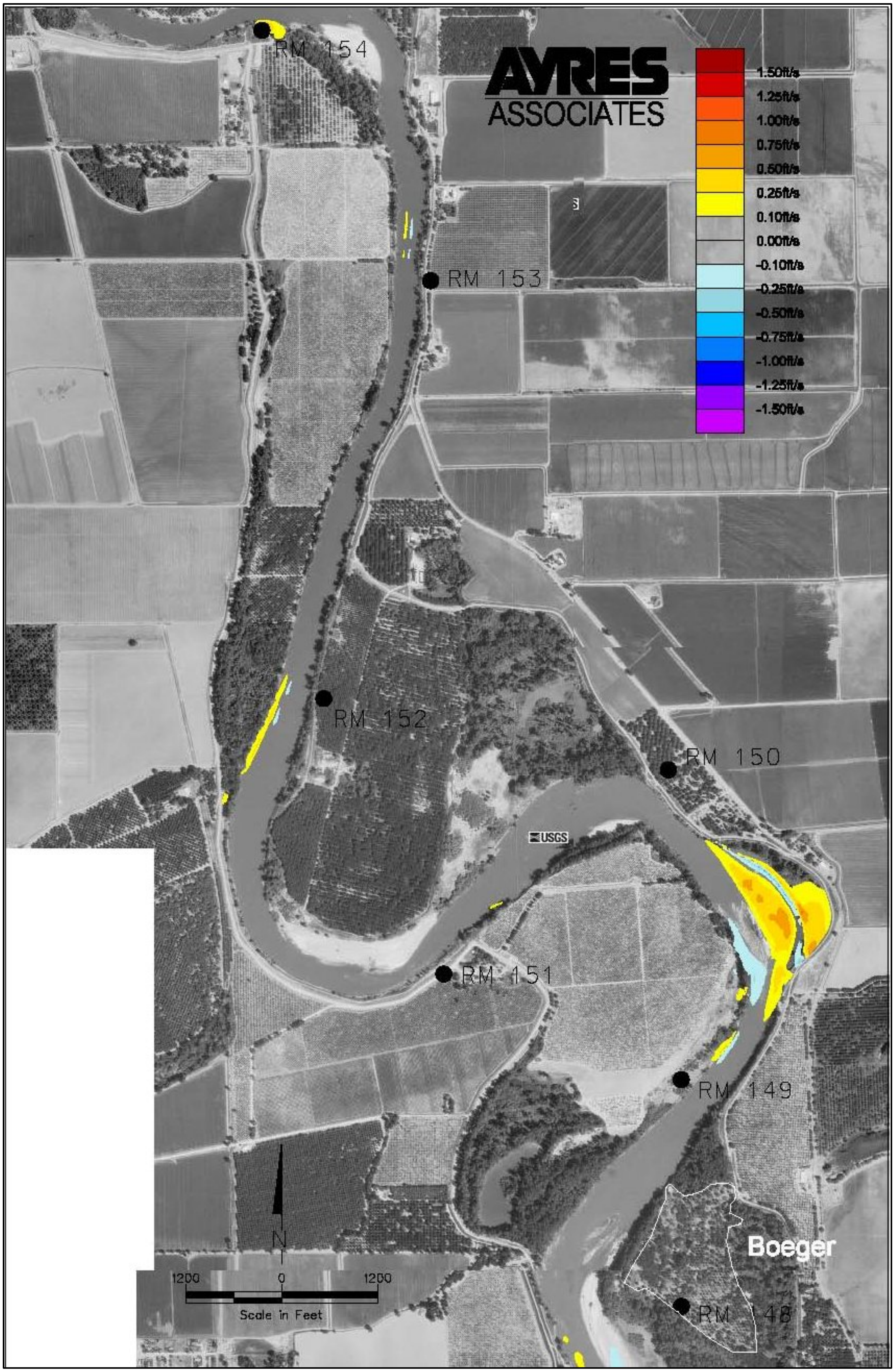

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Colusa North
RM 147
Ward
RM 146
Cruise'n Tarry
RM 145
N
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

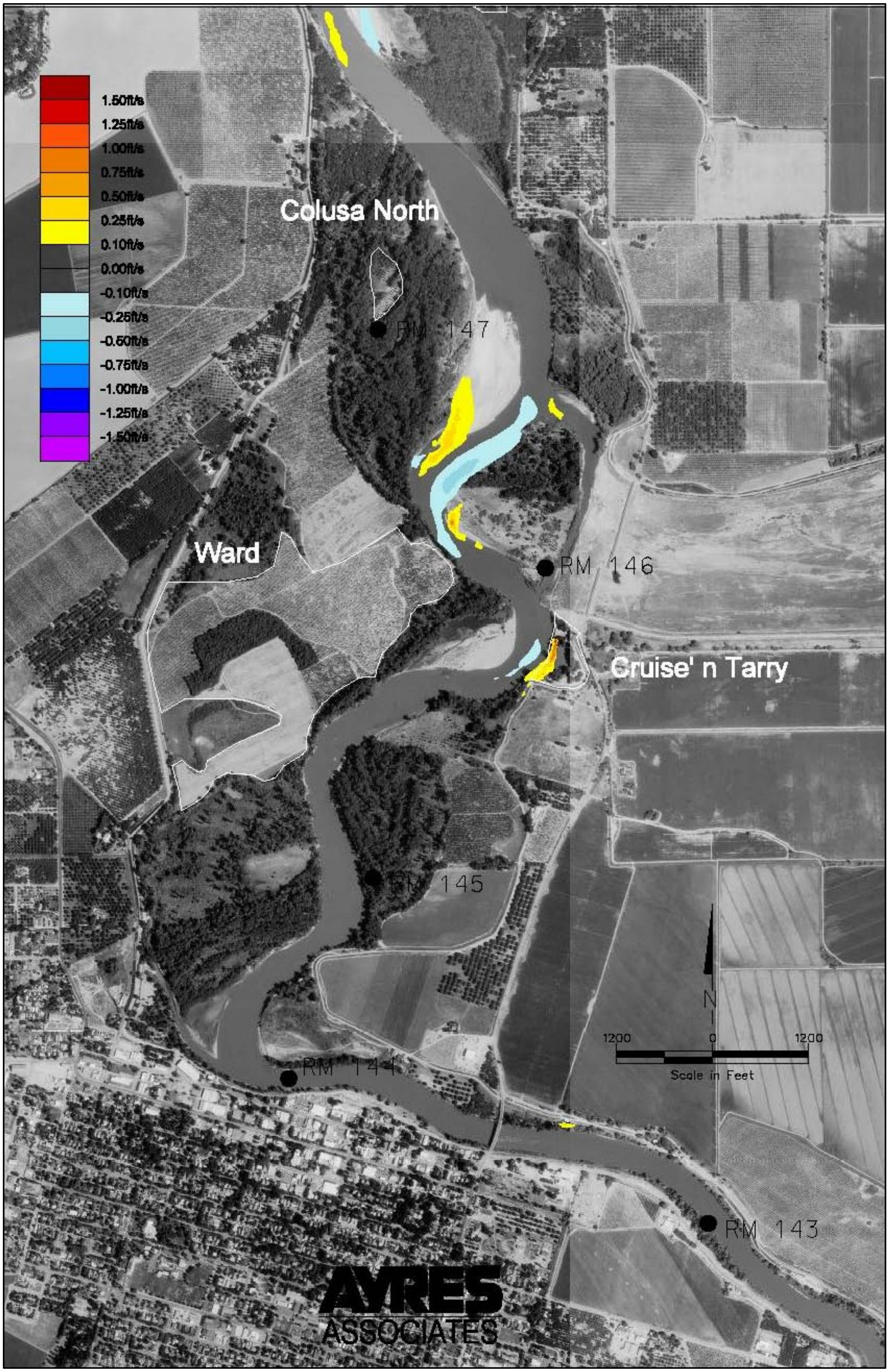
Appendix G – Velocity Differential Plots
Debris Run to Existing Conditions


RM 165
1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.50ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.50ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
N
1200
0
1200
Scale in Feet
RM 164
RM 163
RM 162
Womble
AYRES
ASSOCIATES

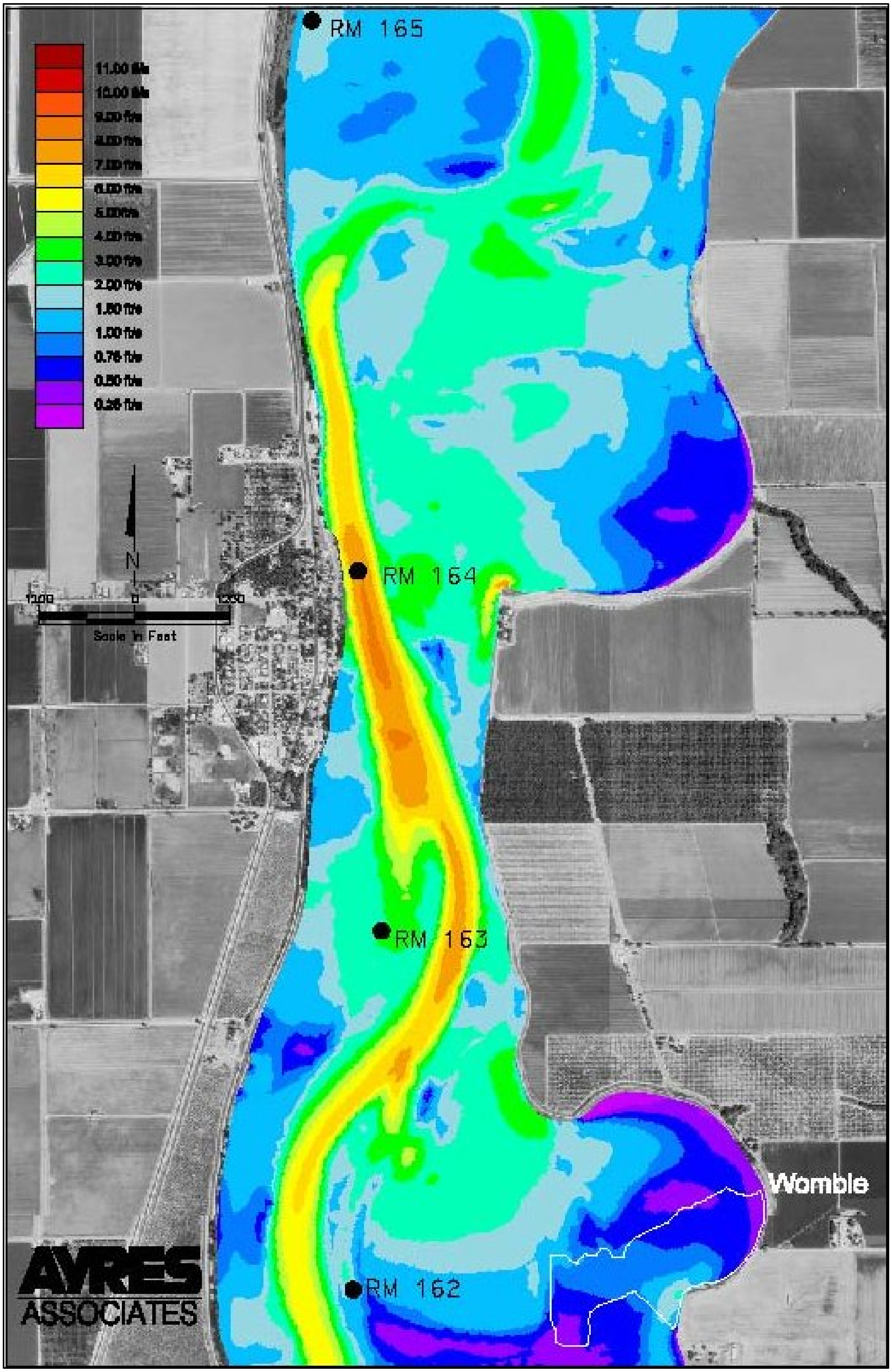

1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.50ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.50ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES ASSOCIATES
N
1200
0
1200
Scale in Feet

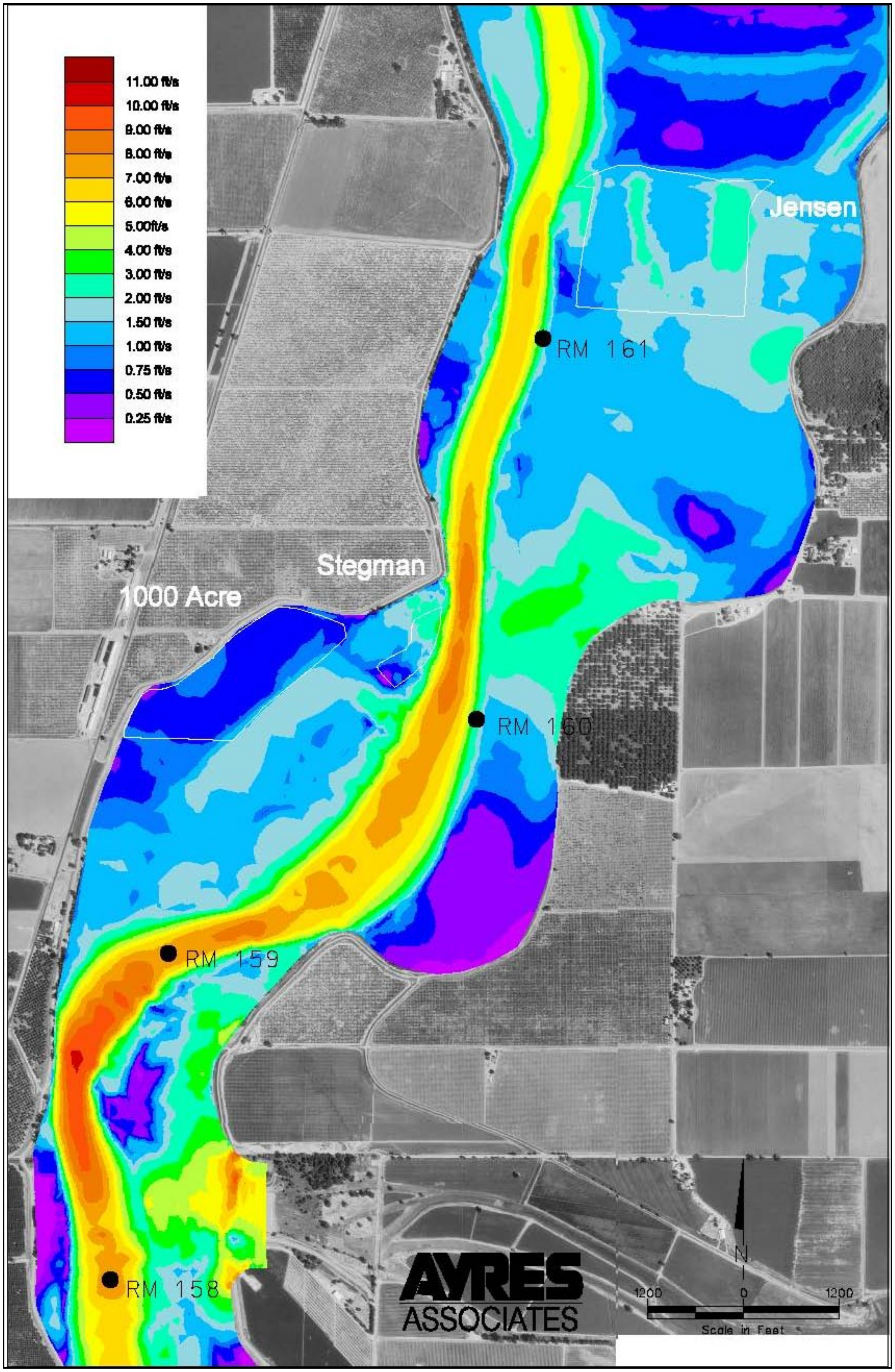

1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.50ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.50ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
RM 158
RM 157
RM 156
RM 155
RM 154
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

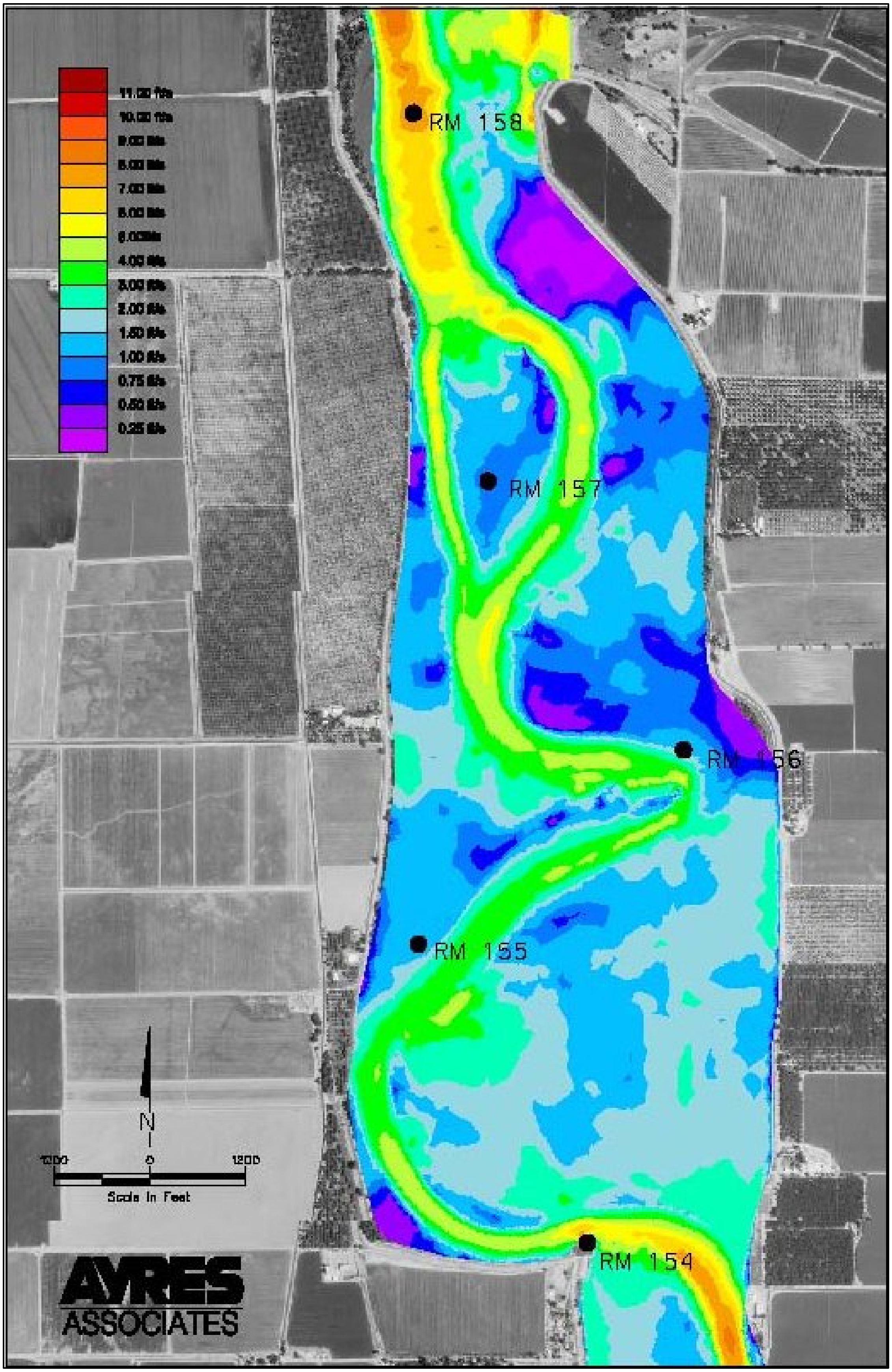

AYRES ASSOCIATES
1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.50ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.50ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
USGS
Boeger
N
1200
0
1200
Scale in Feet

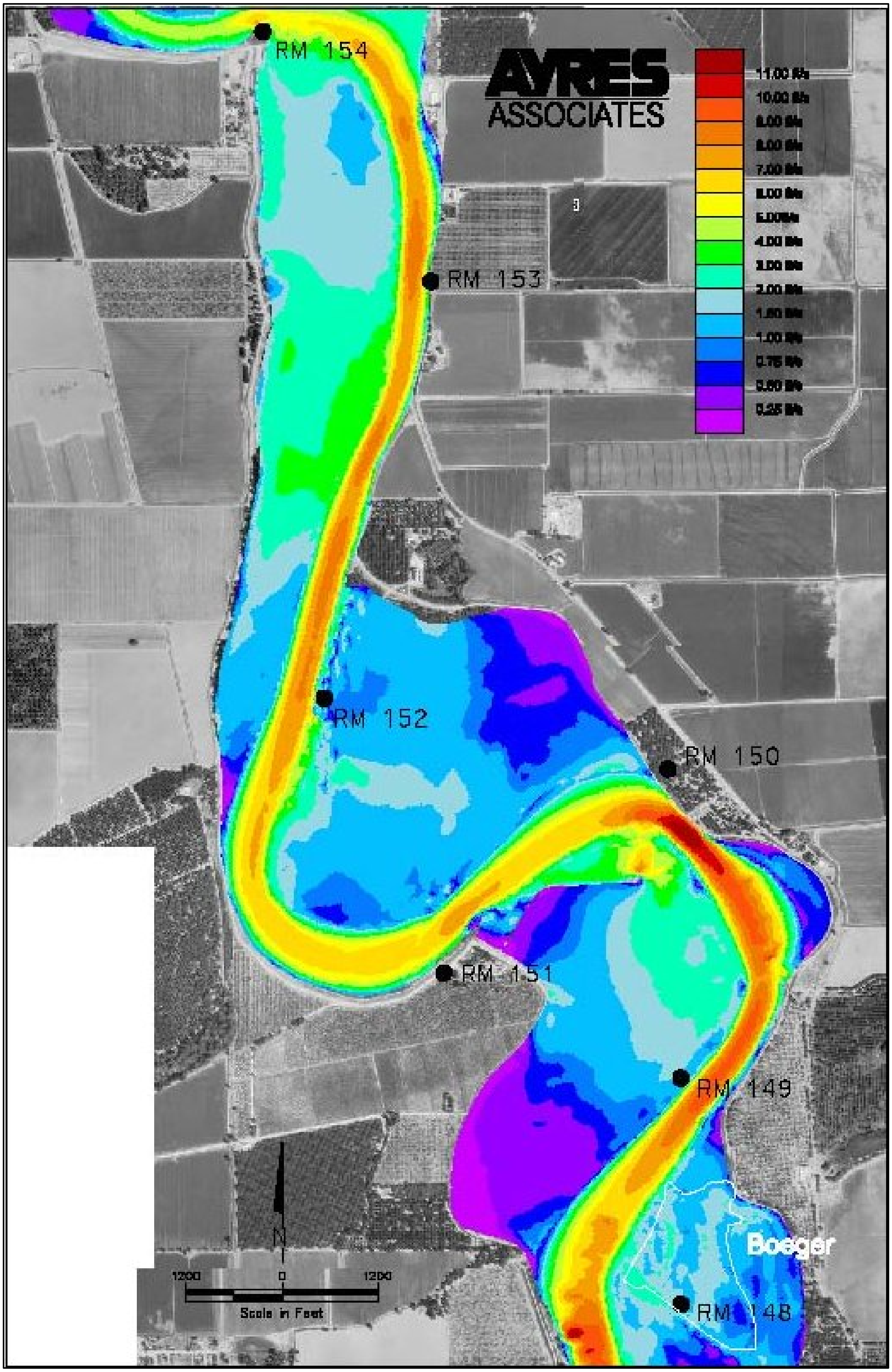

1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.50ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.50ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
Colusa North
RM 147
Ward
RM 146
Cruise' n Tarry
RM 145
N
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

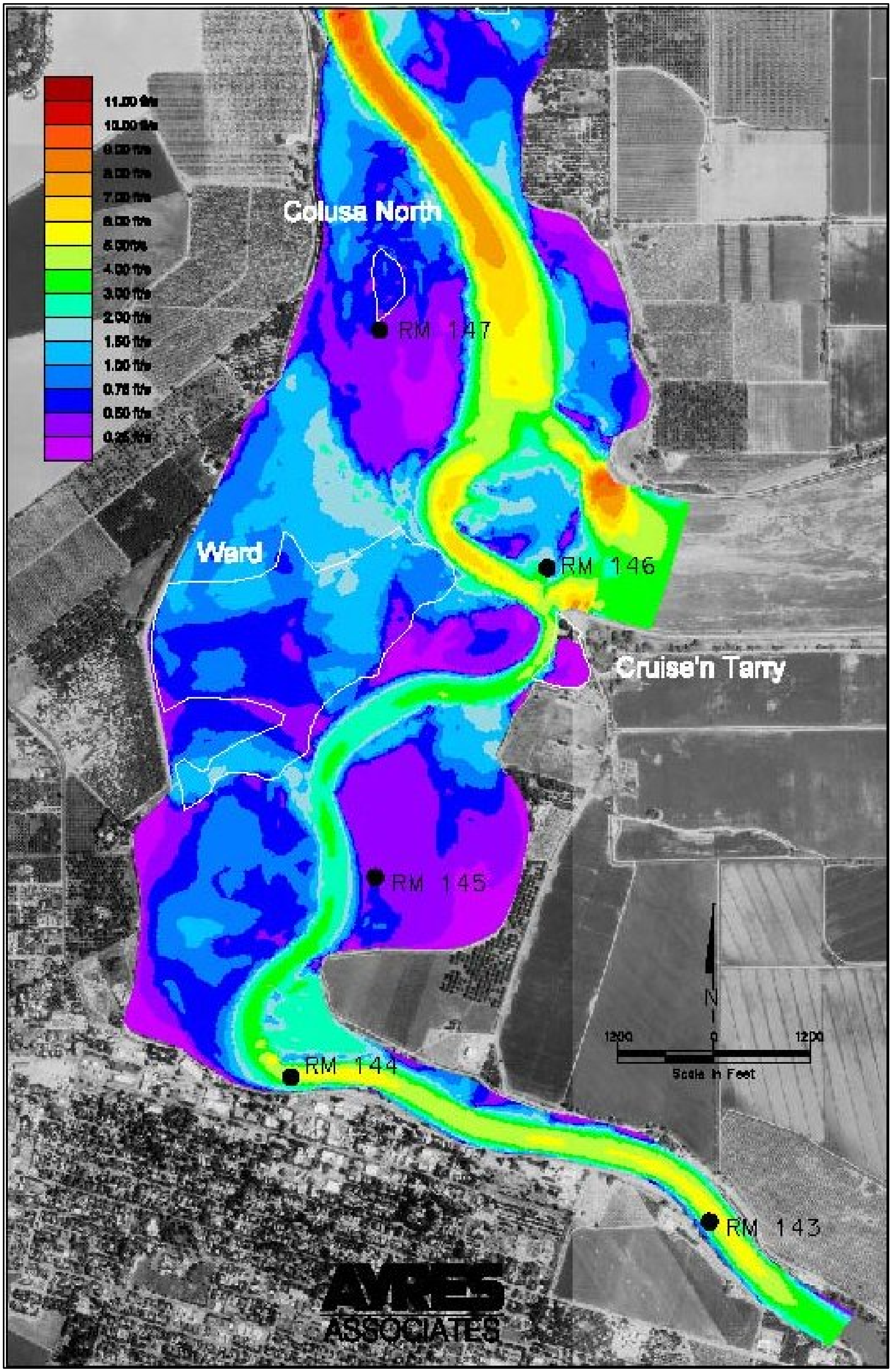
Appendix H – Velocity Plots
With-Project Conditions


RM 165
11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00 ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
N
1000
0
1000
Scale In Feet
RM 164
RM 163
Womble
RM 162
AYRES
ASSOCIATES


11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
N
AYRES ASSOCIATES
1200
0
1200
Scale in Feet

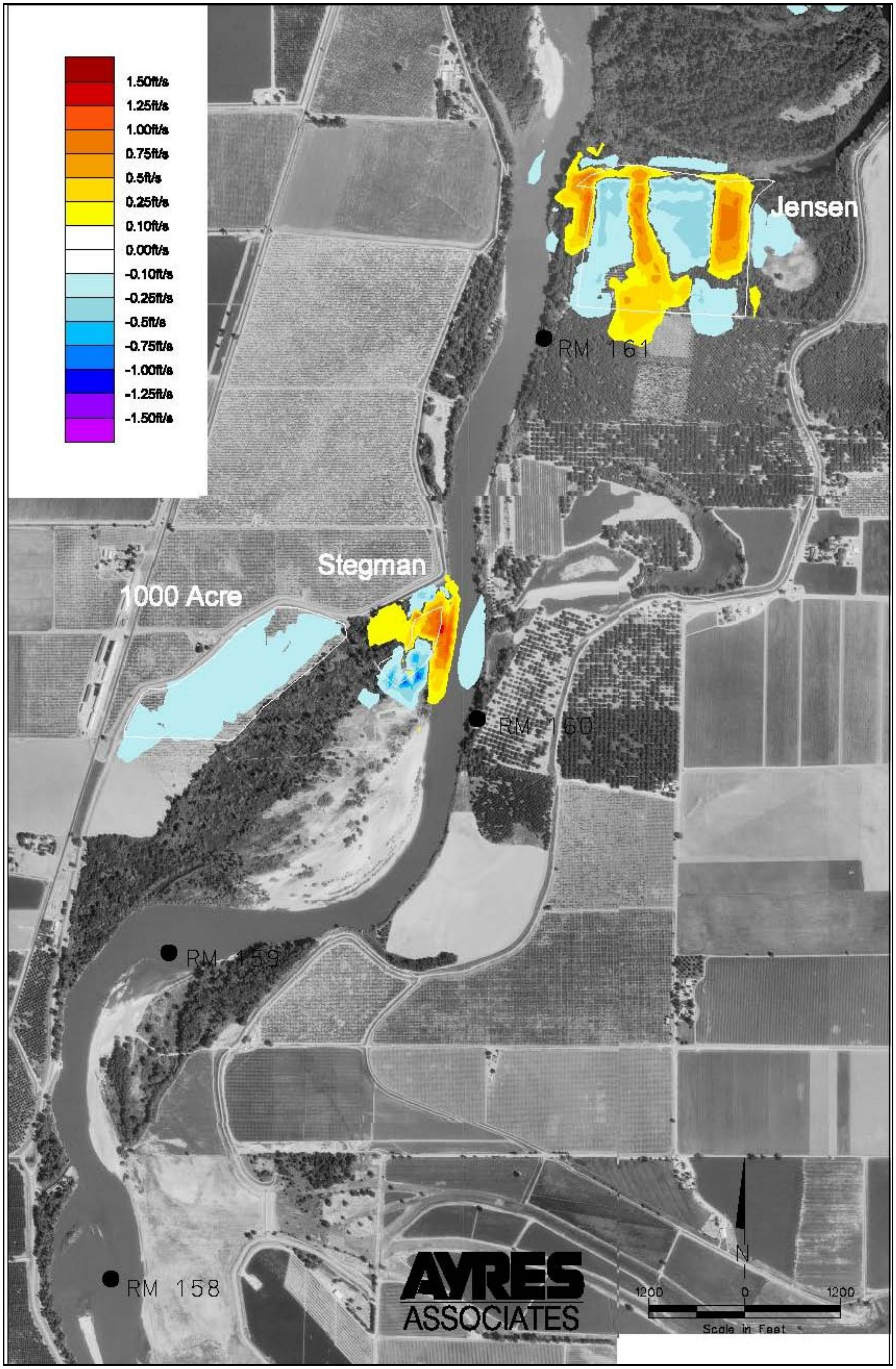

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00 ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
RM 158
RM 157
RM 156
RM 155
RM 154
N
1200 0 1200
Scale In Feet
AYRES ASSOCIATES


AYRES
ASSOCIATES
RM 154
RM 153
RM 152
RM 150
RM 151
RM 149
RM 148
Boeger
N
1200
0
1200
Scale in Feet

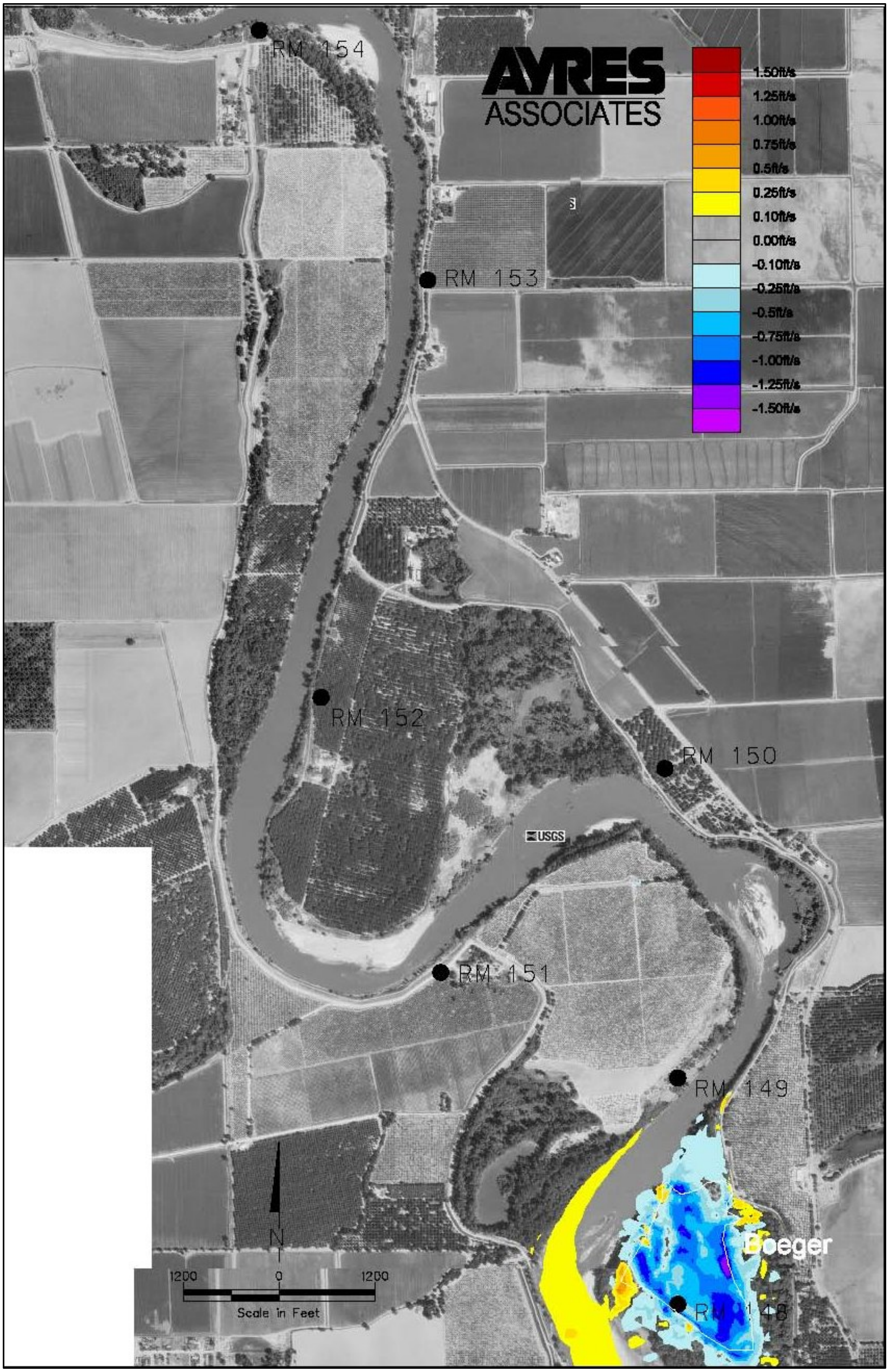

11.00 ft/s
10.00 ft/s
9.00 ft/s
8.00 ft/s
7.00 ft/s
6.00 ft/s
5.00ft/s
4.00 ft/s
3.00 ft/s
2.00 ft/s
1.50 ft/s
1.00 ft/s
0.75 ft/s
0.50 ft/s
0.25 ft/s
Colusa North
RM 147
Ward
RM 146
Cruise'n Tarry
RM 145
RM 144
RM 143
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

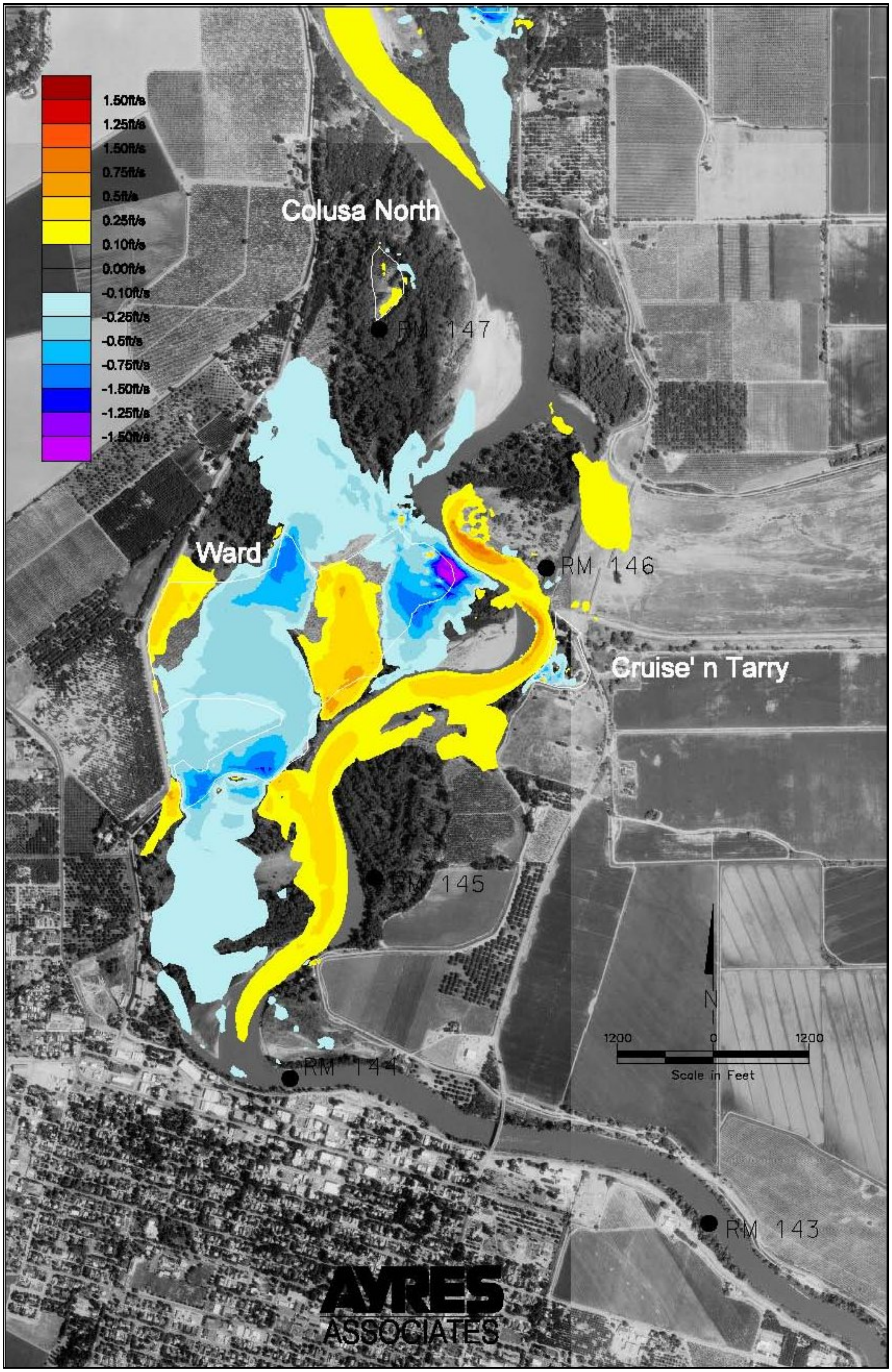
Appendix I – Velocity Differential Plots With-Project Conditions to Existing Conditions


1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.5ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.5ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
N
1200
0
1200
Scale in Feet
RM 165
RM 164
RM 163
RM 162
Womble
AYRES
ASSOCIATES


1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.5ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.5ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES ASSOCIATES
N
1200
0
1200
Scale in Feet

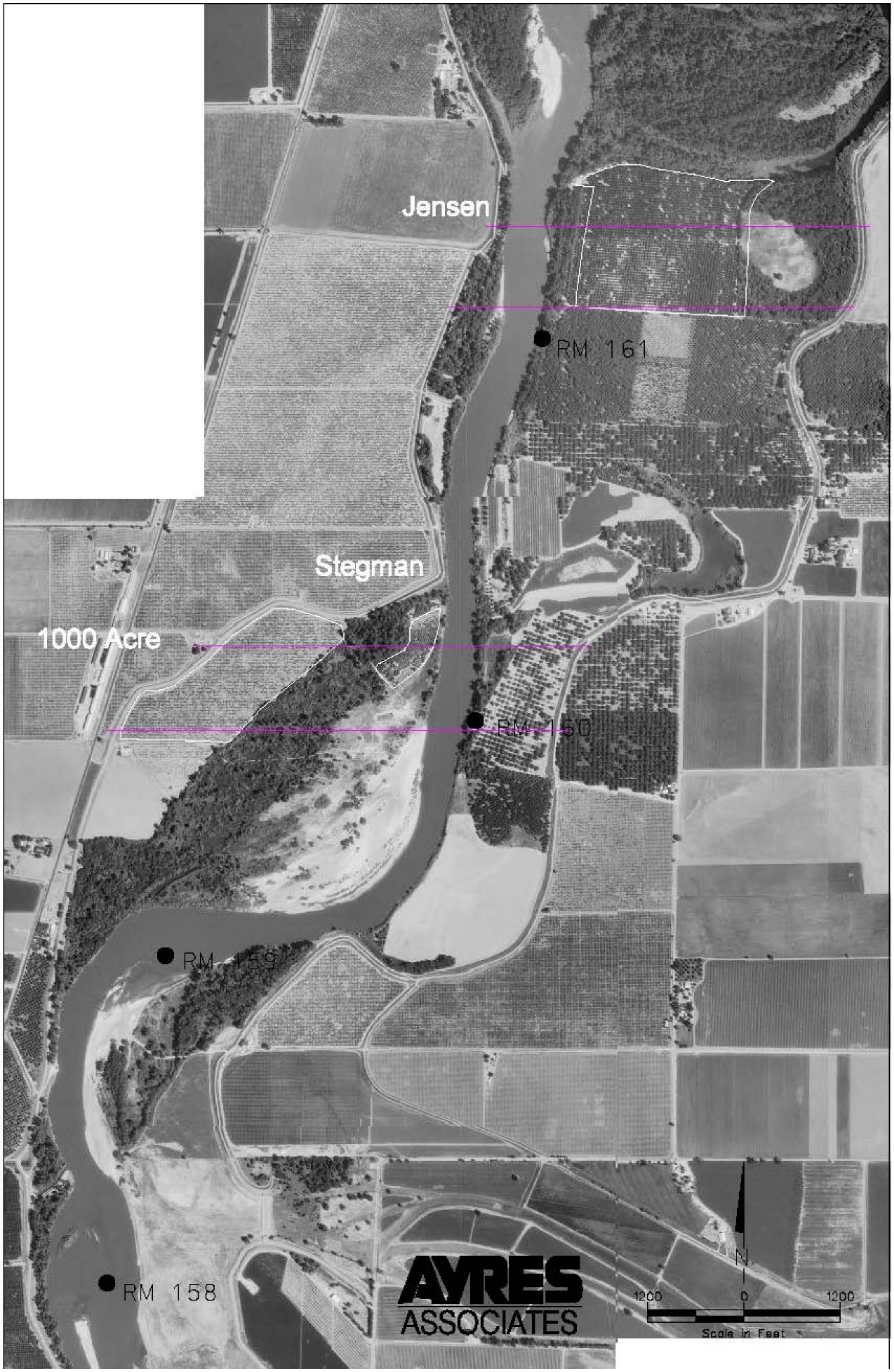

1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.5ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.5ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
RM 158
RM 157
RM 156
RM 155
RM 154
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

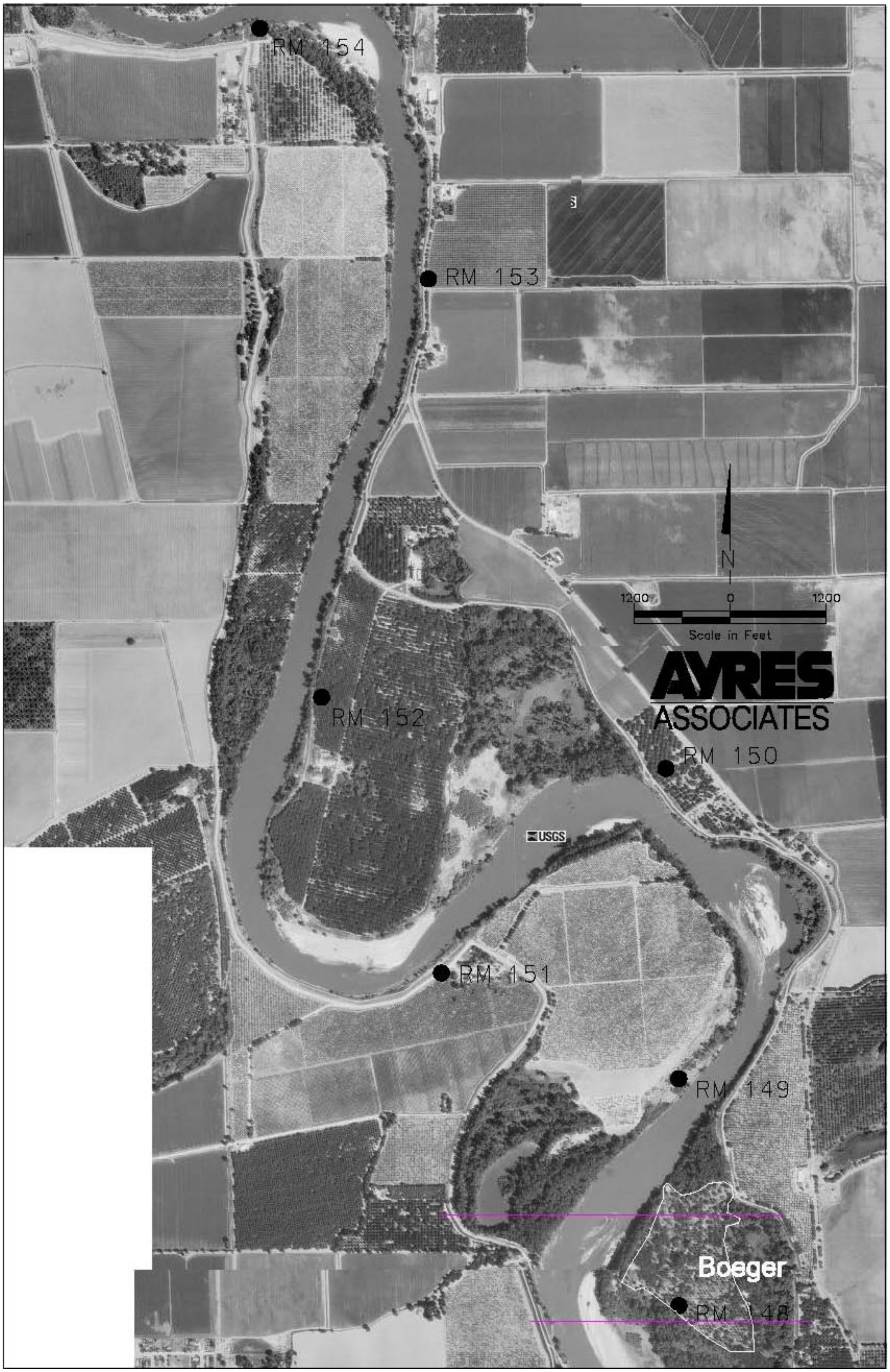

RM 154
AYRES ASSOCIATES
1.50ft/s
1.25ft/s
1.00ft/s
0.75ft/s
0.5ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.5ft/s
-0.75ft/s
-1.00ft/s
-1.25ft/s
-1.50ft/s
RM 153
RM 152
RM 150
USGS
RM 151
RM 149
Boeger
N
1200
0
1200
Scale in Feet

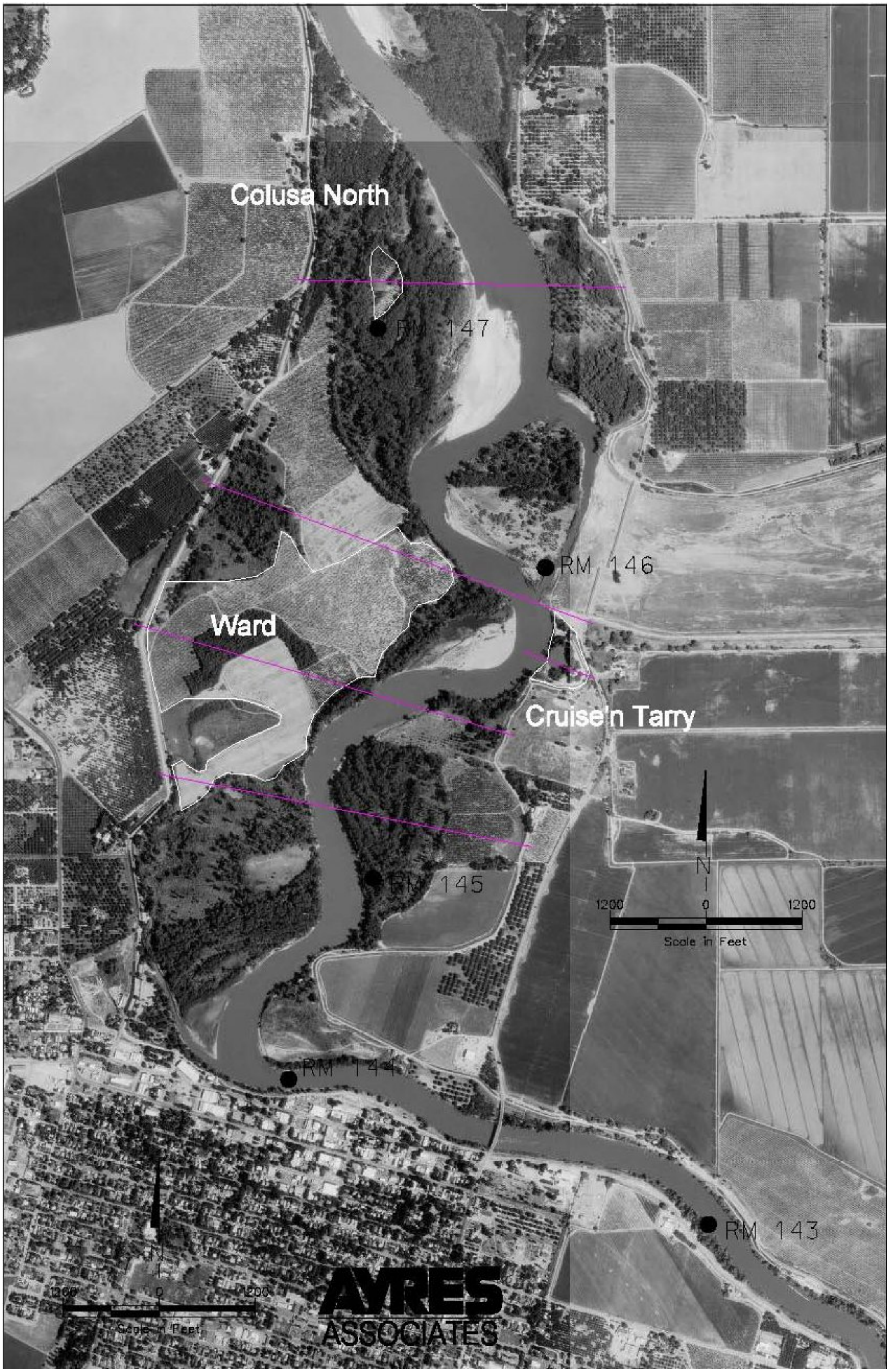

1.50ft/s
1.25ft/s
1.50ft/s
0.75ft/s
0.5ft/s
0.25ft/s
0.10ft/s
0.00ft/s
-0.10ft/s
-0.25ft/s
-0.5ft/s
-0.75ft/s
-1.50ft/s
-1.25ft/s
-1.50ft/s
Colusa North
RM 147
Ward
RM 146
Cruise' n Tarry
RM 145
N
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

Appendix J -
Cross Section Locations
for Water Surface Elevation Comparisons

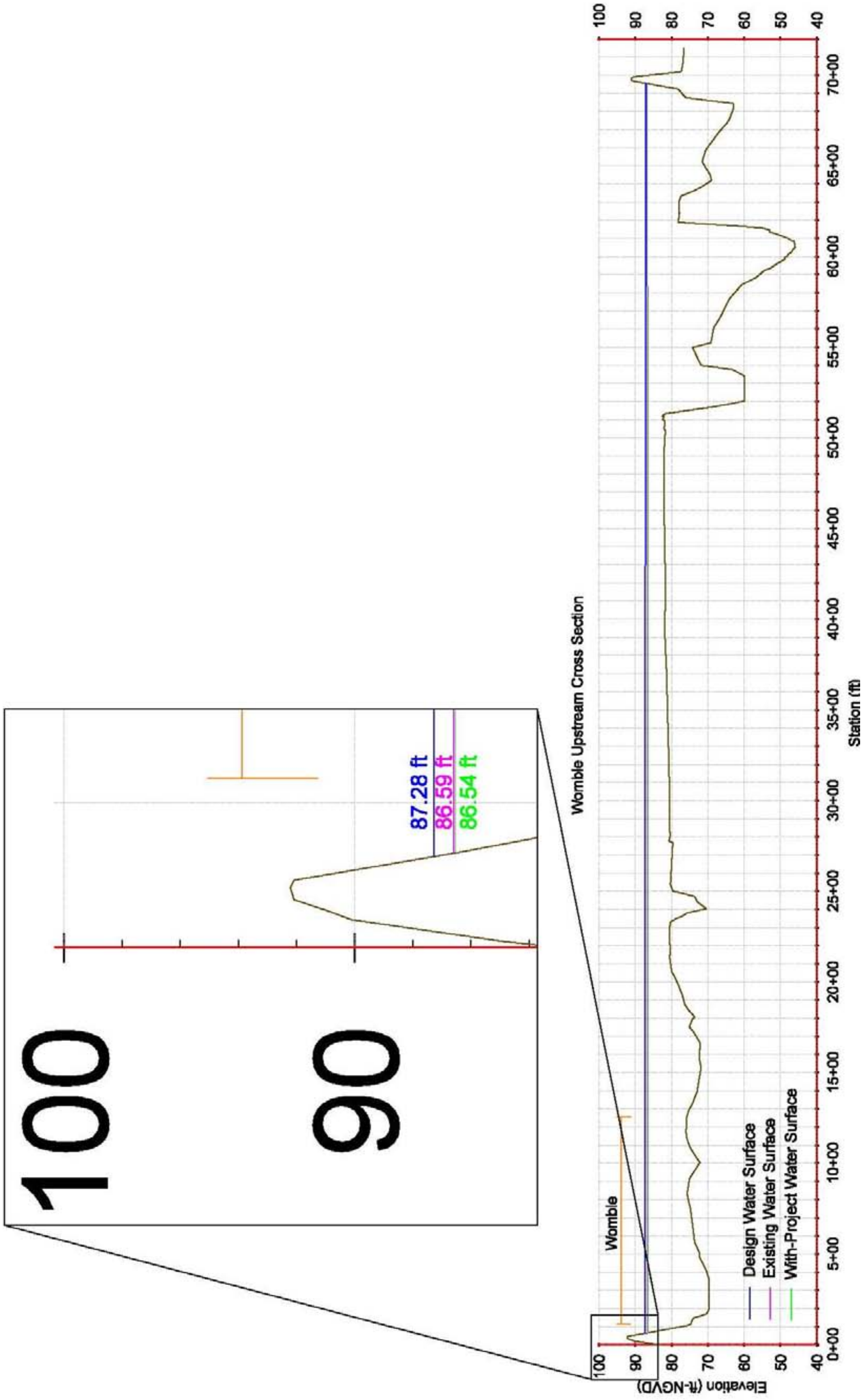

RM 165
RM 164
N
1200
0
1200
Scale in Feet
RM 163
Womble
RM 162
AYRES
ASSOCIATES

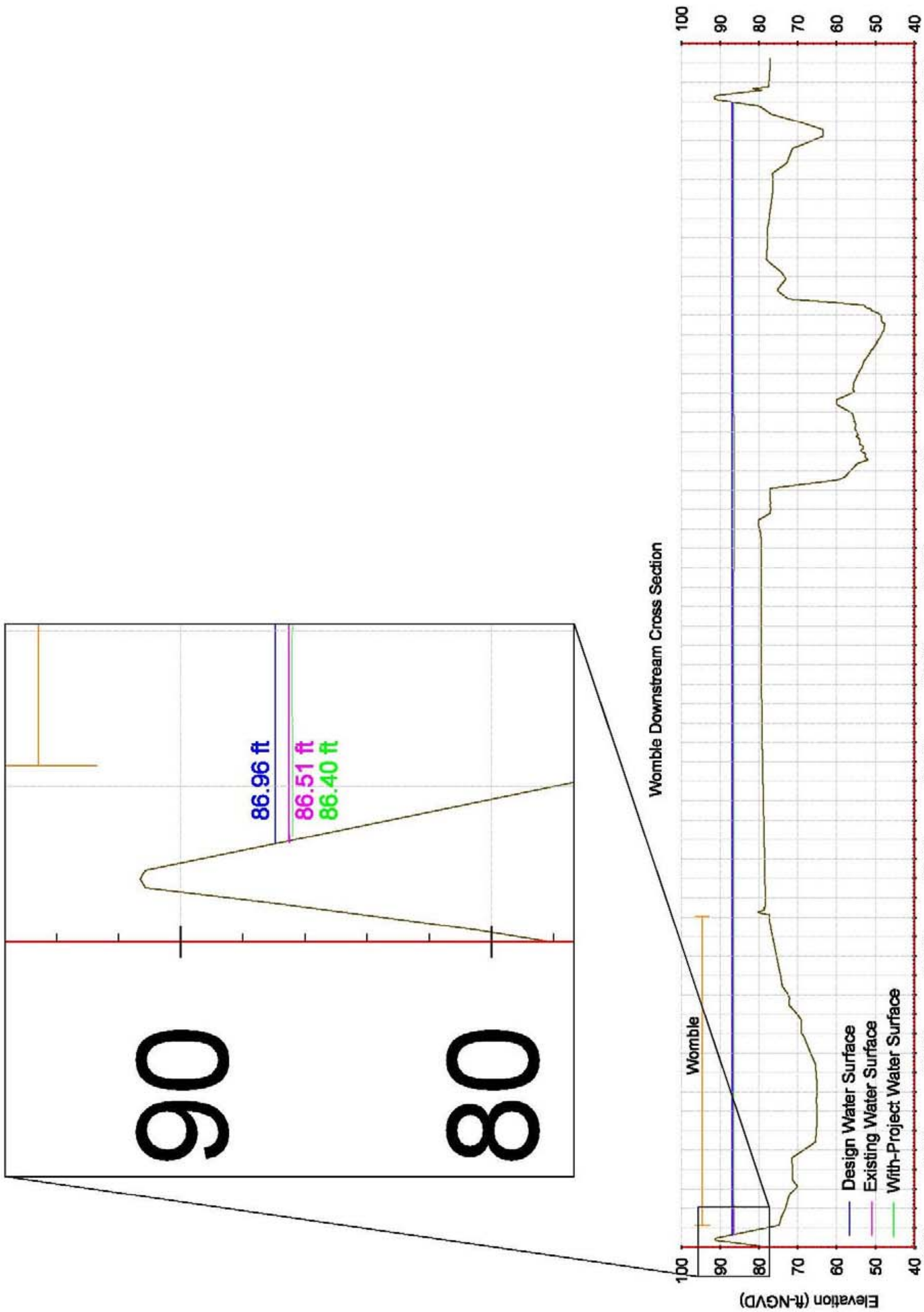

Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES
ASSOCIATES
N
1200
0
1200
Scale in Feet

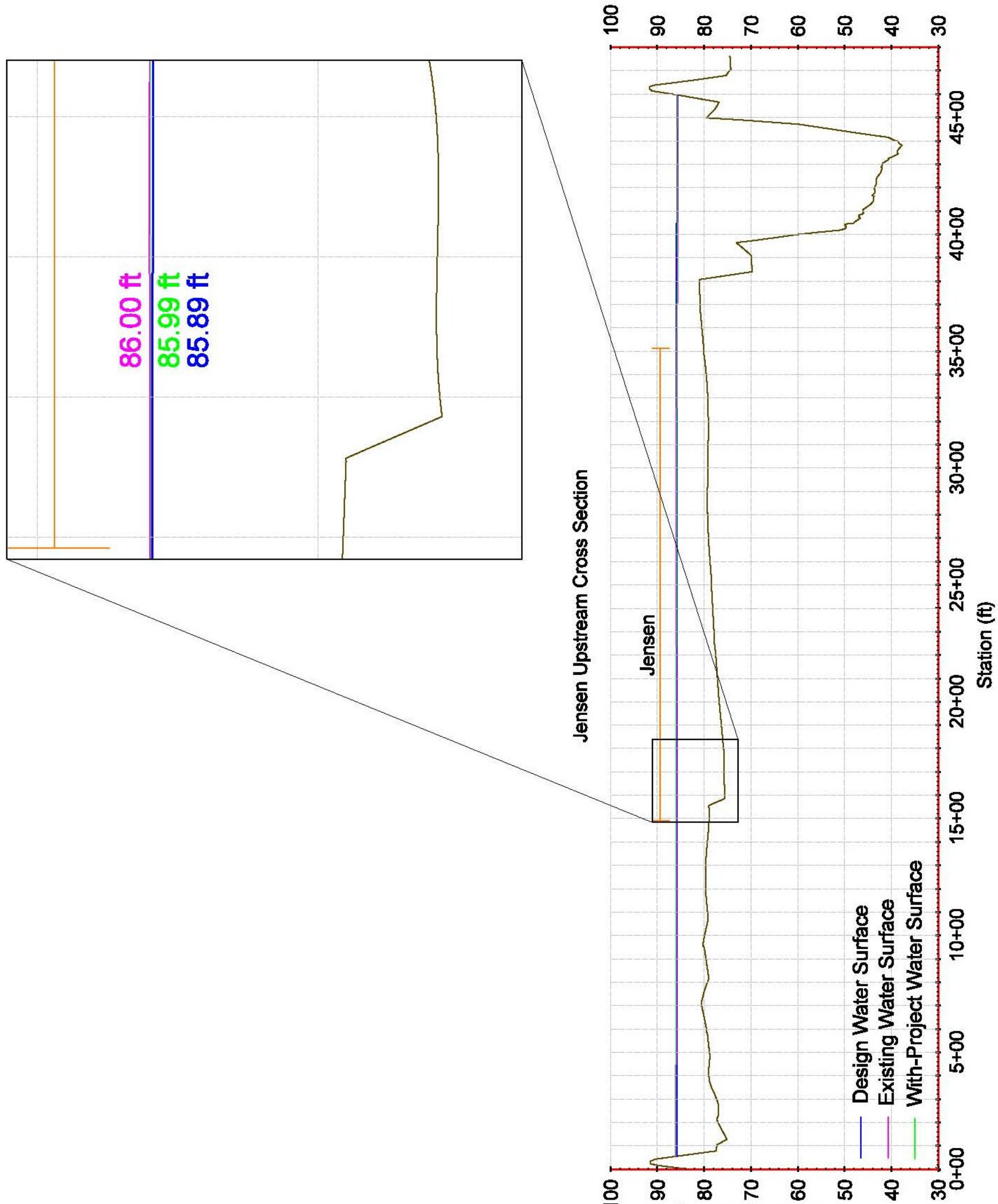

RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES
USGS
Boeger

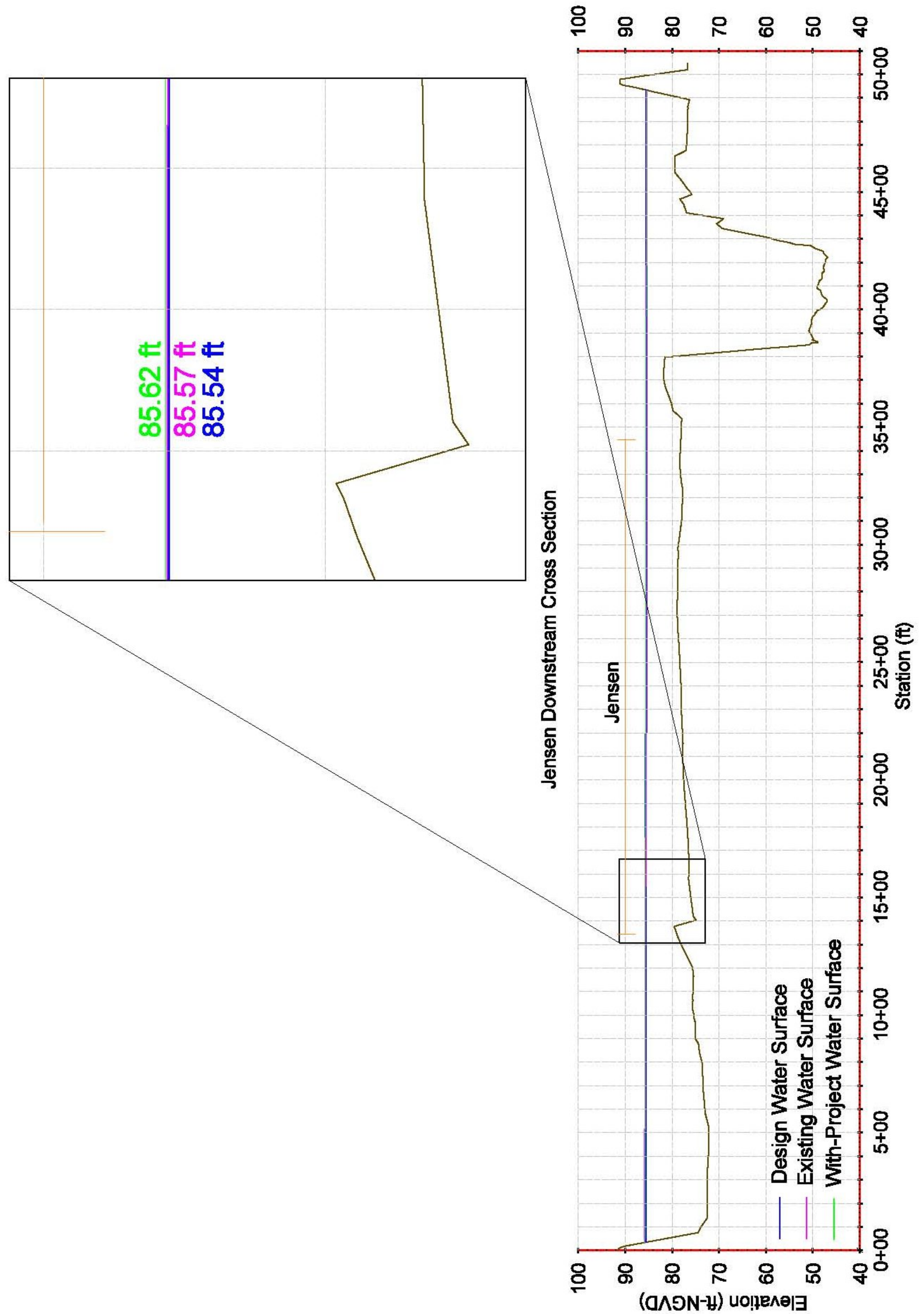

Colusa North
RM 147
RM 146
Ward
Cruise'n Tarry
RM 145
N
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

Appendix K - Water Surface Elevation Cross Sections for Restoration Sites

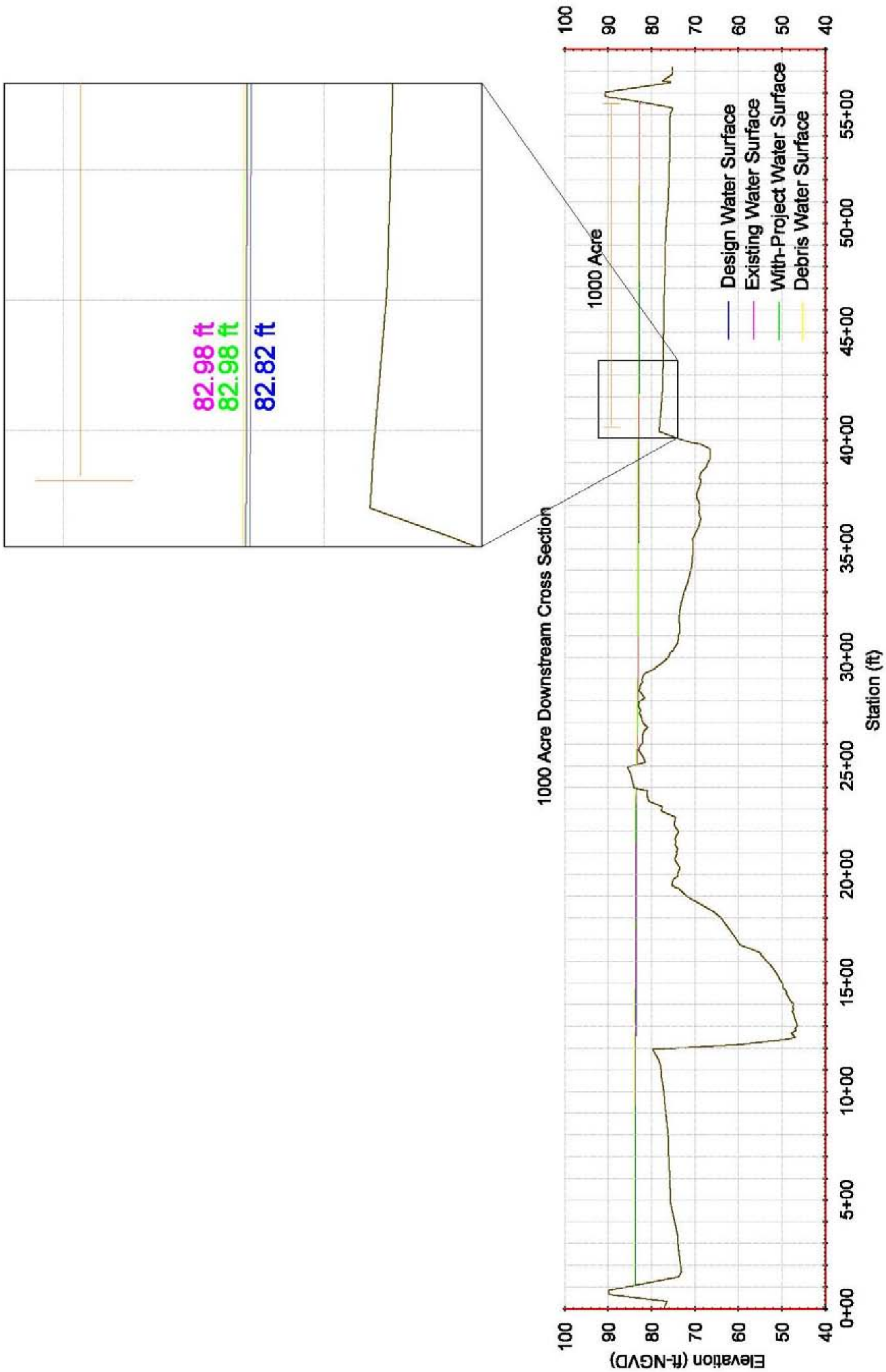

Womble Upstream Cross Section
Station (ft)
Elevation (ft-NGVD)
Womble
Design Water Surface
Existing Water Surface
With-Project Water Surface
87.28 ft
86.59 ft
86.54 ft

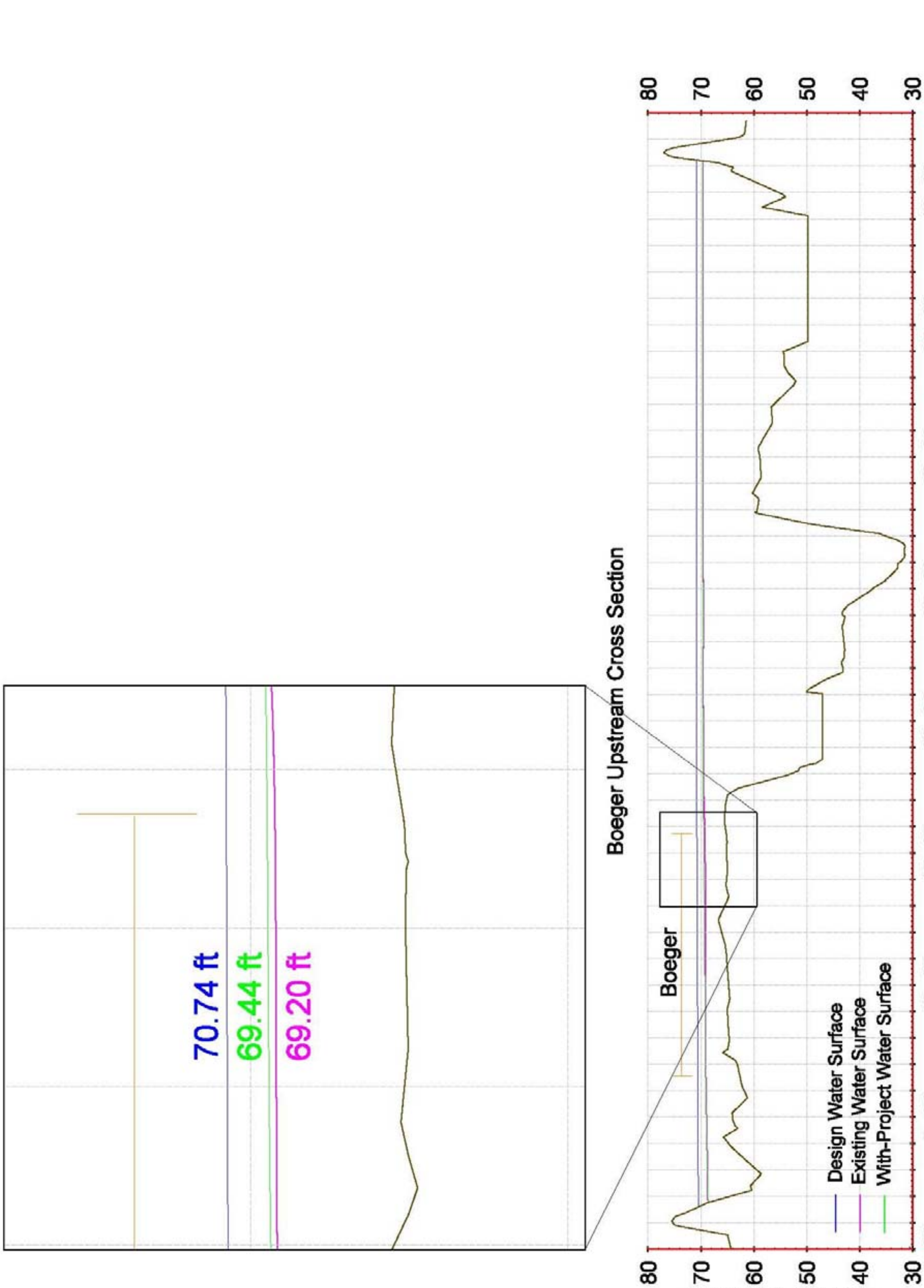

Womble Downstream Cross Section
Womble
86.96 ft
86.51 ft
86.40 ft
90
80
Design Water Surface
Existing Water Surface
With-Project Water Surface
Elevation (ft-NGVD)
Station (ft)
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00
55+00
60+00
100
90
80
70
60
50
40

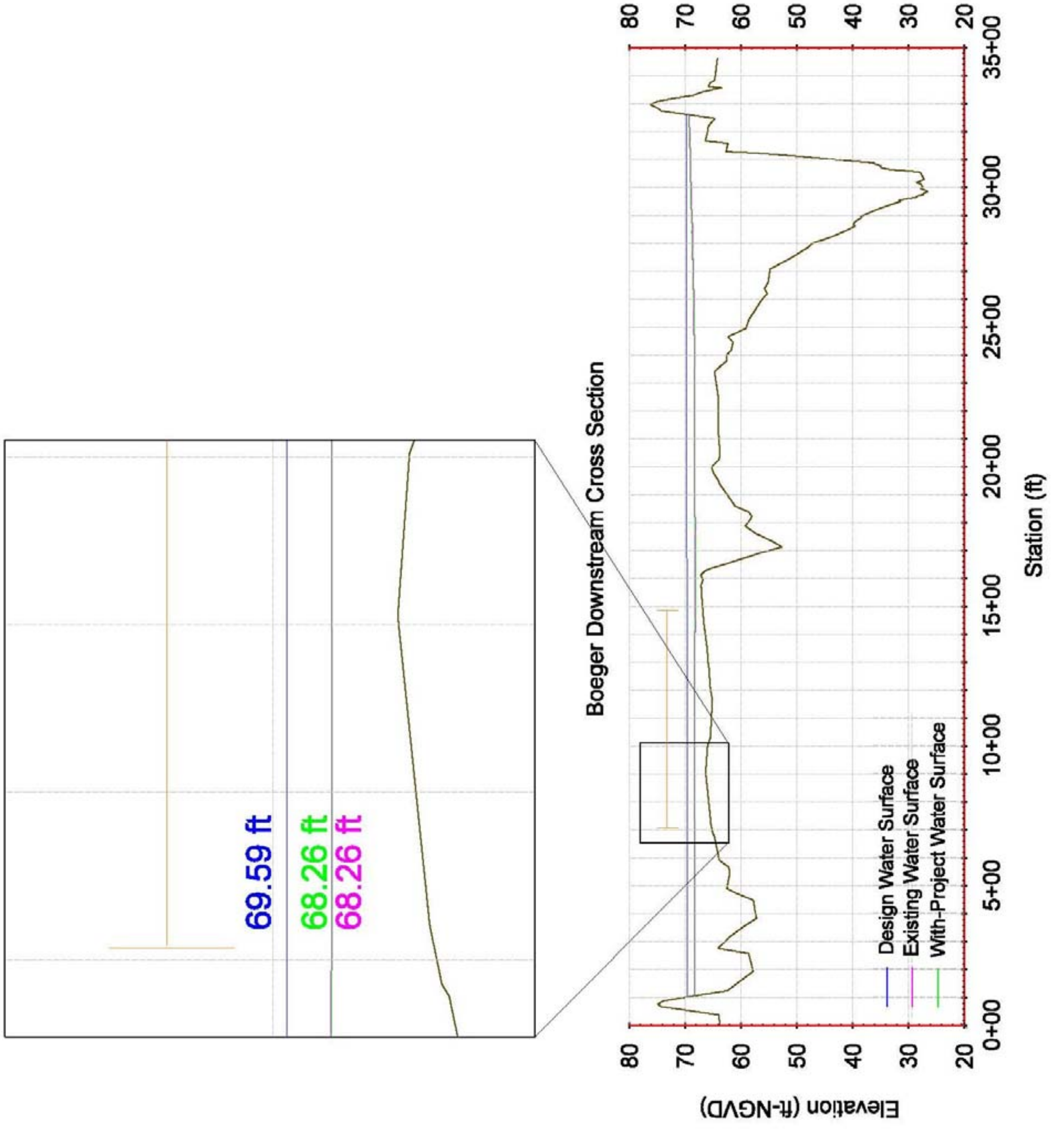

Jensen Upstream Cross Section
Jensen
86.00 ft
85.99 ft
85.89 ft
Design Water Surface
Existing Water Surface
With-Project Water Surface
Elevation (ft-NGVD)
Station (ft)
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
30
40
50
60
70
80
90
100

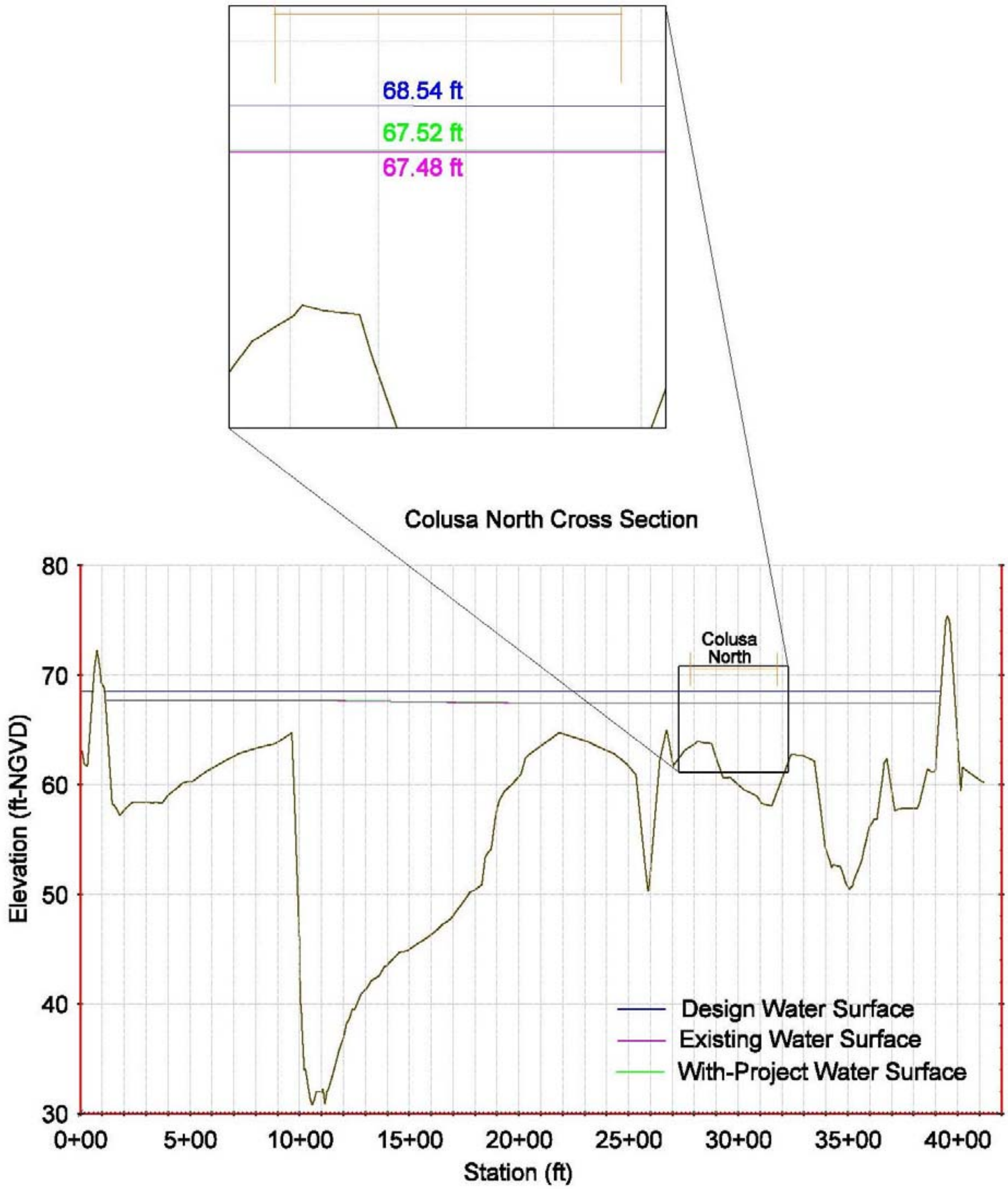

Jensen Downstream Cross Section
Jensen
85.62 ft
85.57 ft
85.54 ft
Design Water Surface
Existing Water Surface
With-Project Water Surface
Elevation (ft-NGVD)
Station (ft)
100
90
80
70
60
50
40
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00

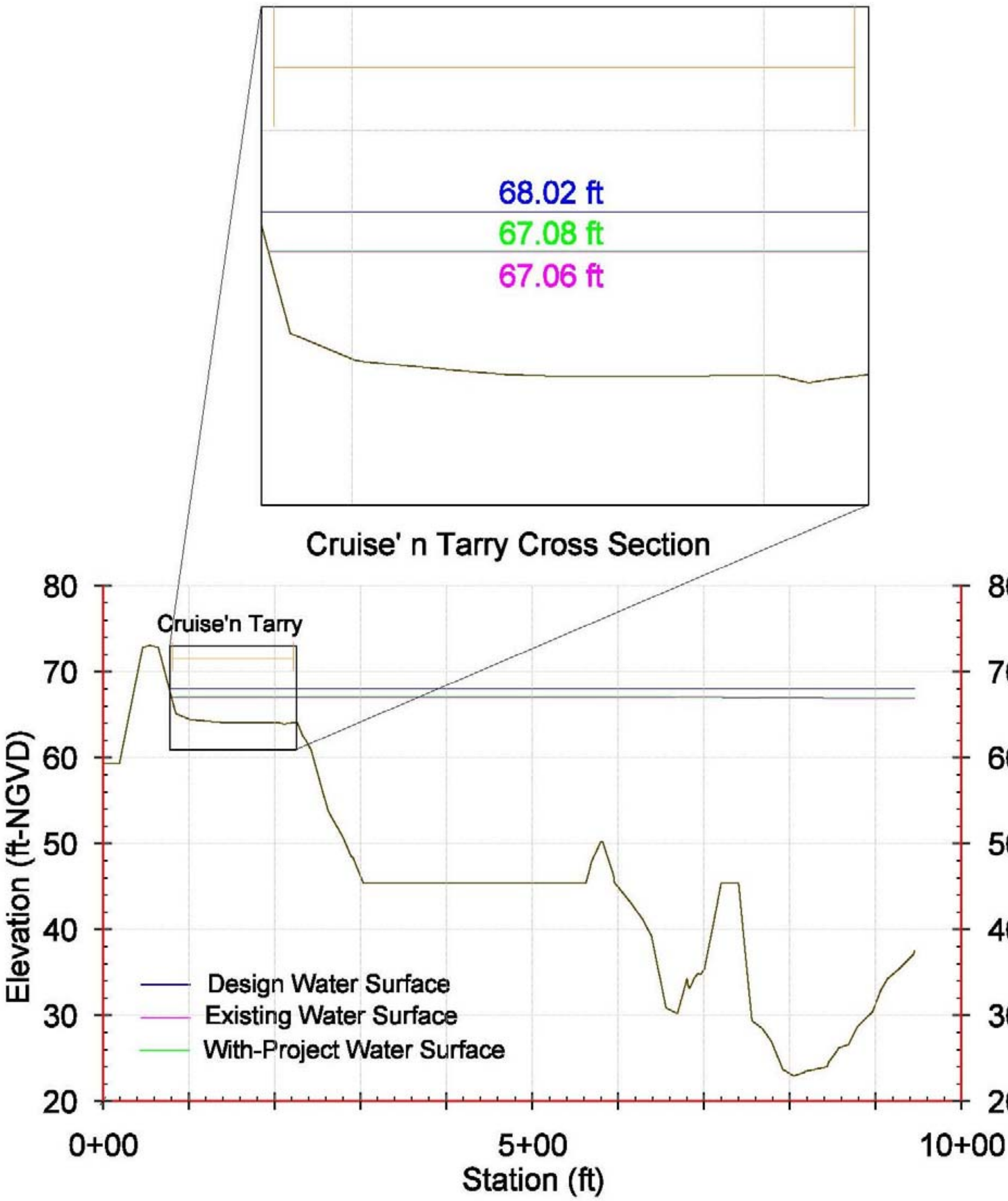

1000 Acre Upstream and Stegman Cross Section
Stegman
1000 Acre
83.95 ft
83.88 ft
83.76 ft
83.30 ft
83.10 ft
83.08 ft
Design Water Surface
Existing Water Surface
With-Project Water Surface
Debris Water Surface
Elevation (ft-NGVD)
Station (ft)
100
90
80
70
60
50
40
30
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00


1000 Acre Downstream Cross Section
1000 Acre
82.98 ft
82.98 ft
82.82 ft
Design Water Surface
Existing Water Surface
With-Project Water Surface
Debris Water Surface
Station (ft)
Elevation (ft-NGVD)
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00
55+00
40
50
60
70
80
90
100

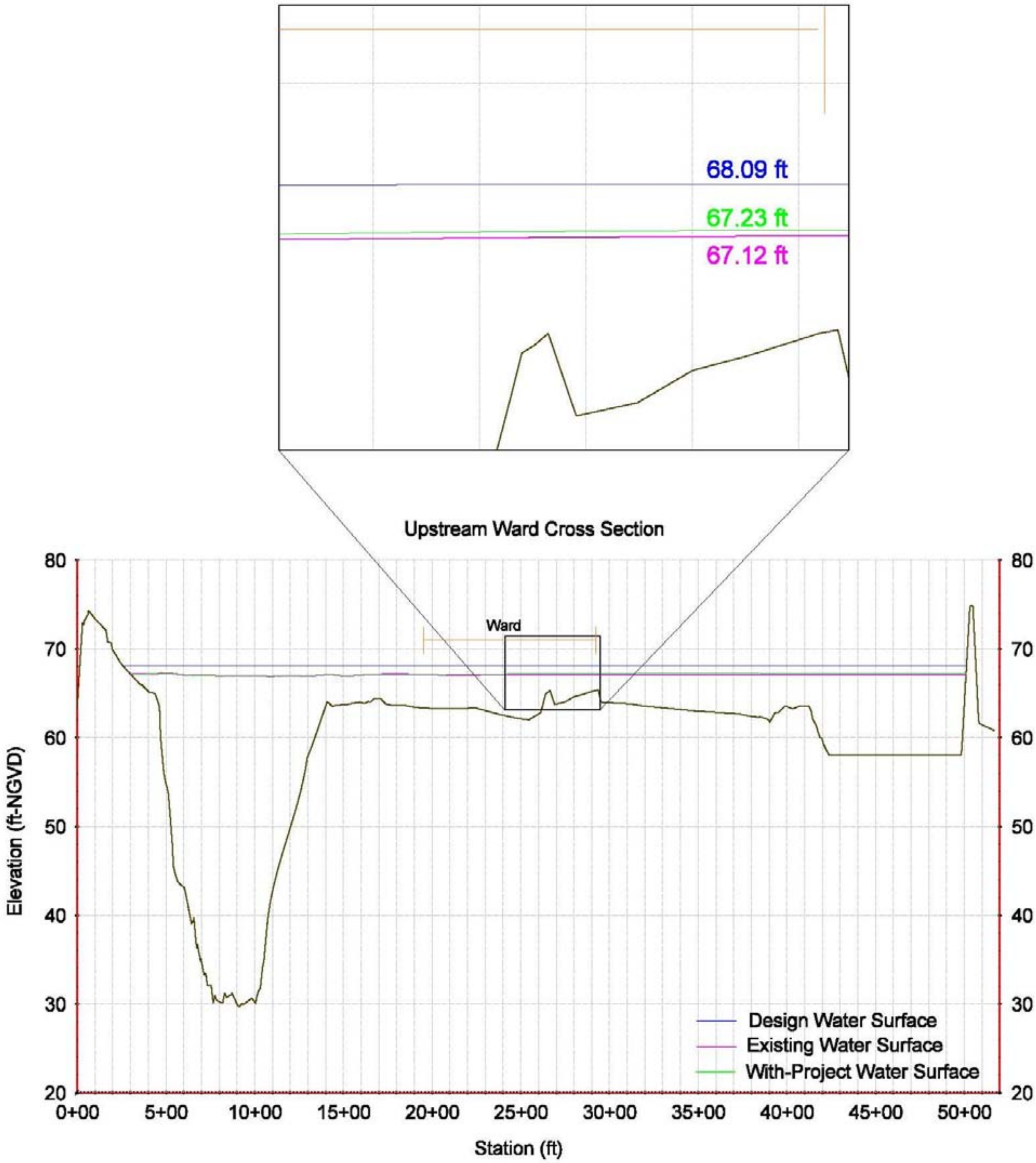

Boeger Upstream Cross Section
70.74 ft
69.44 ft
69.20 ft
Boeger
Design Water Surface
Existing Water Surface
With-Project Water Surface
Elevation (ft-NGVD)
80
70
60
50
40
30
Station (ft)
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00

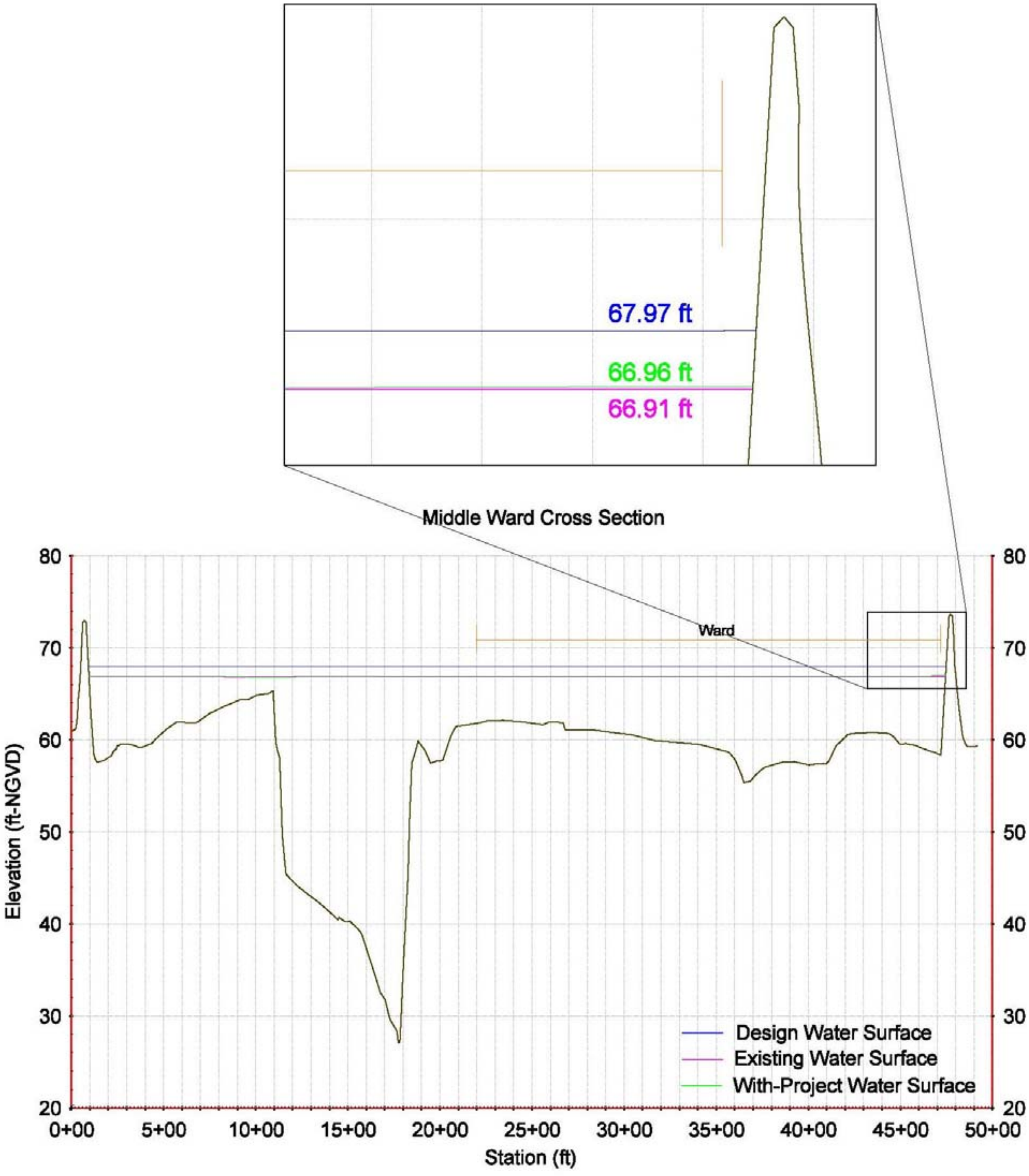

Boeger Downstream Cross Section
Station (ft)
Elevation (ft-NGVD)
Design Water Surface
Existing Water Surface
With-Project Water Surface
69.59 ft
68.26 ft
68.26 ft
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
80
70
60
50
40
30
20


68.54 ft
67.52 ft
67.48 ft
Colusa North Cross Section
Colusa North
Elevation (ft-NGVD)
Station (ft)
80
70
60
50
40
30
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
Design Water Surface
Existing Water Surface
With-Project Water Surface

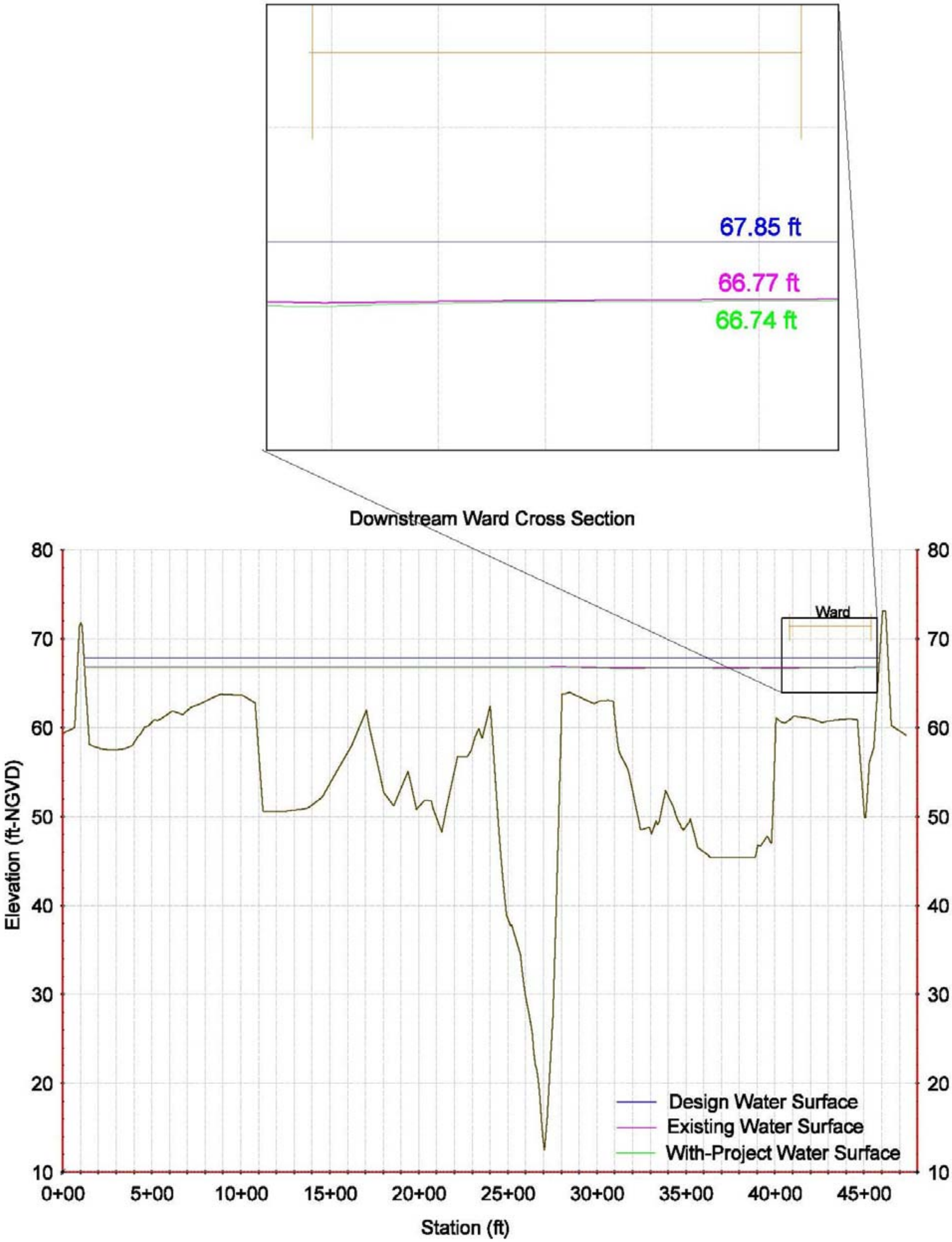


68.02 ft
67.08 ft
67.06 ft
Cruise' n Tarry Cross Section
Cruise'n Tarry
80
70
60
50
40
30
20
Elevation (ft-NGVD)
Design Water Surface
Existing Water Surface
With-Project Water Surface
0+00
5+00
10+00
Station (ft)

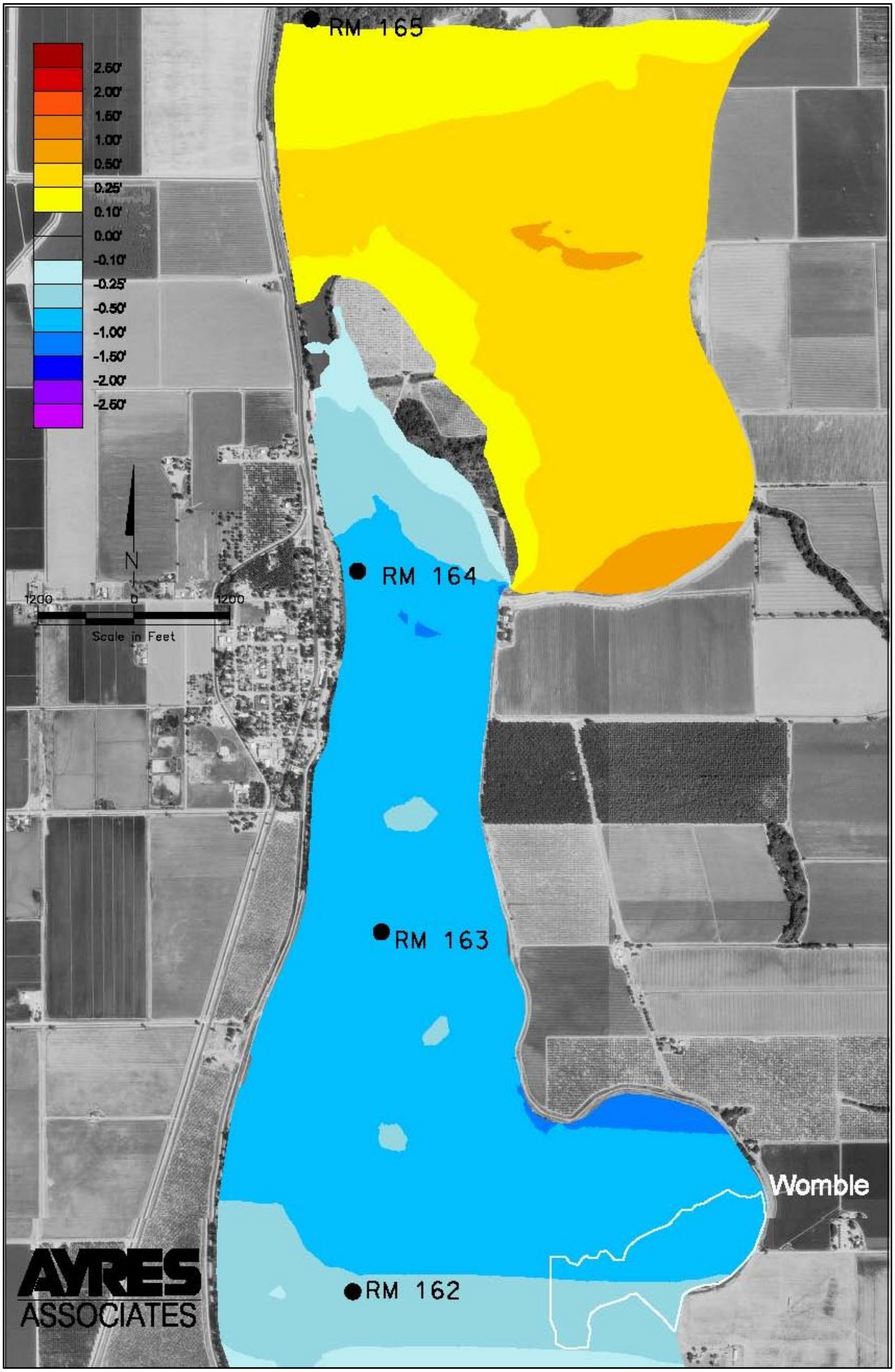

68.09 ft
67.23 ft
67.12 ft
Upstream Ward Cross Section
Ward
Elevation (ft-NGVD)
Station (ft)
Design Water Surface
Existing Water Surface
With-Project Water Surface
80
70
60
50
40
30
20
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00

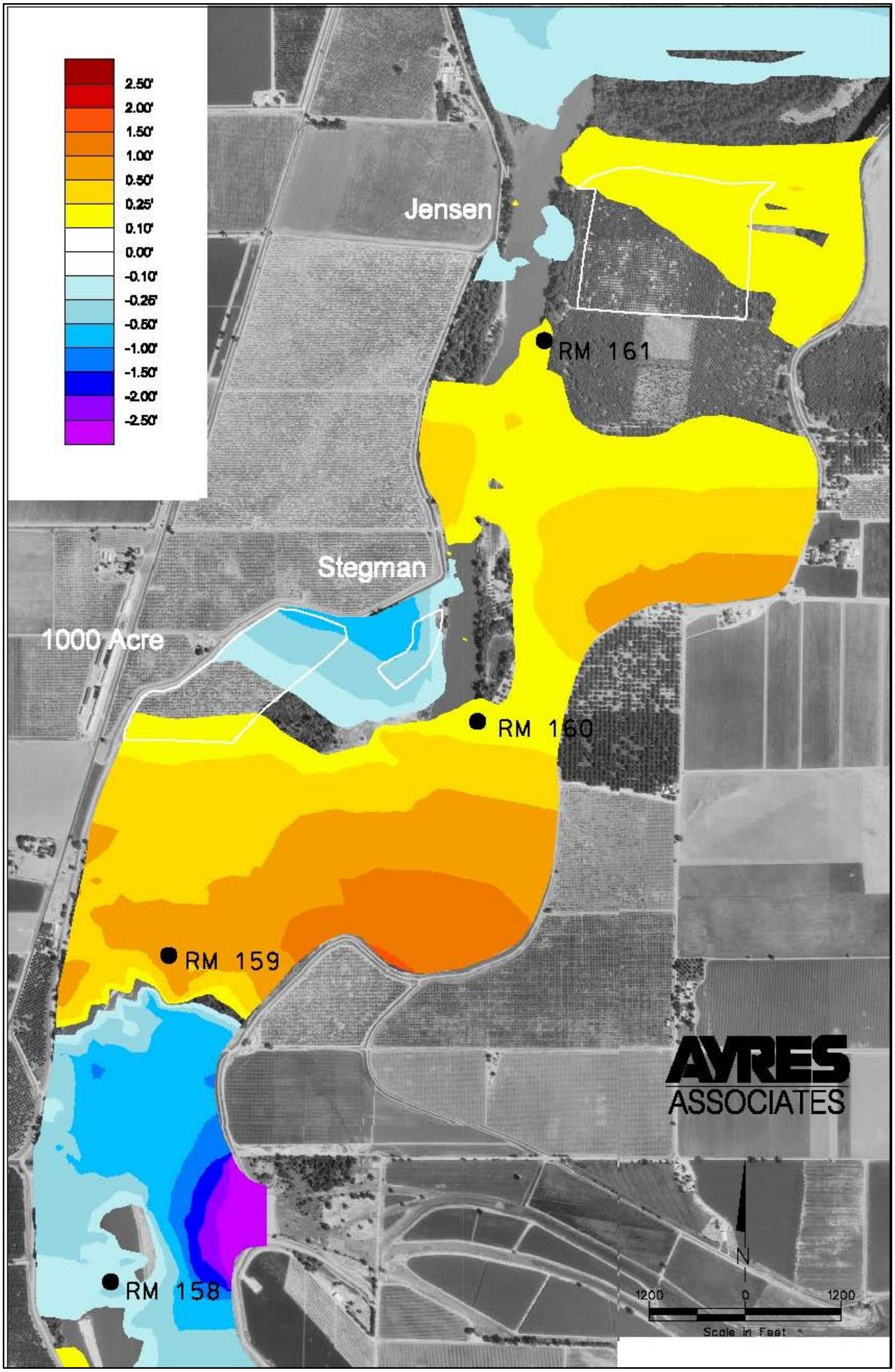


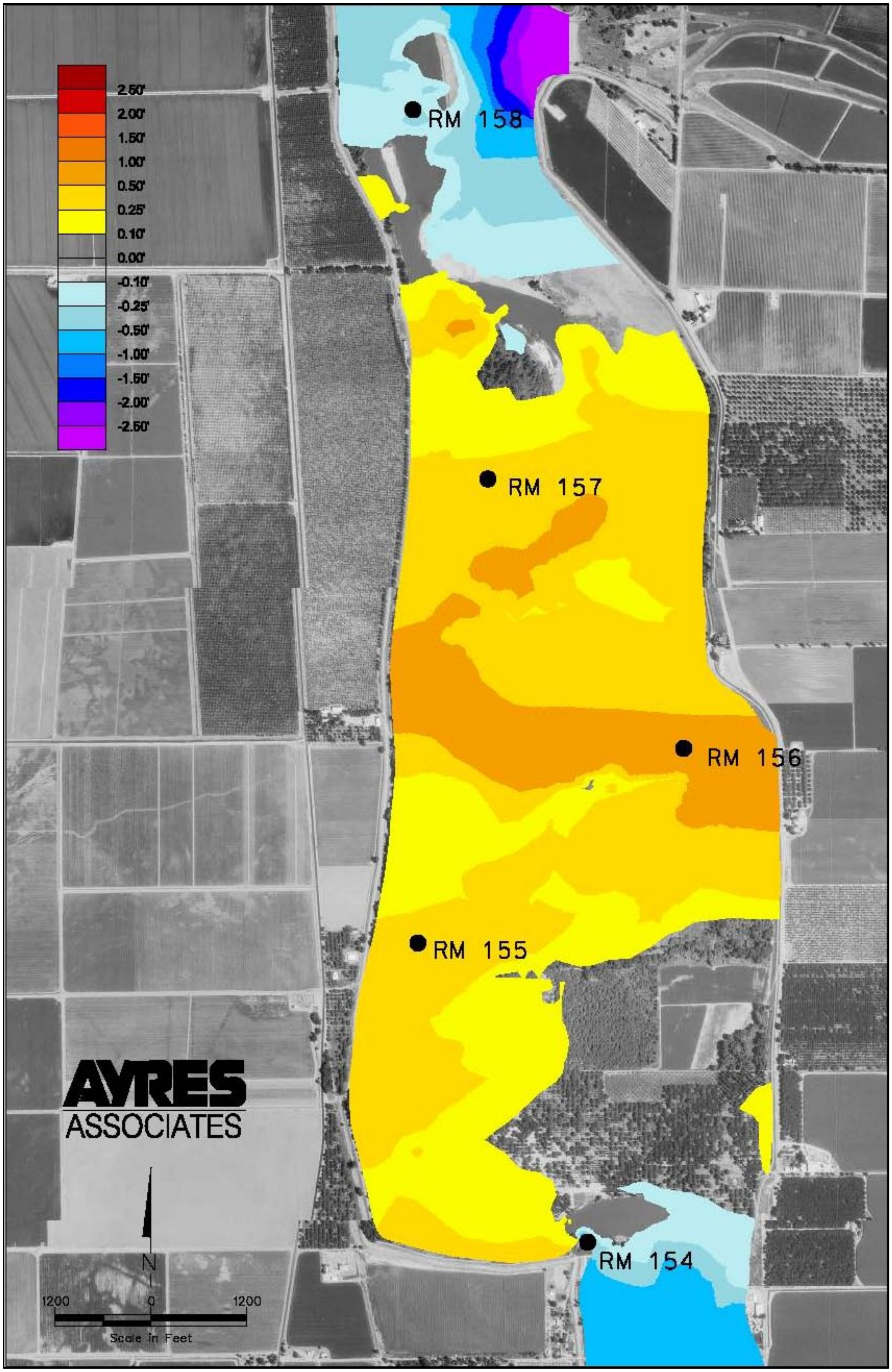
67.97 ft
66.96 ft
66.91 ft
Middle Ward Cross Section
Ward
Elevation (ft-NGVD)
Station (ft)
80
70
60
50
40
30
20
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
50+00
Design Water Surface
Existing Water Surface
With-Project Water Surface

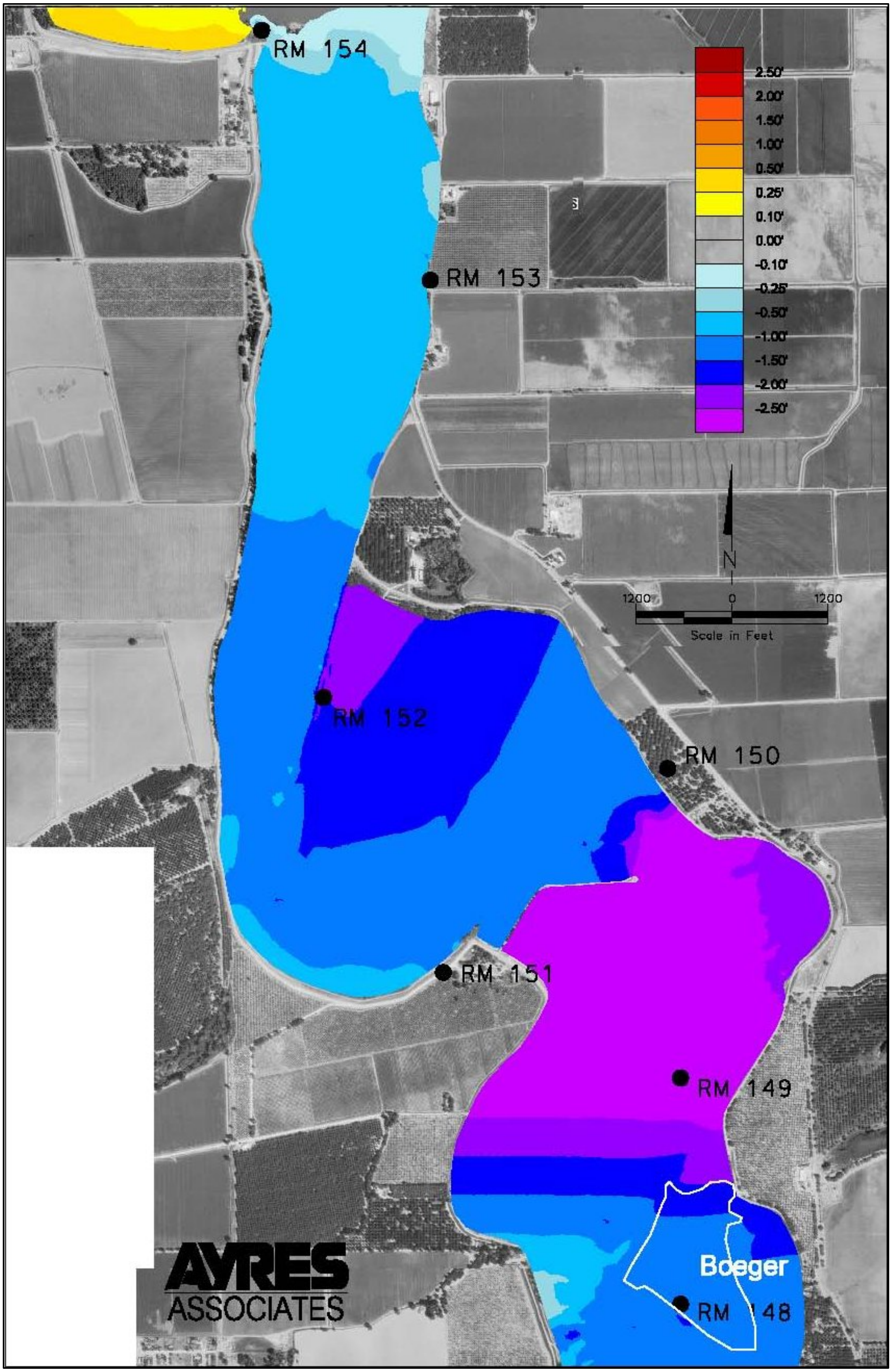

67.85 ft
66.77 ft
66.74 ft
Downstream Ward Cross Section
Ward
Elevation (ft-NGVD)
Station (ft)
80
70
60
50
40
30
20
10
0+00
5+00
10+00
15+00
20+00
25+00
30+00
35+00
40+00
45+00
Design Water Surface
Existing Water Surface
With-Project Water Surface

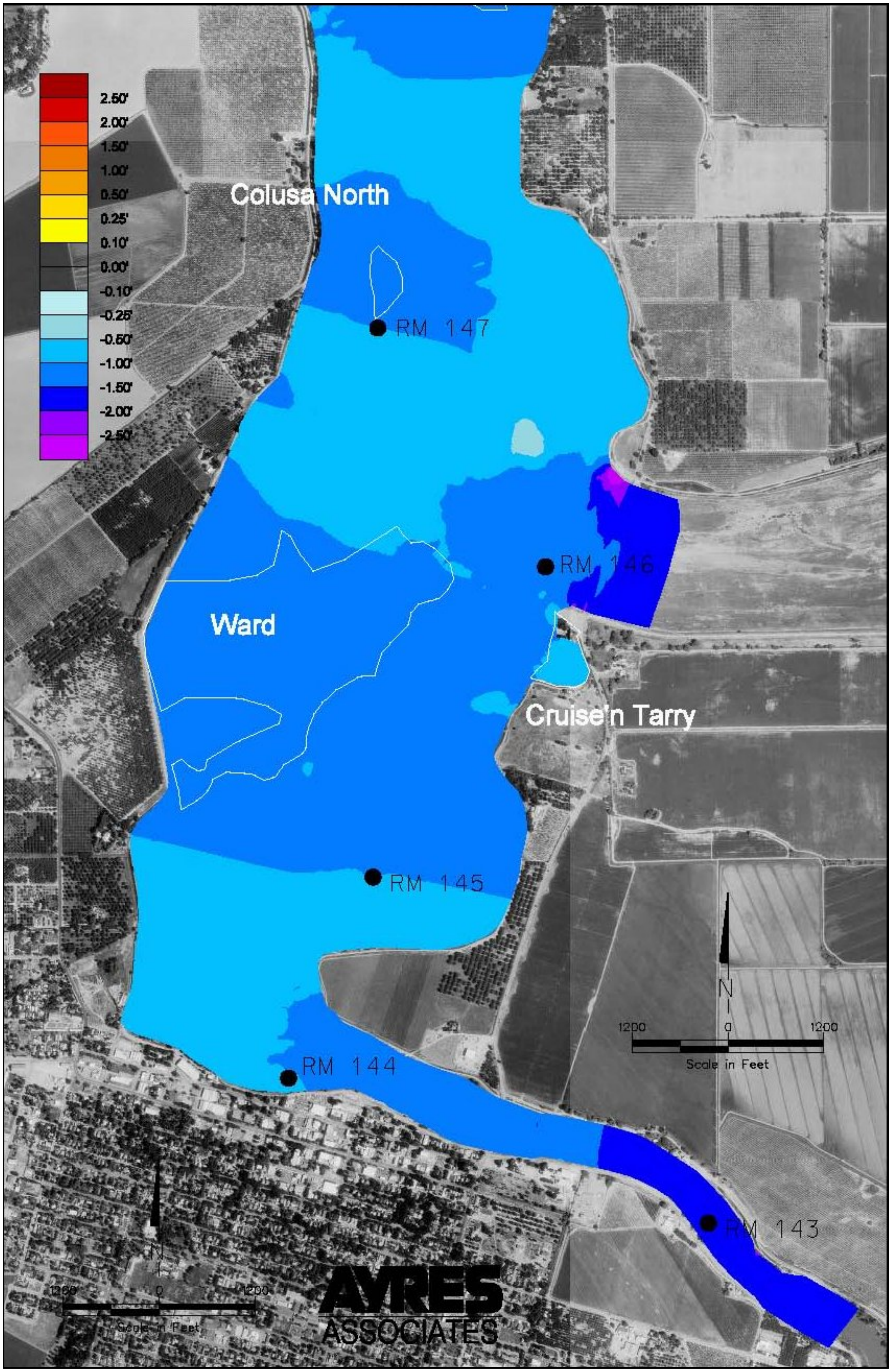
Appendix L - Water Surface Elevation Differential Design Elevation to Existing Elevation


RM 165
2.50'
2.00'
1.50'
1.00'
0.50'
0.25'
0.10'
0.00'
-0.10'
-0.25'
-0.50'
-1.00'
-1.50'
-2.00'
-2.50'
N
1200
0
1200
Scale in Feet
RM 164
RM 163
RM 162
Womble
AYRES
ASSOCIATES

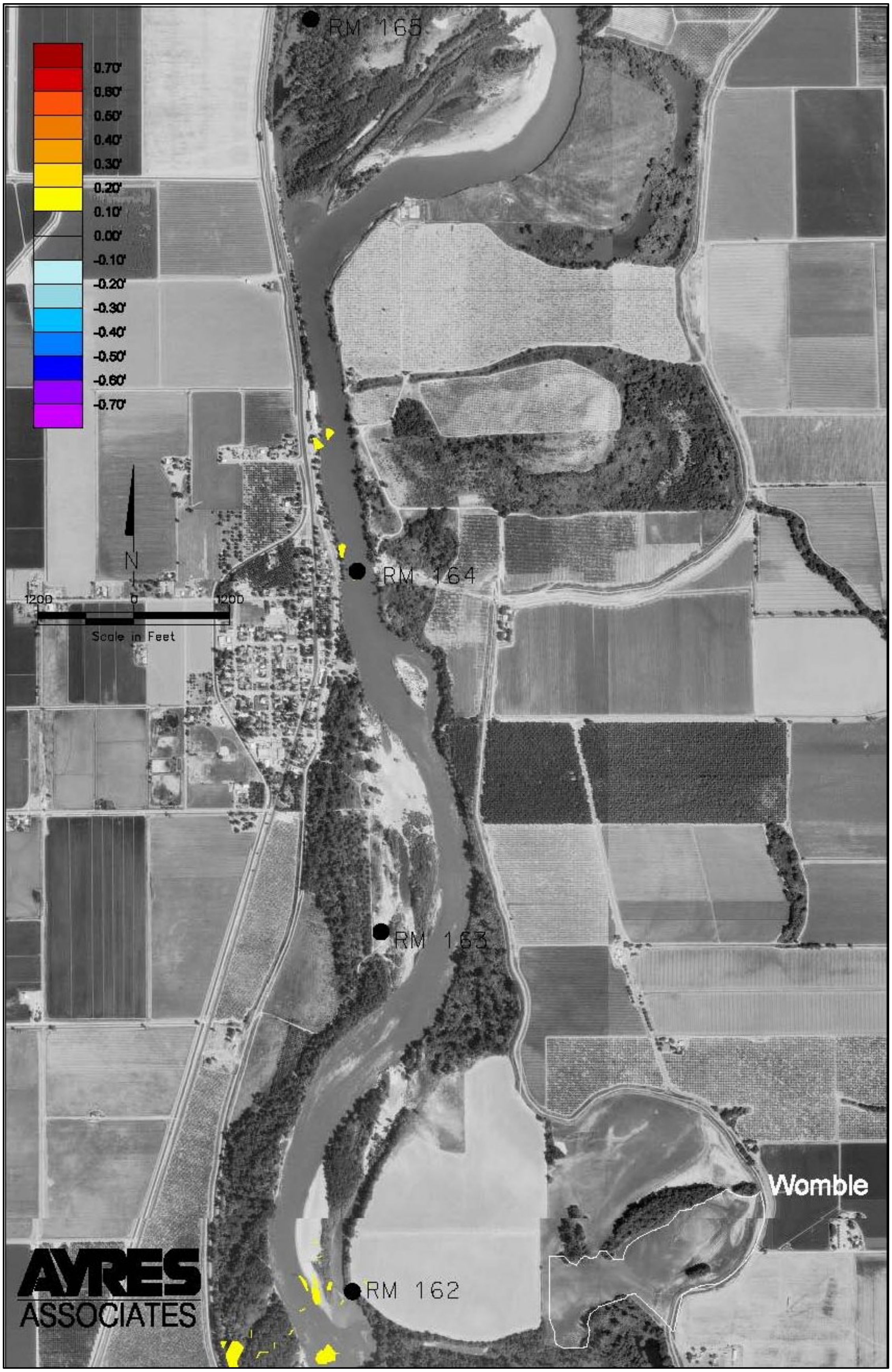

2.50'
2.00'
1.50'
1.00'
0.50'
0.25'
0.10'
0.00'
-0.10'
-0.25'
-0.50'
-1.00'
-1.50'
-2.00'
-2.50'
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
AYRES
ASSOCIATES
N
RM 158
1200
0
1200
Scale in Feet

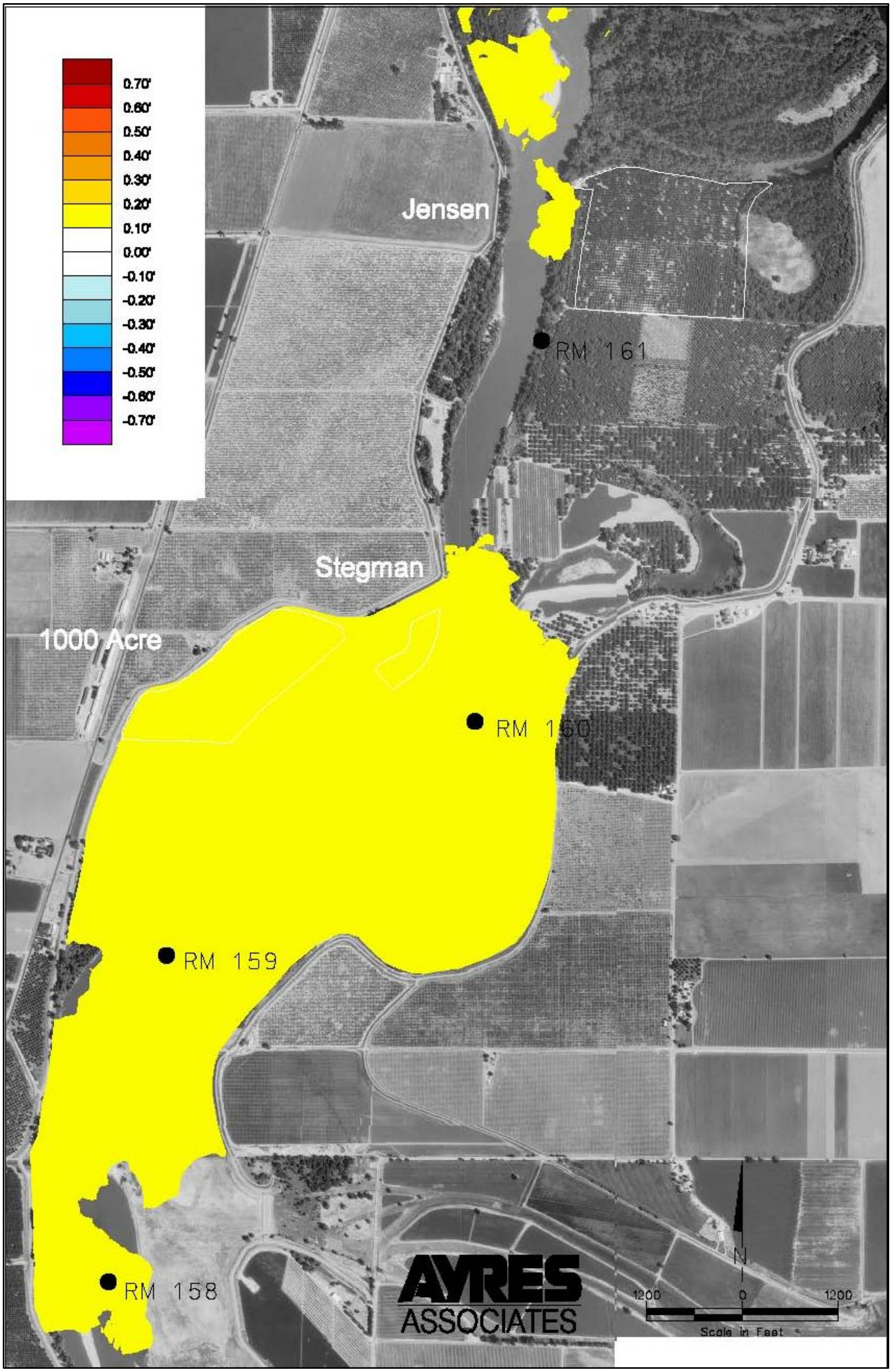

2.50'
2.00'
1.50'
1.00'
0.50'
0.25'
0.10'
0.00'
-0.10'
-0.25'
-0.50'
-1.00'
-1.50'
-2.00'
-2.50'
RM 158
RM 157
RM 156
RM 155
RM 154
AYRES
ASSOCIATES
N
1200
0
1200
Scale in Feet

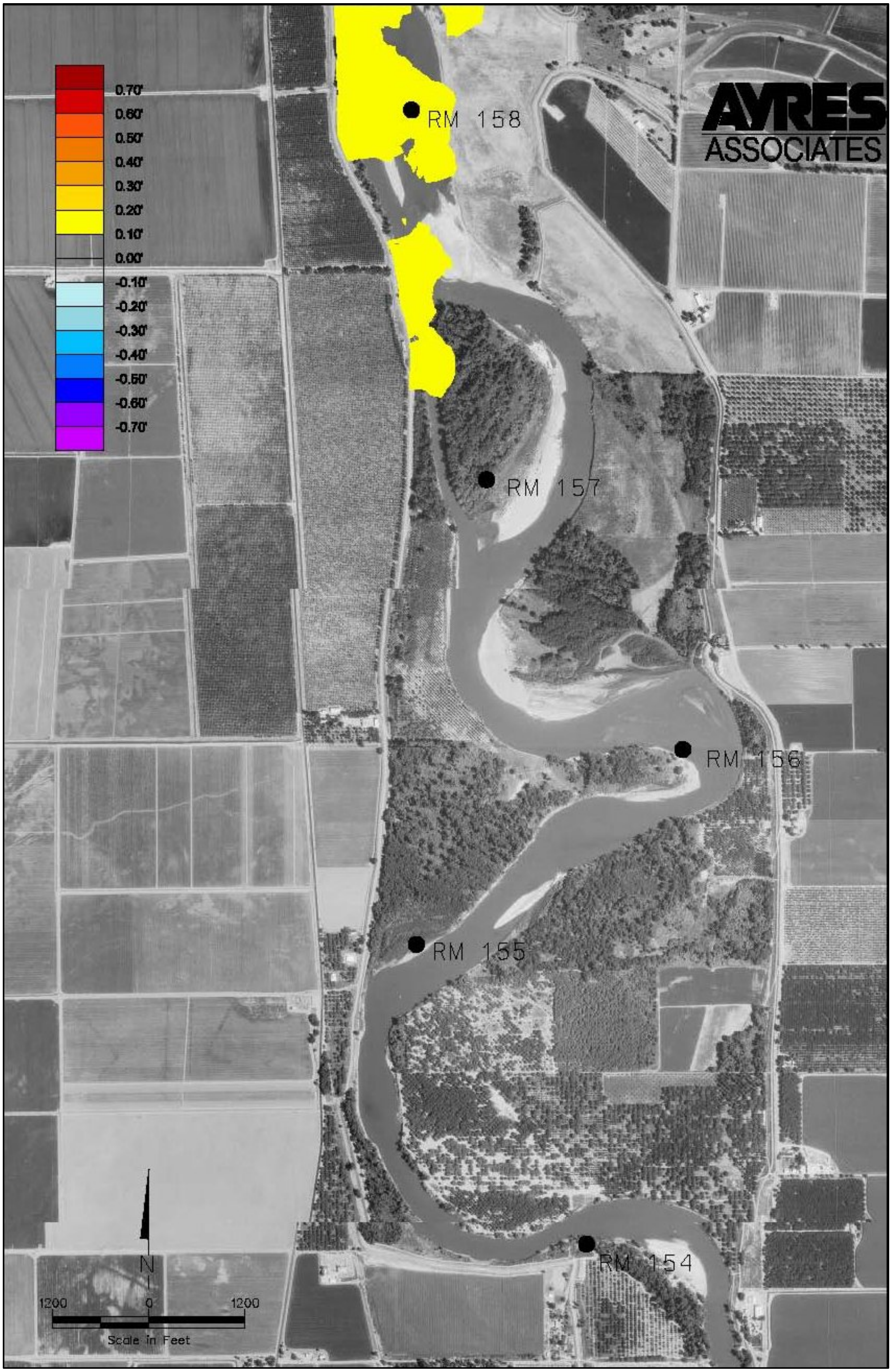

RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
Boeger
2.50'
2.00'
1.50'
1.00'
0.50'
0.25'
0.10'
0.00'
-0.10'
-0.25'
-0.50'
-1.00'
-1.50'
-2.00'
-2.50'
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

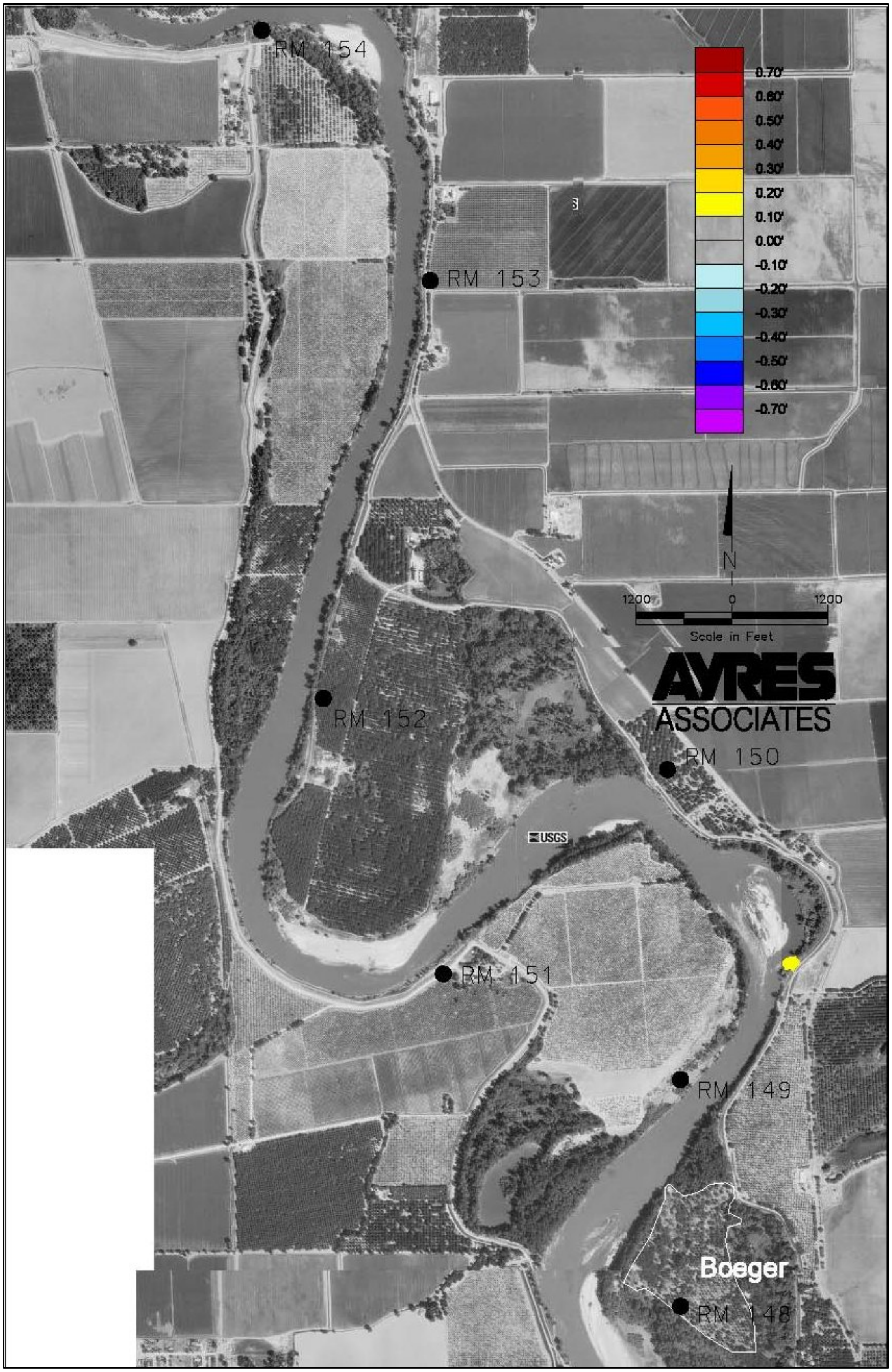

2.50'
2.00'
1.50'
1.00'
0.50'
0.25'
0.10'
0.00'
-0.10'
-0.25'
-0.50'
-1.00'
-1.50'
-2.00'
-2.50'
Colusa North
RM 147
RM 146
Ward
Cruise'n Tarry
RM 145
RM 144
RM 143
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES

Appendix M -
Water Surface Elevation Differential
Existing Elevation to Large Woody Debris Elevation


RM 165
0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
N
1200
0
1200
Scale in Feet
RM 164
RM 163
Womble
RM 162
AYRES
ASSOCIATES

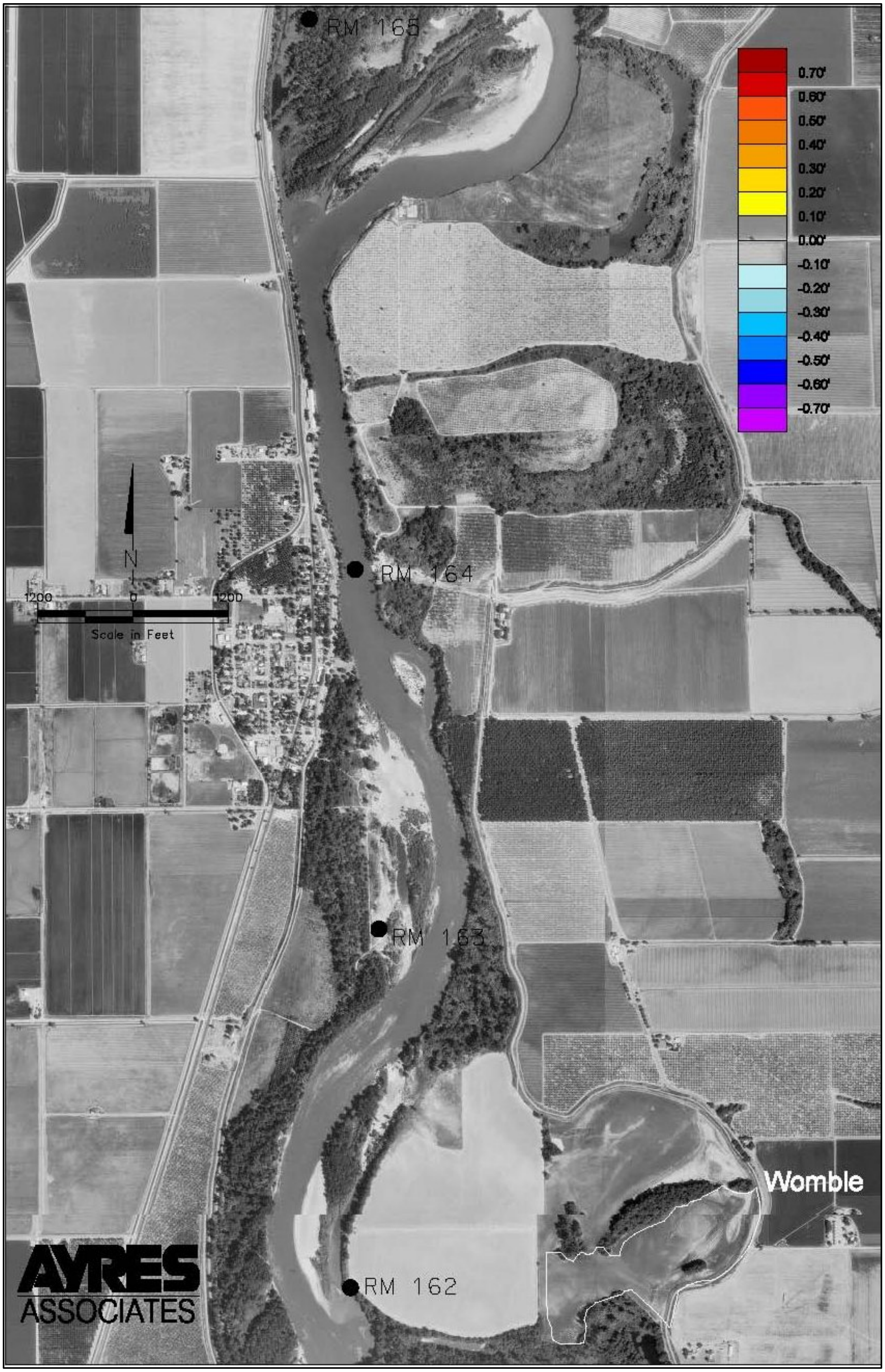

0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
Jensen
RM 161
Stegman
1000 Acre
RM 160
RM 159
RM 158
AYRES ASSOCIATES
N
1200
0
1200
Scale in Feet

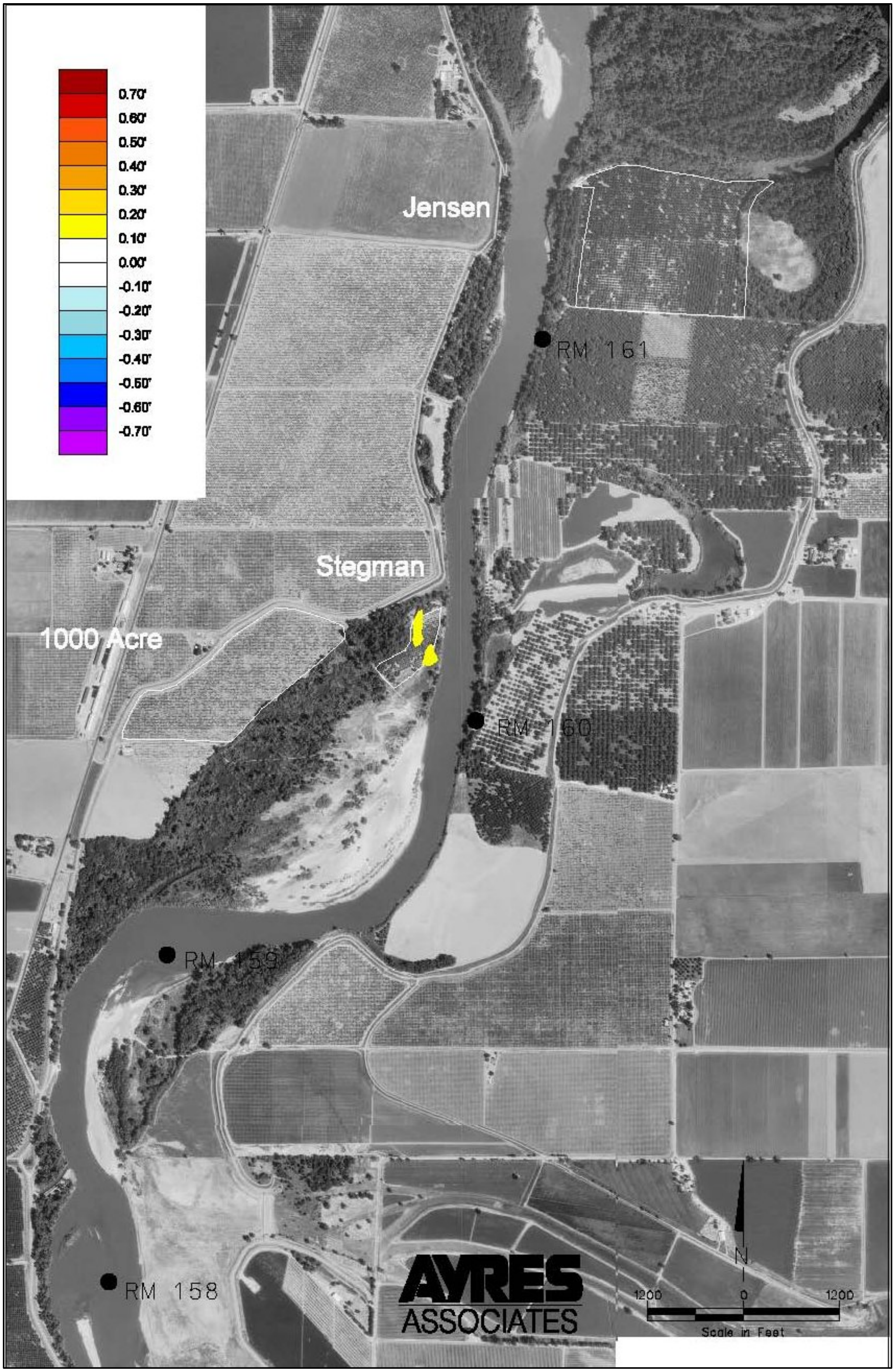

0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
RM 158
RM 157
RM 156
RM 155
RM 154
AYRES
ASSOCIATES
N
1200
0
1200
Scale in Feet


RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES
USGS
Boeger

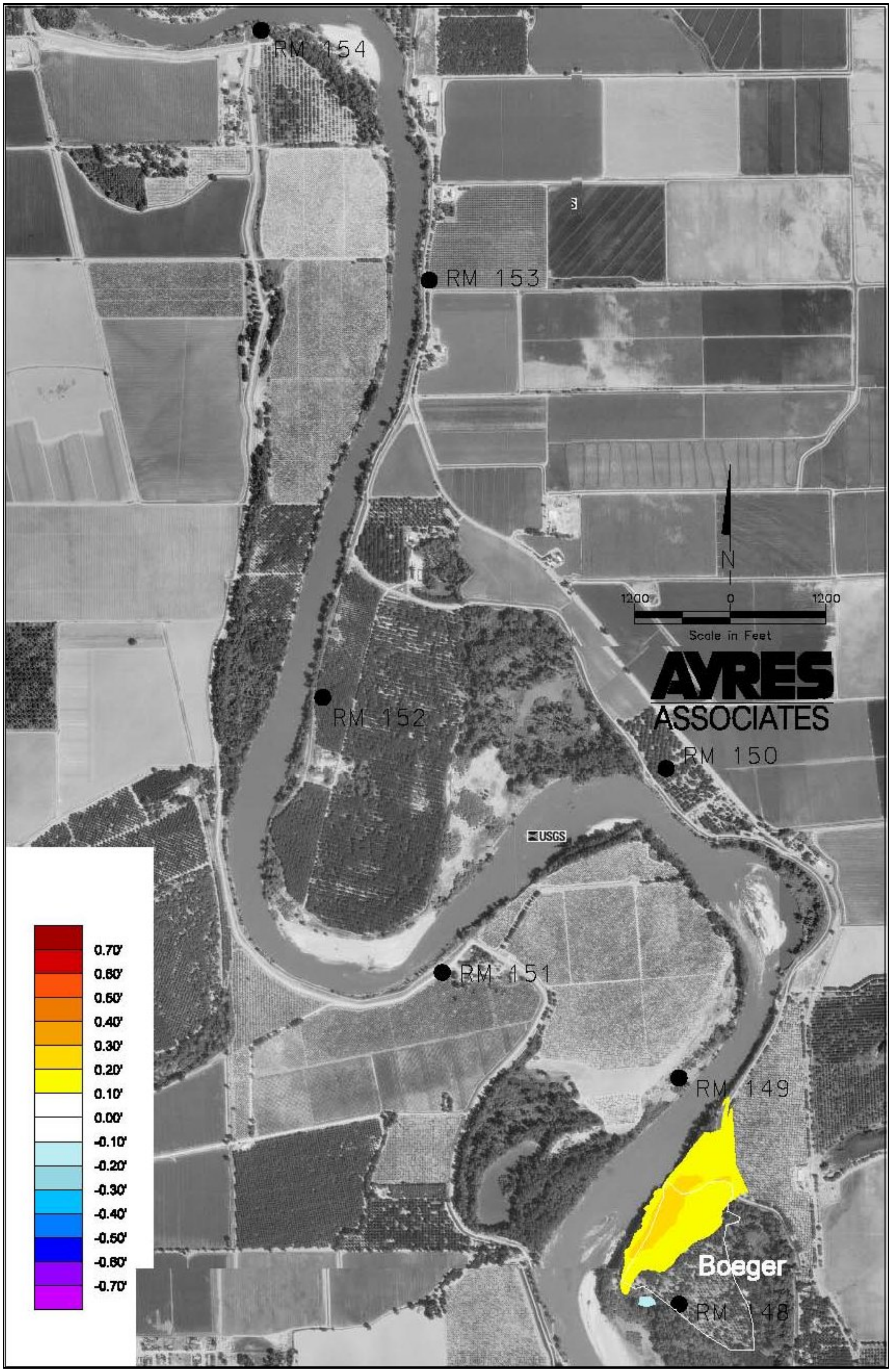

0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
Colusa North
RM 147
RM 146
Ward
Cruise'n Tarry
RM 145
1200
0
1200
Scale in Feet
RM 144
RM 143
AYRES
ASSOCIATES

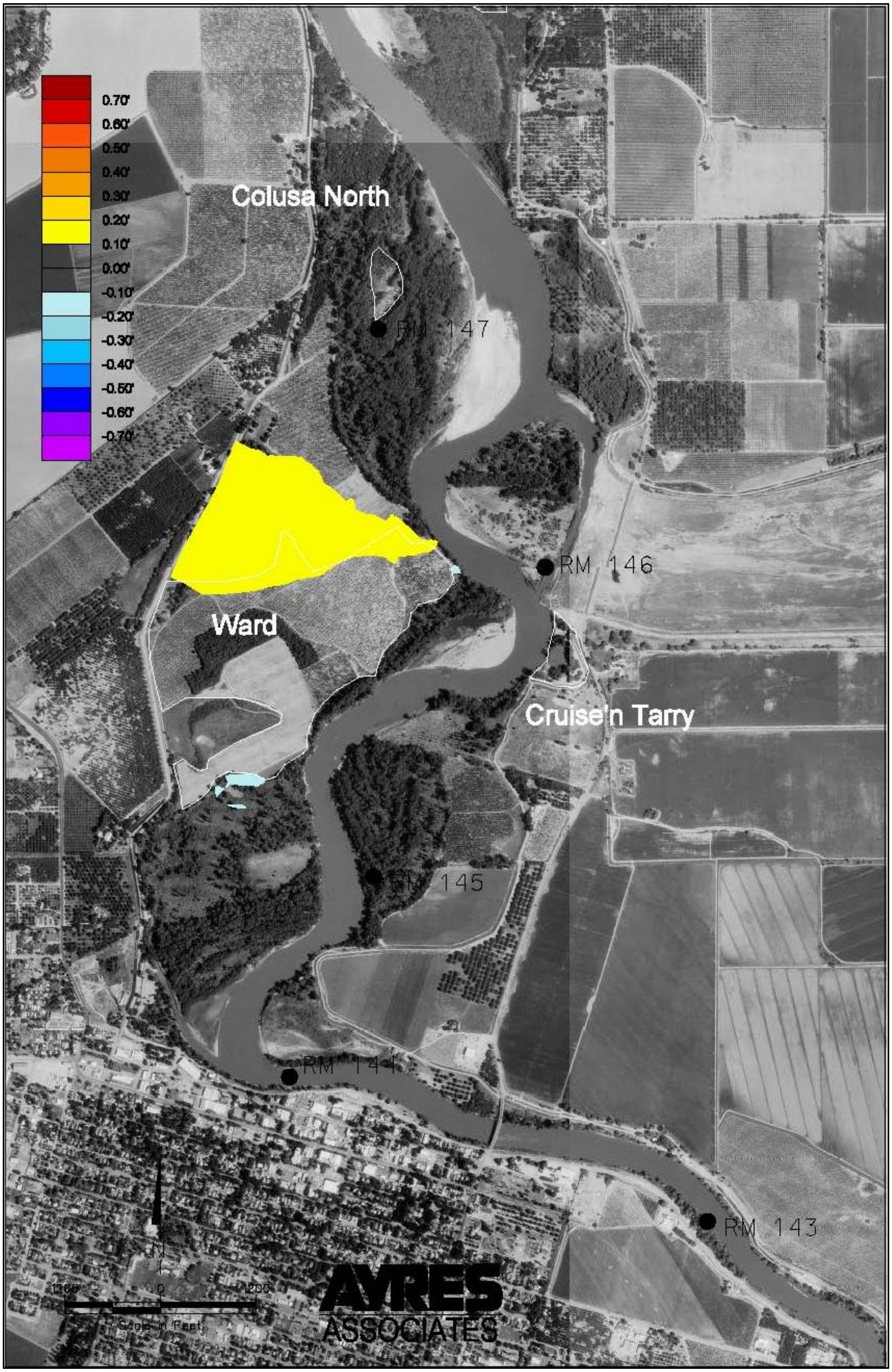
Appendix N - Water Surface Elevation Differential Existing Elevations to With Project Elevations


RM 165
RM 164
RM 163
RM 162
0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
N
1200
0
1200
Scale in Feet
Womble
AYRES
ASSOCIATES


0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
Jensen
Stegman
1000 Acre
RM 161
RM 160
RM 159
RM 158
AYRES ASSOCIATES
N
1200
0
1200
Scale in Feet

0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'
RM 158
RM 157
RM 156
RM 155
RM 154
AYRES
ASSOCIATES
N
1200
0
1200
Scale in Feet


RM 154
RM 153
RM 152
RM 151
RM 150
RM 149
RM 148
N
1200
0
1200
Scale in Feet
AYRES
ASSOCIATES
USGS
Boeger
0.70'
0.60'
0.50'
0.40'
0.30'
0.20'
0.10'
0.00'
-0.10'
-0.20'
-0.30'
-0.40'
-0.50'
-0.60'
-0.70'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RM 144
RM 143
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Scale in Feet
AYRES
ASSOCIATES

Appendix O -
Review Comments to Report with Responses by Ayres Associates

Ayres Associates Inc
2150 River Plaza Dr., Suite 330
Sacramento, CA 95833
(916) 563-7700

March 18, 2008

Colusa Planning Subreach Project, Colusa to Hamilton City 2-Dimensional Hydraulic Model, Response to Comments from:

Mr. Francis E. Borcalli, Consulting Civil Engineer

1. Comment: I concur with the conclusions based upon the results of the hydraulic modeling performed in that there is essentially no significant adverse impact from the proposed restoration of wildlife habitat in the floodplain.

   Response: This comment is consistent with our conclusions in the Report.

2. Comment: The determination that the overflow to the Butte Basin through the Moulton Weir and Colusa Weir is significantly different that the 1957 design is important as it relates to the future analyses of the Sacramento River from Colusa to Knights Landing. This will be particularly relevant in hydraulic analyses that will be performed by DWR under its Central Valley Flood0plain Evaluation and Delineation Program, which has been initiated recently.

   Response: We agree. One of the valuable side benefits of this project is that it provides new insight and documentation on how the system currently operates, which is somewhat different from conventional thinking and how it was designed.

3. Comment: Including a cross section showing the extent of the woody debris in relation to the channel and overbank floodplain would help to illustrate the relative significance of the debris in relation to the modeled results under flood conditions.

   Response: This is a good suggestion and a typical cross section has been added as a figure in Section 6.1.2.

4. Comment: Editing the report, especially the conclusions.

   Response: This has been done.

5. Comment: Refining the delineation of the habitat restoration sites on the graphics in the appendices so they are readable.

   Response: This has been done within the limits available to us in the software for making the figures.

6. Comment: Including a list of tables and figures in the Table of Contents.

   Response: This has been done.

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2150 River Plaza Dr., Suite 330
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March 18, 2008

DRAFT - Colusa Planning Subreach Project, Colusa to Hamilton City 2-Dimensional Hydraulic Model, Response to Comments from:

Colusa Indian Community Council, Cahil Dehe Bank of Wintun Indians

1. Comment: The model was calibrated using high water marks from the 1995 storm event. How does this model compare to other high water events along the Sacramento River? Did you consider using other events for calibration?

   Response: The reasons the 1995 event was used for calibration was as follows:
   a) Surveyed high water marks were available from DWR
   b) This event was close in time to the river topographic survey (1997)
   c) Aerial photography was available to document over bank land use for roughness
   d) Many people along this reach of the river remember that event and where the water levels were.

   Other events were not considered primarily because we could not verify the shape or roughness of the river at the time of older events. Also we are unaware of surveyed high water marks for other events.

2. Comment: Would there be any impact to the Tribe's water diversion (located just north of RM 157) due to the lowering of flow at RM 157 and the possibility of deposition? (Section 6.1.2).

   Response: There is no impact to the Tribe's water diversion just upstream of RM 157 from any of the proposed restoration scenarios. Section 6.1.2 discusses a hypothetic run to demonstrate impacts of adding (or for that matter removing) large woody debris within the main river channel.

3. Comment: Section 6.2.3 states that the water surface on the Boeger property is below the 1957 design profile and 0.25 feet above the hydraulic model run of the design flow *(existing conditions with design flow).* While 0.25 feet is small, it is still an increase as shown by the comparison of mode results. There is concern with the statement that the water levels are higher as a result of restoration, but since they are less

that the 1957 design profiles the increase is acceptable. This situation also occurs at Jensen (downstream), Stegman, Colusa North, and Ward sites. It seems that a more straight forward measure of hydraulic impacts of the restoration project is a comparison of model results with and without the restoration projects, as opposed to a comparison of the project model runs and a hybrid of the 1957 design profile and "existing" model results. What is the basis for such a hybrid comparison? In addition, only the impacts for the system design event were considered. What are the impacts of the restoration project for more frequent events?

Response: The guidance used in this report for the determination of hydraulic impacts was provided by the Reclamation Board Staff and called for no infringement into the design freeboard (1957 design flow profile). This is consistent with the recent Reclamation Board ruling that granted a permit for restoration of the Ward property last December. More frequent flow event were not modeled because there is no historic baseline for a comparison. Also, it takes at least a 2-year event to get into the overbank floodplains in most areas, so there is no interaction for this most frequent high flow. For other frequent flows, up to the 10-year event, water depths will be less than those modeled and therefore no effect on freeboard.

This report went beyond the minimums and also looked at the potential effects of changes in velocity, erosion and deposition patterns and seepage and no significant impacts were detected.

4. Comment: Because the velocities are expect to increase on the opposite riverbank of the Boeger property, per Section 6.4, the Tribe world like assurance that the western levee would not be subjected to increase erosion. The model shows an increase in velocity at the design event, but what would the results of the model be if smaller, but more frequent, storm was used? Would the bank be subjected to higher velocities?

Response: The velocity increase on the west levee (0.25 to 0.5 fps) is the result of changing the land use on the Boeger site from crops to a riparian mix. If the historic land use of orchard was used for the Boeger site (1986), it is our opinion that there would be no increase in velocities through this reach from the proposed conversion.

We don't have the installation date of the revetments on the west levee, but they were in place in 1989 (Corps of Engineer, Sacramento River and Tributaries, Bank Protection Maps) and this site doesn't show up as an existing erosion site within the Corps of Engineers, Erosion Inventory of the Sacramento River Bank Protection Project, 2007. We can not, however, provide an "assurance" that erosion will not occur in the future.

STATE OF CALIFORNIA
THE RESOURCES AGENCY
DEPARTMENT OF WATER RESOURCES

DWR Review of Ayres Associates' Colusa Subreach Model for Ward Tract Restoration

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December 4, 2007

Introduction

The Nature Conservancy (TNC) and the Sacramento River Conservation Area Forum (SRCAF) collaborated in Colusa Subreach Planning to engage the public in considering restoration of portions of the leveed section of the Sacramento River north of Colusa. Ayres Associates (Ayres) performed hydraulic analysis to review the existing floodplain capacity and determine the hydraulic effects of restoring habitat at eight potential sites. As guided by the Colusa Subreach Planning Advisory Workgroup and consulted Reclamation Board staff, the analysis includes modeling of the entire Colusa Subreach from Princeton to Colusa so that cumulative effects are considered.

This model review report focuses on one of the eight modeled sites, Ward Tract, which DWR proposes to restore in cooperation with The Nature Conservancy and California State Parks and Recreation (California Parks). The Ward property has been deeded to the California Parks for continuing stewardship of the land. A portion of the restoration at Ward Tract is to serve as mitigation for riparian habitat lost when DWR performed maintenance of Tisdale Bypass during 2007. Although all eight potential TNC restoration sites were evaluated in Ayres' hydraulic analysis in order to analyze their hydraulic effects along the river, DWR proposes only to restore Ward Tract. This report focuses on the modeling analysis of the Ward Tract, in support of securing an encroachment permit from the Reclamation Board.

Under contract to TNC, Ayres performed modeling to compare existing conditions with proposed restored conditions. When Ward Tract was acquired, it contained a mature walnut orchard. After acquisition, TNC converted the land to field crops in preparation for restoration. Field crops is the land use type that was input as the existing condition at Ward Tract in Ayres' model. This represents the more conservative case for purposes of change detection. The property is proposed to be restored to a mix of grassland, oak savannah, and riparian forest habitats, with maintenance requirements such as mowing to maintain the grassland explicitly identified in permitting. This report reviews Ayres' modeling assumptions and results.

Review of Modeling Assumptions

Before using Ayres' model results in their application to the Reclamation Board, DWR reviewed Ayres' modeling assumptions, as well as the modeled stage and velocity results. Modeling assumptions examined included consideration of the boundary conditions and roughness values used. To gauge appropriateness of how site conditions were characterized, DWR performed a literature review of roughness values, field-checked vegetation at several locations throughout the full reach, photo-documented site conditions, and compared what was observed to the vegetation uses assigned in the "existing conditions" model geometry file. DWR also verified the design and historical flows used, and contacted several experts with 'institutional memory' to investigate differences between design and objective flows, and the fairly wide range of flow splits recorded in historical hydrology.

Review of model methods and results was largely based on access to Ayres Draft Report and Ayres' presentation on calibration, existing conditions, and restored conditions runs. DWR staff did not re-run the model.

Boundary Conditions

The term 'boundary conditions' encompass choices modelers make about the extent of the system to model (i.e. the location of boundaries), the stage and flow to specify at the edges of the model, and which variables the model will solve for.

Model Assumptions

- The 22-river-mile model is inclusive of all eight potential restoration sites.
- The upstream boundary condition (inflow) was set to the 1957 design inflow of 160,000 cfs. Historical flow splits were specified at the weirs to achieve calibration. The boundary conditions used at Moulton and Colusa weirs were scaled up from the 1958 flow splits, at 35,700 and 73,000 cfs (+/- 500 cfs) respectively. Flow splits were scaled up from 1958 measurements because 1958 inflows to the subreach were only 2,000 cfs less than the design flow.
- The downstream boundary condition (stage) was set based on stage measurements at Colusa Bridge, adjusted for the distance between the Colusa bridge and the downstream boundary condition using the slope exhibited in the design water surface downstream of Colusa Bridge.
- Ayres checked for flow conservation within 5% through the modeled reach.

Review

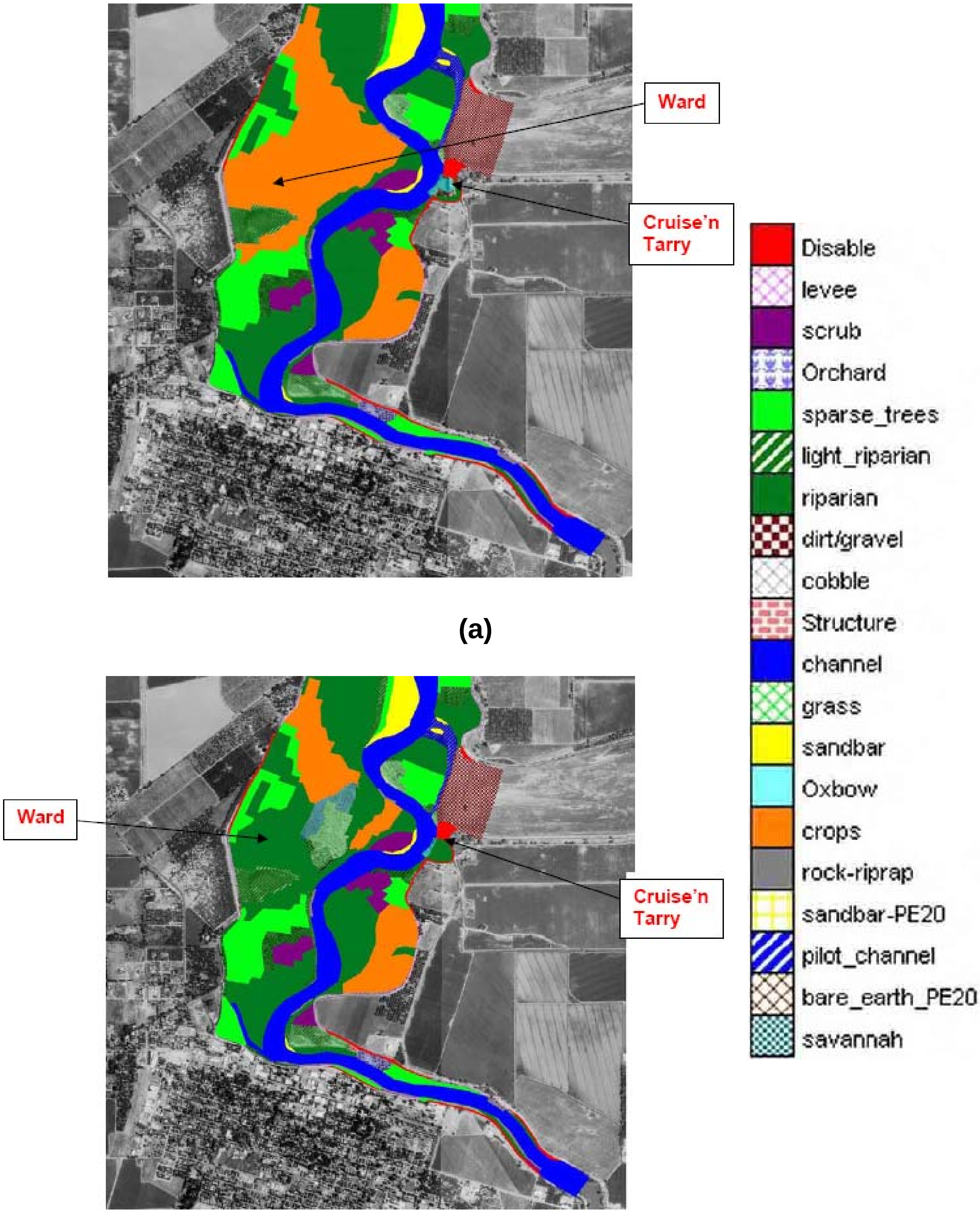
- The model extent included the entire 22-river-mile reach, inclusive of all eight potential restoration sites.
- DWR verified the 1957 design inflow of 160,000 cfs and 1958 historical flow splits at Moulton and Colusa weirs Ayres reported. DWR further investigated the non-standard use of historical flow splits at Moulton and Colusa weirs. Using historical flow splits at the weirs has the effect of reducing the flow in the main stem of the river at Colusa. DWR concluded that it was acceptable to use historical flow splits at the weirs because:
  - 1) Longtime DWR and USACE engineers [Mel Yarwood, Dan Tibbitts, Don Twiss, Bob Childs, Wayne Johnson, Bud Pahl] who have worked on the Sacramento Flood Control System were asked about the potential discrepancy between design flows over Moulton and Colusa Weir, and modeled flows there. None of the engineers contacted was surprised that the system appears to be functioning differently now than at the time of Authorization. The engineers agreed that:
    - a) The Flood Control System has changed since it was first designed. Accretion in some areas and erosion others is expected to have modified capacity throughout the length of the system.
    - b) It is the Project Design Profile that is authorized, not the design flows. Project design flows were back-calculated from the Project Design Profile with much less sophisticated methods than are currently available.
  - 2) Current analysis tools allow inclusion of a greater level of detail to hydraulic analysis than was available when the Flood Control System was designed. For example, the design profile shows no water surface effect of the Colusa Bridge.
  - 3) In the three highest recorded historical events in the area, where inflow to the Colusa Subreach ranged from 157,000 cfs to 170,000 cfs, measured flow at Colusa Bridge Gage was only 44,800 to 51,800 cfs. Under the modeled flow splits 50,800 to 51,800 cfs passed the Colusa Bridge Gage.
- The downstream boundary condition (stage) was set by adjusting the rating curve value at the Colusa Bridge to account for the distance from the bridge to the downstream boundary condition.
- Summing the outflows at each outflow area (Moulton, Colusa, and the south end of the model) and comparing that total to the inflow, Ayres found conservation of flow to be well within 5%.

Bathymetry and Material Roughness

The wetted surface that water flows over, the bathymetry of the channel, is another ‘boundary’ of sorts that must be input to the model. Characteristics of materials (e.g. vegetation, soils, and structures) along this surface affect the resistance presented to the water as it flows. Hydraulic roughness, often referred to as Manning’s ‘n’, represents this resistance to flow, and is an important input variable in modeling.

Model Assumptions

- The bathymetry of the reach is represented with a finite element network, or mesh. The mesh was formed from two data sources: a 1997 bathymetric survey by Ayres and 2006 LIDAR topography provided by TNC. The size and orientation of elements was varied to represent hydraulic features, structures, and topographic changes.
- Assignation of material types to elements of the mesh was based on 1998 USGS aerial photography and 2005 Natural Resource Conservation Service aerial imagery.
- Hydraulic roughness: Manning’s ‘n’ roughness values were initially set in the high range of appropriate values based on literature review. Hydraulic roughness needed to be modified (decreased) in order to achieve a good fit in calibration of the model.
- The model is calibrated to the January 10, 1995 high flow (143,000 cfs), for which high water marks are available.
- In the existing conditions (without project) run, the Ward Tract restoration area was represented as being in crops (n = 0.035). (See **Figure 1 a**).
- In the restored conditions (with project) run, the Ward Tract restoration area was represented as being in a mix of vegetation types: grassland (n = 0.032), savannah (n = 0.045), and riparian forest (n = 0.090). (See **Figure 1 b and Figure 2**).



(a)

(b)

Figure 1: (a) Existing Conditions (Without Project) and (b) Restored Conditions (With Project) Land Use in the vicinity of Ward Tract, as represented in the model. (adapted from Ayres Associates)

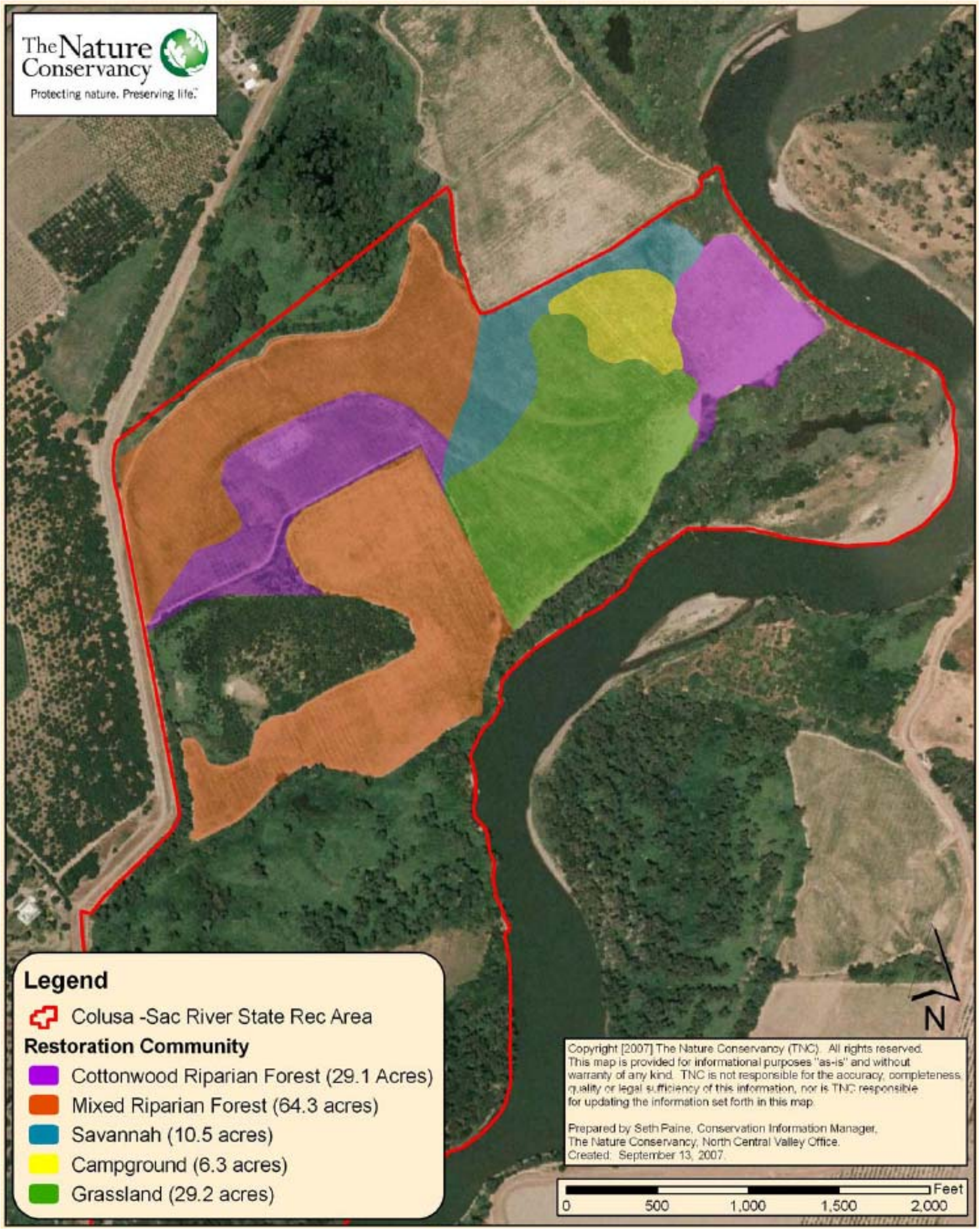


Figure 2: Representation of Land Use Types in the Restored Conditions (With Project) Model in the vicinity of Ward Tract. (The Nature Conservancy). Note that the Colusa-Sacramento River State Recreation Area property is larger than the portion of Ward Tract that is modeled to undergo changes in land use type.

Review

- The data sources are appropriate, and the bathymetry appears to capture hydraulic features, structures, and topographic changes.
- DWR staff compared the existing land use material types present in the field between RM 142.5 and 164 with those represented in the model by spot-checking the 22-mile Colusa Subreach from levees and available access points. Photographs as well as GPS readings were taken at 18 locations. DWR found that the categories used in the model closely approximated the field conditions. The modeled land use types and location of the field sites as well as select photographs can be seen in **Appendix A**.
- DWR considered both whether the current land use type matched the land use assigned in the model, and whether the roughness value assigned to that land use type appeared consistent. In **Appendix B**, a direct comparison of multiple locations with the same land use designation is displayed, to offer a sense of the similarity and variability of a given land use designation. Crops, orchard, and sand bar appear quite similar, while light riparian, riparian, and sparse trees show more variation between sites.
- The reasonableness of Manning's 'n' roughness coefficients used in the model was placed in context by reviewing five hydraulics literature sources. Overall, the values were reasonable. A table showing the literature review results is included in **Appendix C**.
- Calibrating to available high water marks for a similarly high flow event (143,000 cfs in 1995 vs. the 160,000 cfs design flow) is appropriate.
- Starting at the high end of potentially representative hydraulic roughness values and modifying them to calibrate the model is an acceptable way of achieving calibration. DWR also created a table showing typical hydraulic roughness values used for the land use types similar to those Ayres used in their model.
- The model calibration trends at or slightly above the measured high water marks, at most locations, especially along the downstream half of the model, where the Ward Tract is located. (See **Figure 3**) Ward Tract is located between River Miles 145 and 146. The calibration of the model trending at or slightly above the measured high water marks is both conservative, and an indication that raising hydraulic roughness values would reduce the closeness of fit of the model calibration.

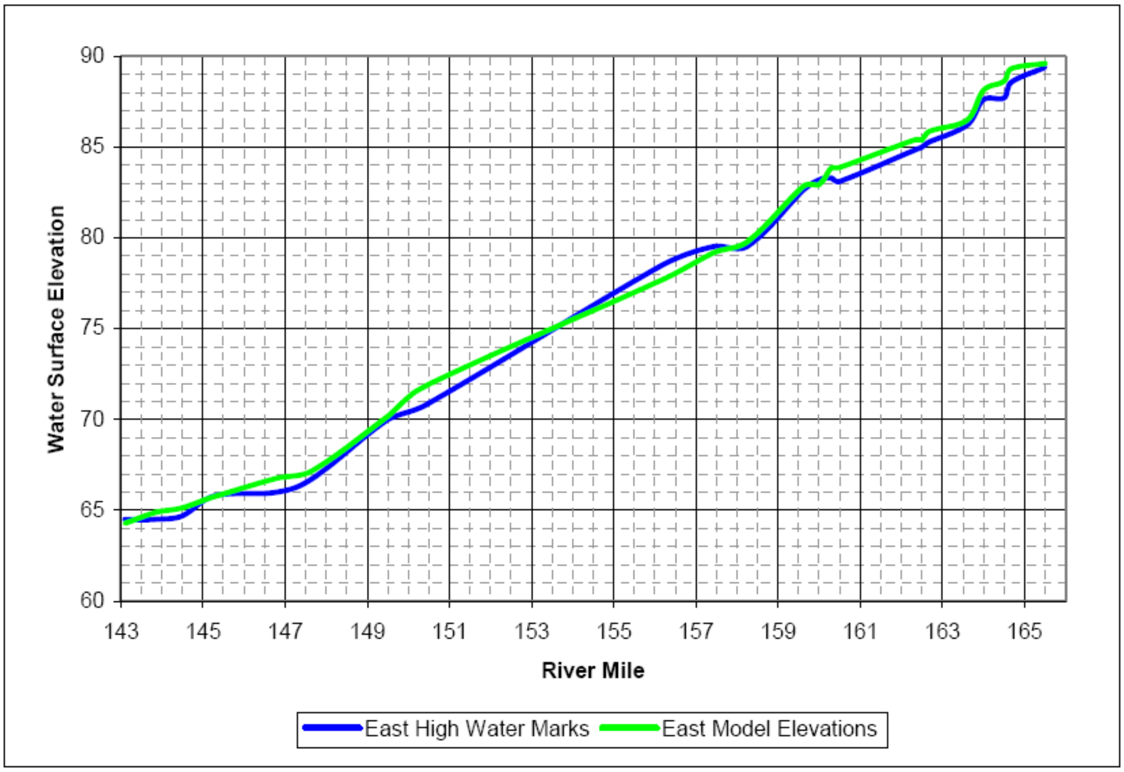


Figure 3: Comparison of Modeled Water Surface Profile with High Water Marks on the East Bank. (Ayres Associates) Note that model calibration trends at or slightly above the measured high water marks at most locations, including the vicinity of Ward Tract (RM 145 to RM 146)

- It is conservative to reflect the existing conditions, crops (n = 0.035), rather than the conditions of Ward Tract when it was purchased for restoration, orchard (n = 0.075), in the existing conditions (without project) model run. (See **Figure 1**). Setting material roughness to the lower value in the existing conditions run will predict greater change when comparing restored condition results with existing condition results.
- The distribution of vegetation types in the restored condition (with project) run creates an overbank flow corridor where the low hydraulic roughness of the grassland (n = 0.032) and savannah (n = 0.045) are placed. (See **Figure 2**). This will encourage some of the water that would otherwise have flown around Cobb's Bend to short-cut across Ward Tract. This will tend to keep stage low.

Interpretation of Model Results

Having considered the modeling assumptions, it is also important to interpret model results carefully, and to consider model results in context. To understand how to compare the design profile with modeled results, one needs to consider the level of detail inherent in each. Some guidance on how to interpret color-coded figures is also provided in this section.

USACE Flood Control Project requirements are specified in terms of a design water surface elevation profile (design profile). The design profile is specified along the Sacramento River with a single elevation at any given cross-section. The design profile is provided in graphic format (as contrasted with tabular format) and values at any given location may be interpolated, by eye, from the graphic. **Figure 4** shows the level of detail specified in the USACE channel design profiles, which are available electronically on the Reclamation Board web page at http://recbd.ca.gov/profiles/ Hatch marks delineate elevation change every 2.5 feet.

The format of the water surface elevation results from the model is very different; model results are two dimensional, showing more of the actual complexity of flow patterns. (See **Figure 5**). The shades of blue in **Figure 5** represent ranges of water surface elevation. Two dimensional modeling examines localized results that it would not be possible to discern in one dimension, where every cross-section would use average values. For use in the two dimensional model, the one dimensional information contained in **Figure 4** was applied across the finite element mesh shown in **Figure 6**.

In graphics of model results that follow **Figure 6**, color coding is used to illustrate differences in water surface elevations among the USACE 1957 design profile, existing conditions (without project), and restored conditions (with project). Cool colors (greens, blues and purples) on comparison plots indicate negative values, areas where the modeled condition compared is below the design profile. Comparison plots also leave areas where values within a specified range transparent, allowing the background aerial photograph to show through. Higher values are indicated by the warm end of the color spectrum.

Similar conventions are used to portray velocity distributions and changes in velocity distribution. Existing conditions, as well as changes in velocity distributions, affect resultant conditions. For example, an increase in velocity of 0.5 ft/sec could result in erosion or deposition, depending on the initial conditions in an area. Unlike the water surface elevation results, the velocity results contain no comparison to design conditions because there are no design velocity conditions with which to compare. In interpreting results, it is important to be mindful of whether a given plot illustrates water surface elevation or velocity. Attention to the units used (ft or ft/sec) is useful in differentiating between water surface elevation and velocity-related plots.

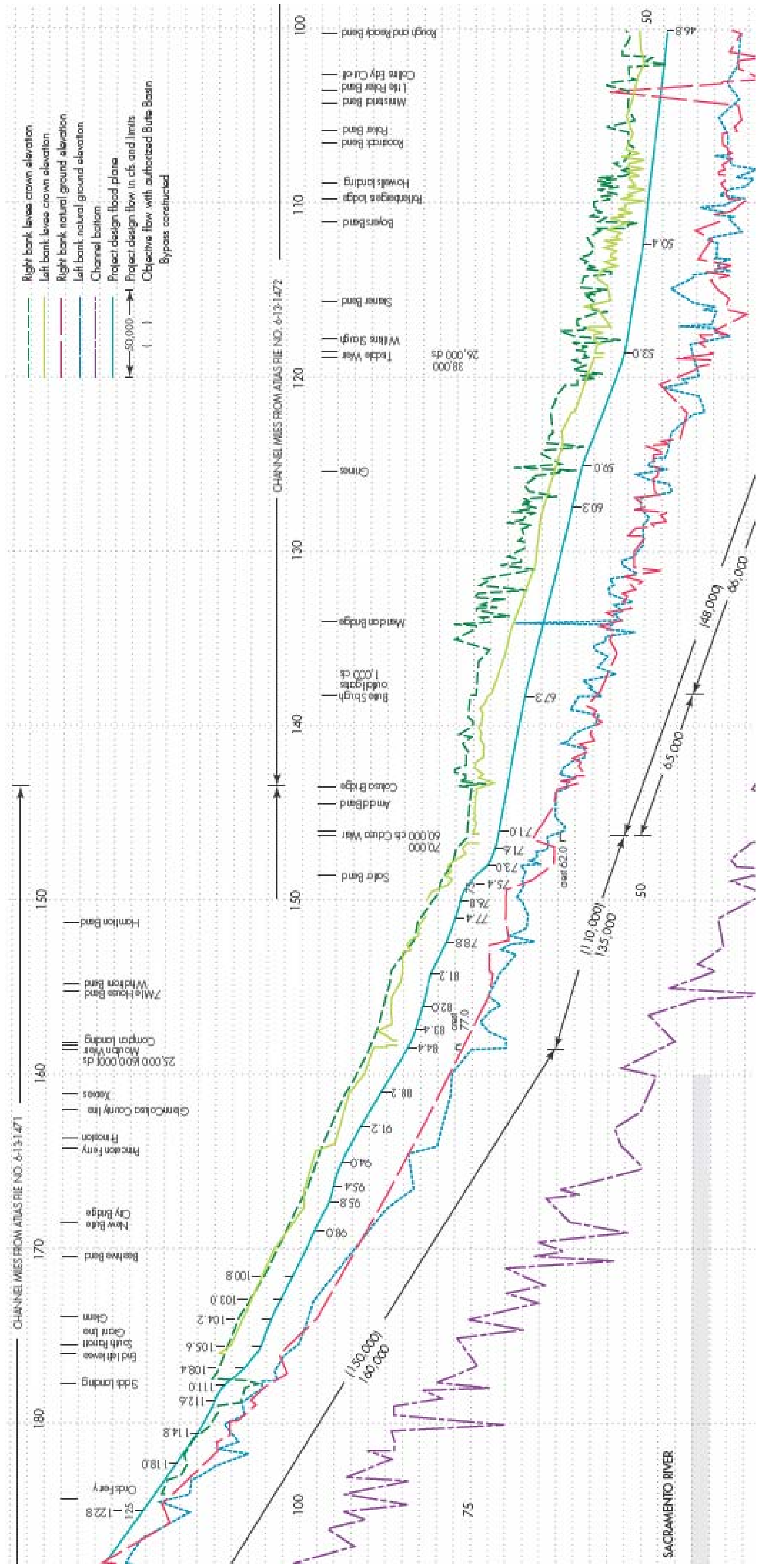


Figure 4: Excerpt from Sacramento River channel design profiles (Reclamation Board electronic conversion of original USACE profiles)

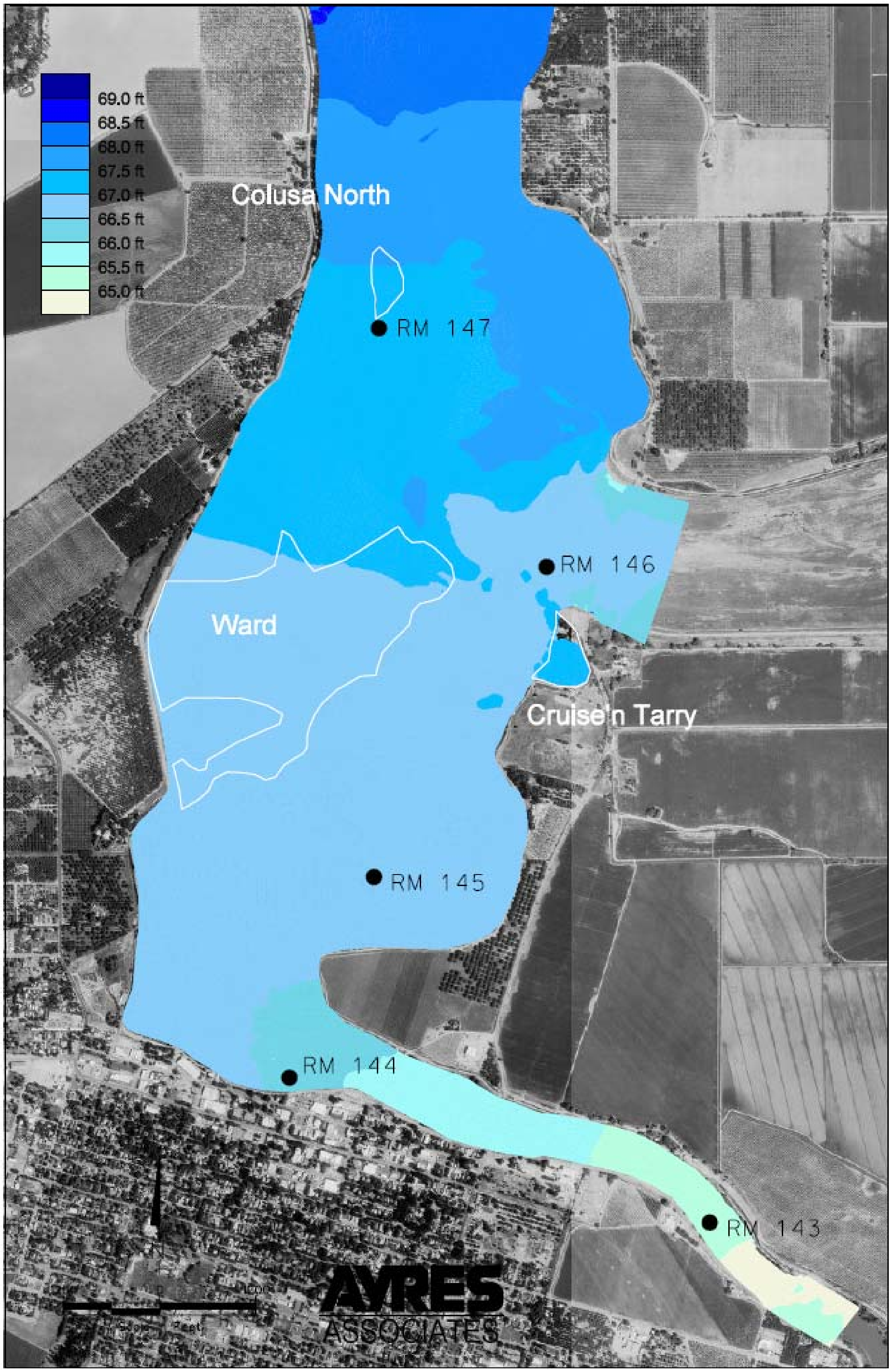


Figure 5: Example of two dimensional results: modeled water surface elevation, Existing Conditions (Without Project) (Ayres Associates)

While two dimensional modeling shows much more detail than one dimensional modeling, the scale of the elements in the model is on the order of thousands of square feet, not small enough to represent individual trees, nor fine enough to perfectly represent a curving levee wall. (See **Figure 6**).

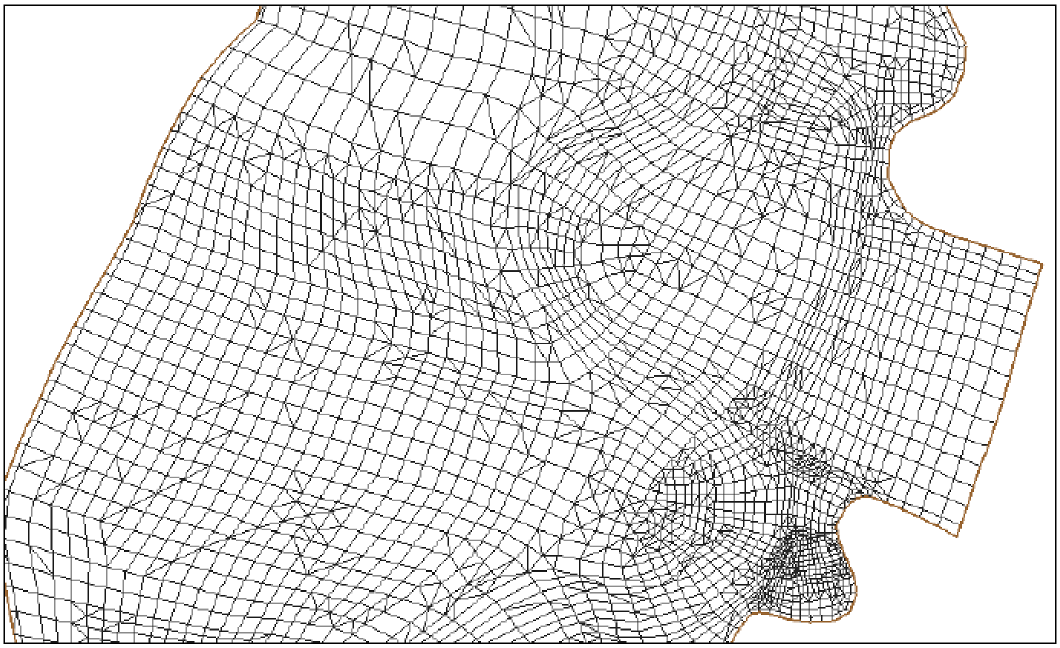


Figure 6: Example of finite element mesh (Ayres Associates)

One should also be aware that there is error in field measurement of land and water elevations, and calculation of flows. Confidence in measured flow measurements may range from +/- 5% to +/- 15%. While the modeled restored conditions did result in a slight (1,000 cfs, ~1 %) increase in flow over Colusa Weir, this change is small when considering potential flow measurement error.

	Existing Conditions Model	Restored Conditions Model
Inflow to Subreach	160,000 cfs	160,000 cfs
Moulton Weir	35,700 cfs	35,700 cfs
Colusa Weir	72,500 cfs	73,500 cfs
Channel below Colusa	51,800 cfs	50,800 cfs

There are several potential sources of error in stage measurement. High water marks pose a special problem where wind waves may be significant, and it may be difficult to tell whether high water reached the top or bottom of a wide swath of debris. There is also rounding error inherent to intensive calculation methods. Just because computer results can be generated to many places past the decimal does not mean those are all significant digits. Taking results to be meaningful to approximately 1/10th of a foot is common practice.

Stage

Model Results

- Model results indicate that for eight river miles upstream of the Ward Tract property, and three river miles downstream of it, under existing vegetation conditions, when 160,000 cfs enters the Colusa Subreach, the water surface ranges from 0.25 to 3 feet below the design profile. (See **Figure 7** to view River Miles 144 through 147, and Ayres' report for graphics of more distant sites). In the immediate vicinity of Ward Tract, the water surface ranges from -0.5 to -1.5 feet below the design profile. Note that the design profile itself is at least 3 ft below the levee crest.
- With the project's proposed restored vegetation conditions, the water surface remains 0.25 to 3 feet below the design profile (See **Figure 8**). There are some slight localized water surface differences (both positive and negative) compared to modeled existing conditions (Compare **Figure 7** and **Figure 8**)
- **Figure 9** isolates the difference between existing conditions and restored vegetation conditions. The yellow triangle indicates the area upstream of Ward Tract where there would be an approximately 0.1 ft rise in water surface elevation. The maximum rise in water surface elevation along the west levee is 0.12 ft. The maximum rise in water surface elevation within the yellow triangle shown is 0.15 ft. The maximum rise in water surface elevation along the eastern levee, north and south of the Colusa Bypass is 0.03 and 0.01 ft respectively.
- The cross section shown in **Figure 10** compares the differences among the design profile, existing conditions (without project) water surface elevations, and restored condition (with project) water surface elevations. This cross-sectional location along the upstream portion of Ward Tract was selected for illustration because it cuts through the area that is modeled to undergo 0.1 to 0.2 ft of water surface elevation rise, as shown by the yellow triangle in **Figure 9**.
- **Figure 10** also illustrates freeboard at the levees, and the typical water depth over Ward Tract under the modeled high flow scenario. It indicates a typical difference between the restored conditions (with project) water surface elevation and the design profile of 0.86 ft. The difference shown between existing (without project) and restored (with project) water surface elevation at this cross section is 0.11 ft.
- **Figure 11** provides a map key showing the location of the cross section provided in **Figure 10**.

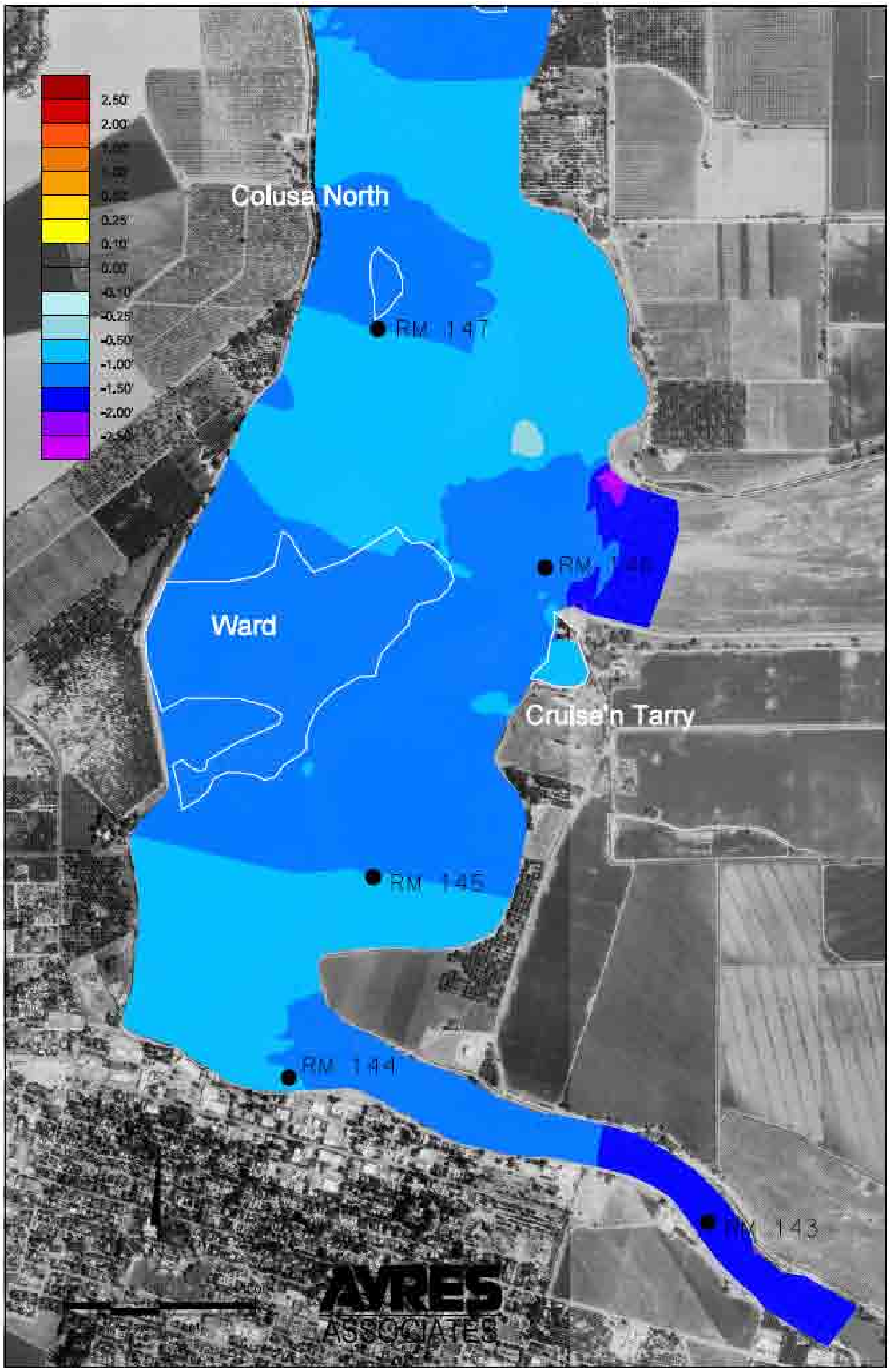


Figure 7: Difference between Design Profile and Existing Conditions (Without Project) modeled water surface elevations (Ayres Associates)

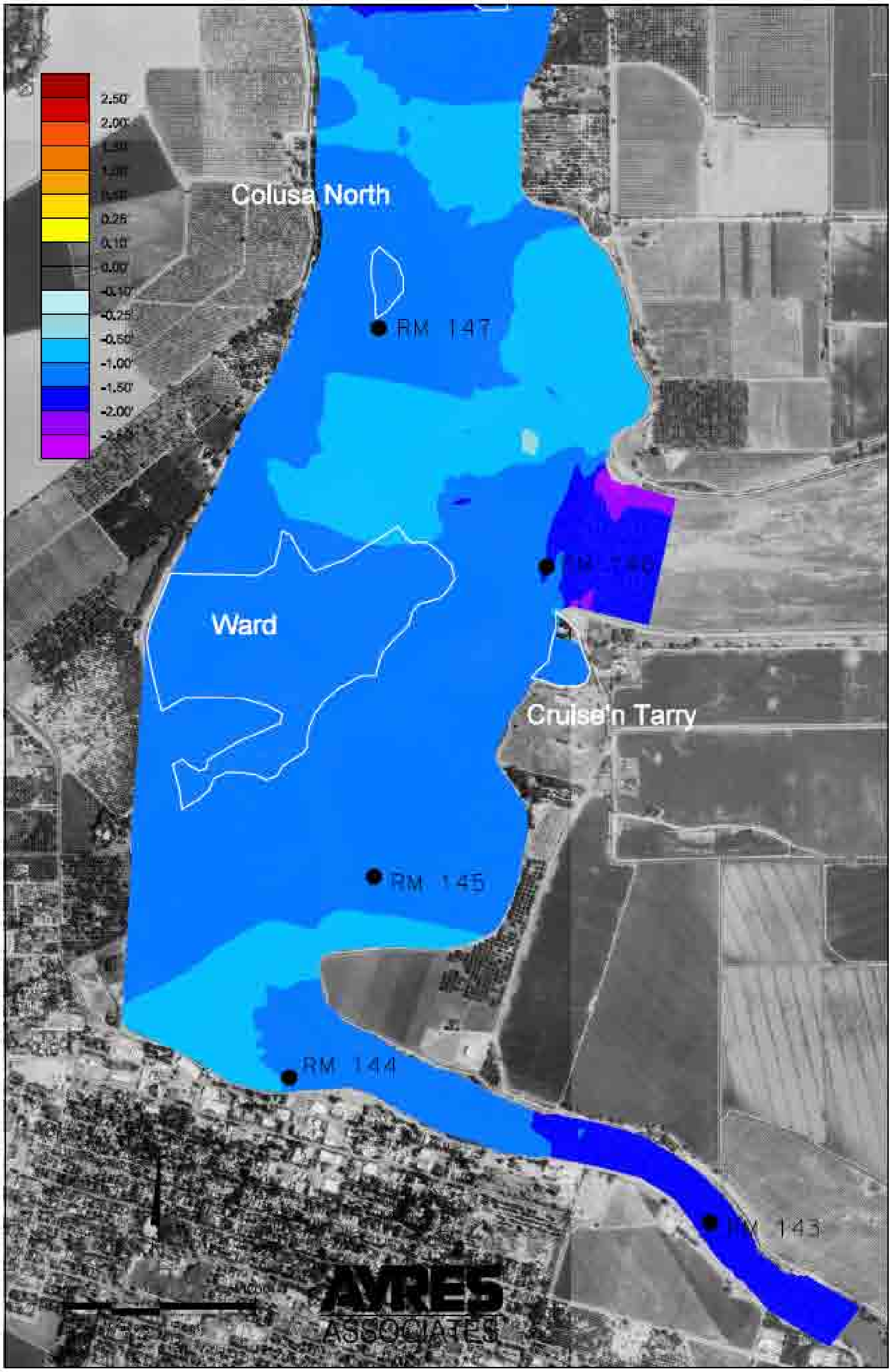


Figure 8: Difference between Design Profile and Restored (With Project) modeled water surface elevations (Ayres Associates)

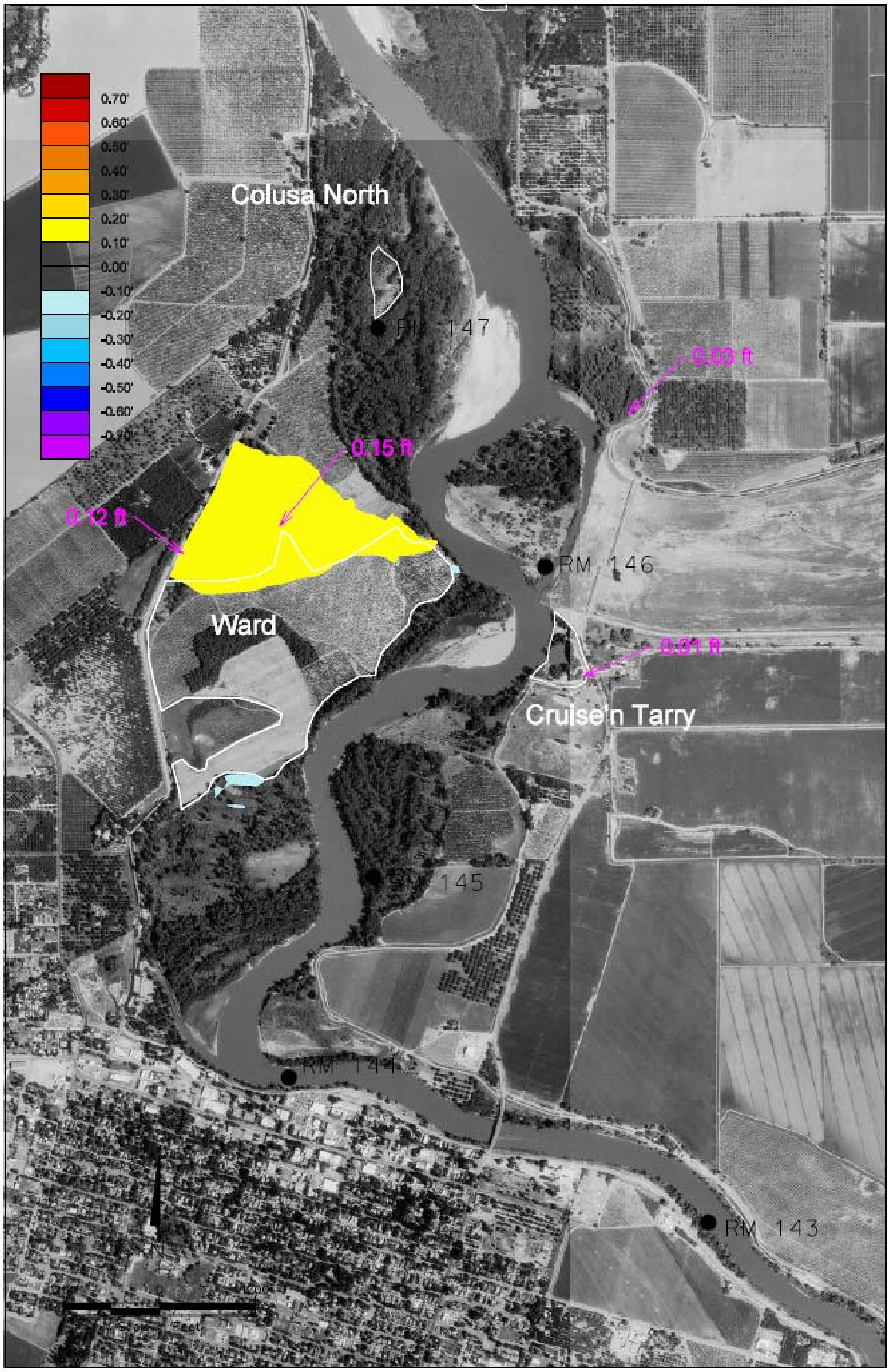


Figure 9: Net change in Water Surface Elevation; Difference between modeled Existing Conditions (Without Project) and Restored (With Project) water surface elevations (Ayres Associates)