Appendix D

# Phillip Williams & Associates Bridge Analysis

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# FINAL M E M O R A N D U M

**DATE:** April 10, 2006

**TO:** Carolyn Shoulders

**COMPANY:** National Park Service

**FROM:** Ann Borgonovo, Matt Wickland

**RE:** **Bridge Sensitivity Analysis Using Hydraulic and Sediment Transport Modeling**
**Big Lagoon Creek and Wetland Restoration**

**PWA Ref. #:** 1664.03

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Philip Williams and Associates (PWA) is pleased to present the results of the hydraulic and sediment transport analysis for various bridge configurations for the Big Lagoon Creek and Wetland Restoration project. This work has been performed under our scope of services with National Park Services (NPS) dated August 22, 2005. The purpose of this modeling is to provide further input on Marin County's Pacific Way Bridge design in support of the Environmental Impact Study/ Environmental Impact Report (EIS/EIR).

Hydraulic modeling results are presented first, including modeling approach, refinements and various iterations to meet design objectives. We then discuss the results of sediment transport analysis on select bridge designs. The supporting figures are listed at the end of this memorandum. The model cross-sections are also provided in Appendix A.

## BACKGROUND

NPS is working toward restoring hydrologic and ecologic processes of Redwood Creek and Big Lagoon, near Muir Beach. All restoration alternatives included realigning Redwood Creek eastward to the valley low point and installing a new creek crossing along Pacific Way road. Currently the roadway is so low that it floods frequently during rain events, resulting in regular road closures. Although the current roadway does not function well for access, hydraulically it provides little obstruction to flood flows. Therefore replacing the bridge and raising the road to reduce road flooding has potential to increase upstream flood elevations in the vicinity of the Pelican Inn and homes on Lagoon Drive.

PWA has hydraulically evaluated alternative bridge designs to help alleviate this potential flooding. This analysis is an important step toward selecting the appropriate dimensions and design for the new bridge.

In addition, we have performed sediment transport analyses on selected bridge configurations to help characterize bridge effects on sediment transport.

## HYDRAULIC MODELING APPROACH

The one-dimension hydrodynamic software MIKE 11 was used to model various different bridge scenarios for Redwood Creek under the 10-year and 100-year flow events. This modeling effort was a refinement of previous modeling performed as part of the Feasibility Study (PWA, 2002) and EIR/EIS analysis (PWA, 2005b). First we refined the Existing Conditions model which establishes baseline conditions and serves as the basis for comparing design options. We then modeled four basic scenarios for creek alignment and bridge location. For each scenario, we varied bridge dimensions (lengths and heights) to determine the minimum dimensions that would not increase 100-year water levels upstream of the bridge. The basic modeling scenarios are as follows:

**Table 1 – Summary of Modeling Scenarios**

| Scenario | Description | Creek Alignment | | Bridge Location |
|---|---|---|---|---|
| | | Upstream of Bridge | Downstream of Bridge | |
| 1 | No Action (Alternative 1)<br>Existing Conditions | Existing | Existing | Existing Location<br>on Pacific Way |
| 2 | Creek Restoration (Alternative 2)<br>No Bridge | New [(1)] | New [(2)] | Not Applicable<br>(No Bridge) |
| 3 | Creek Restoration (Alternative 2)<br>New Bridge | New | New | Centered at New Channel<br>along Pacific Way |
| 4 | Creek Restoration (Alternative 2)<br>Relocate Pacific Way & Bridge | New | New | Centered at New Channel<br>~80 ft south of Pacific Way |
| 5 | Modified Design<br>Widen Existing Bridge | Existing | New | Existing Location<br>on Pacific Way |

(1) Realignment of the creek to the approximately low point of the valley, between the existing channel and Pelican Inn.
(2) Realignment of the creek to the approximate low point of the valley in Green Gulch pasture.

Scenarios 2 through 4 are variations of Alternative 2, the Creek Restoration. For reference, the conceptual design for the Alternative 2 (including refinements dated 5/18/05) is shown in plan and profile on Figures 1 and 44, respectively (PWA, 2005a).

Scenario 5 is a scaled-back version of the Creek Restoration which was requested by NPS. Under this modified design, the bridge and the upstream channel reach remain in the same general location. Downstream of the bridge the channel would be realigned to the approximate valley low point in Green Gulch pasture. Other assumptions for this scenario include:

- Dredging the existing channel upstream of the bridge (similar to New Channel dimensions below).
- Raising the road as needed to reduce flooding.
- Removal of the levee road and 90 feet of the parking lot (similar to Alternative 2).

The model setup for Scenario 1, Scenarios 2 through 4, and Scenario 5 are shown schematically on Figures 2, 3 and 4, respectively. The model cross-sections (A through S) are shown in Appendix A.

## MODEL REFINEMENTS

PWA refined the hydraulic model to better reflect our current understanding of existing and design conditions during a large event (e.g. 100-year flood). We incorporated additional topographic data provided by NPS and refined some of our assumptions regarding roughness, bridge conditions and dimensions of the design channel. These refinements are discussed in more detail below.

### Topographic Data

The MIKE-11 model was updated with new topographic survey data provided by NPS in August 2005. Two new cross-sections, C* and D*, were added to the model. (Note that Section C* was modified to reflect that the low area between the Pelican Inn and the fill pad north of the Pelican Inn is assumed to function as a backwater and would not significantly contribute to floodplain conveyance.) The longitudinal profile along the left bank of the existing channel (Figure 5) was also incorporated in the model to better characterize the link between the main channel and left floodplain.

The MIKE 11 model was originally constructed using topographic data from both ground surveys and aerial photogrammetry. In general, the channel sections are based on ground survey and the rest of the topography is from aerial photogrammetry (Towill, 2000). As a quality control check, surveyed cross-sections C* and D* were compared with aerial photogrammetry from approximately the same location. As shown on Figures 6 and 7, the aerial photogrammetry generally agrees with the ground survey, giving confidence in the accuracy of topographic data used in the model.

### Channel and Floodplain Roughness

Floodplain and channel roughness values for the design conditions model were selected to simulate conditions after vegetation has established (greater than ~5 years). Therefore similar roughness values were used for existing and design conditions. In general, channel roughness was assumed to be 0.06 based on previous model calibration (PWA, 2005b). Floodplain roughness was assumed to vary with water depth. The selected roughness is 0.20 for flows up to 4 feet water deep. Above this water depth, the roughness was decreased to 0.12 to represent the lower resistance from floodplain vegetation.

### Existing Channel

Under Existing Conditions, the dredged portion of the channel directly beneath and upstream of the Pacific Way Bridge was assumed to fill to pre-dredging elevations during a 100-year event. This adjustment was made to reflect sediment deposition expected to occur upstream of the bridge during a large event. This assumption is based on the constriction of the existing bridge and is also consistent the sedimentation observed upstream of the bridge since 2002 dredging, as shown in Figure 8 (source: Environmental Data Solutions).

**New Channel**
For Design Conditions, the dimensions of the new channel were adjusted to better match field measurements of the existing channel upstream on the Banducci site. The design channel is five feet deep, with a bottom and top width of 25 and 35 feet respectively (Figure 44). These channel dimensions would result in some overbank flow during the 2-year event.

As another refinement, we assumed that a portion of the existing channel upstream of Pacific Way would remain (i.e. not be filled) to serve as a backwater channel. This will allow for some flood protection benefit, as well as provide some salmonid rearing habitat. This backwater channel is part of the previous design refinements for Alternative 2 (PWA, 2005a).

Another design approach for improving winter rearing habitat is to increase the frequency of out-of-bank flows downstream of the bridge by reducing channel conveyance. Currently the new channel has uniform dimensions throughout the project reach. However the channel has higher roughness and a slightly flatter slope in Green Gulch pasture, as compared to the reach upstream of the new bridge. The higher roughness value (n = 0.09) in Green Gulch pasture is based on our assumption that we would have more large woody debris (LWD) in the channel for complexity, habitat enhancement, etc. We assume less LWD will be placed and maintained in the upstream reach (n = 0.06) due to the proximity of private property and Pacific Way road. The channel slope upstream of the bridge (~3.7%) is more consistent with the channel profile upstream of the project boundary (roughly 4%); downstream of the bridge the channel slope flattens slightly (~2.5%) as it approaches the channel mouth. The channel has an approximate conveyance capacity of 560 and 300 cfs, upstream and downstream of the bridge, respectively. Therefore we anticipate that out-of-bank flows more frequently in the reach through Green Gulch pasture. As with all our modeling conditions, these assumptions will be refined during the detailed design phase.

**New Bridge**
For the model, the proposed bridge was assumed to have a two-foot thick deck and to be 36 feet wide, allowing for two-way traffic and a pedestrian path. The assumed bridge width was provided by Marin County; the actual bridge width may be reduced during detailed design. Bridges of 50 feet in length were modeled with no piers. We assumed that the bridges longer than 50 feet would have two-foot wide piers spaced at 40-foot intervals along the length of the bridge. (The bridge routine used in MIKE 11 is not sensitive to the exact locations or shape of bridge piers). Bridge submergence and overflow was allowed to occur in the model.

For Scenarios 3 and 4 the new bridge was assumed to be centered at the new channel. For Scenario 3 the bridge is located along the current road alignment. Under Scenario 4 we assumed that Pacific Way would be realigned perpendicular to the flow direction as shown on Figure 9. For Scenario 5 we assumed the existing bridge would be widened to the east.

Any bridge longer than 50 feet was modeled as three separate (but connected) bridge components spanning the right floodplain, channel and left floodplain. This approach better simulated how channel flows would be distributed across the floodplain during a 100-year event. This also allowed us to better represent the actual distance of the bridge from upstream structures, such as the Pelican Inn. Section D* on Figure 3 provides a graphic representation of how the bridge was modeled in MIKE-11.

The new bridge was modeled with the bridge openings approximately perpendicular to the flow direction. Where the bridge is aligned along Pacific Way, the actual bridge length may be slightly longer because the right floodplain opening is not perpendicular to Pacific Way. Therefore, for long spans under Scenarios 3 and 5, we estimated the bridge length (as measured along Pacific Way) assuming a skew angle of 30 degrees on the right floodplain. For shorter spans (150 feet or less) no adjustment was made for skew since flow would be mostly perpendicular to the bridge. Table 2 presents the modeled bridge opening and Table 3 presents the adjusted bridge length. For the road realignment under Scenario 4, the bridge would be perpendicular to the flow direction, so no bridge length adjustment was needed.

For channel and bank areas immediately underneath the bridge, a roughness value of 0.035 was used. For floodplain and overbank areas underneath longer-spanning bridges, the assumed roughness value was 0.045, assuming that the 36-foot wide bridge would shade-out most vegetation.

**Pacific Way Road**

In the hydraulic model, new Section D* was used to reflect the effects of Pacific Way Road (e.g. road height, roughness, etc.) under existing and design conditions. Each model scenario includes two to four closely spaced cross-sections (variations of Section D*) to represent the new or existing road. For some design scenarios we considered raising Pacific Way Road to reduce flooding. For this case, we assumed an embankment with approximately 3:1 (horizontal to vertical) side slopes. A roughness coefficient of 0.03 was used for Pacific Way road and the embankment.

## HYDRAULIC MODELING RESULTS

Based on previous meetings with NPS and Marin County, we understand that at a minimum the new bridge cannot increase upstream flood elevations compared to Existing Conditions. Ideally the new bridge would provide additional benefits of reducing flooding levels for upstream properties. We used the model to test various bridge configurations (length, height and location) that meet this design criterion for the 100-year flow.

Table 2 provides a detailed list of model runs performed for this analysis. To allow comparison of flooding effects, we have presented the predicted water levels at the three structures closest to the bridge: the Pelican Inn, and the downstream and upstream homes on Lagoon Drive. The bridge configurations that achieve the design criteria of no increase at existing structures (to the nearest tenth of a foot) under the 100-year flood event are summarized in Table 3 below.

**Table 3 – Bridge Configurations that Do Not Increase Flood Elevations under a 100-Year Event***

| Scenario | Description | Bridge Dimensions | | Raised Road Elevation (feet NGVD) |
|---|---|---|---|---|
| | | Deck Elevation (feet NGVD) | Length (feet) | |
| 3 | Creek Restoration (Alternative 2) New Bridge at Pacific Way | 21.5 | 266 | ~15 to 21.5 |
| | | 18.0 | 300 | ~15 to 18 |
| | | 16.5 | 50 | 15.5 |
| 4 | Creek Restoration (Alternative 2) New Bridge 80 feet south of Pacific Way | 21.5 | 200 | ~15 to 21.5 |
| | | 17.0 | 280 | ~15 to 18 |
| 5 | Modified Design (Widen Existing Bridge) | 16.5 | 50 | 15.5 |

* Further analysis was performed to identify bridge configurations that also did not increase flood elevations under the 5-, 10- and 50-year events. See Tables 4 and 6 below.

For comparison we have also plotted predicted water levels profiles for Scenarios 1, 2, 3 and 5. For legibility we only plotted one bridge configuration for Scenario 3, the 50-foot bridge and raised road. Additional profiles for other bridge configurations, including Scenario 4, can be provided as needed.

The 10- and 100-year water levels for the right floodplain, near the Lagoon Drive structures, are shown on Figures 11 and 12, respectively. The 10- and 100-year water levels for the left floodplain close to the Pelican Inn are provided on Figures 13 and 14, respectively. The results for the various scenarios are discussed in more detail below.

**Scenario 1 – Existing Conditions**

Under Existing Conditions, Pacific Way road does not obstruct floodplain flows because it is essentially at grade between the existing bridge and Highway 1. Consequently the road floods frequently and is impassible for several days each winter.

Because the backwater effects for a new bridge would be most pronounced just upstream, the predicted water level at the Pelican Inn under Existing Conditions (17.1 feet NGVD) was established as the baseline for “no net change.” Note that the finished floor of Pelican Inn (el. 17.65 feet NGVD) is approximately half a foot above the predicted 100-year water level for Existing Conditions.

**Scenario 2 – Creek Restoration (No Bridge)**
We first modeled the restored creek design without the bridge to understand changes to flood levels if there were no new obstructions on the floodplain. As shown in Table 2, this scenario decreased 100-year flood levels by approximately 0.4 feet at Pelican Inn and 0.7 feet further upstream on Lagoon Way.

**Scenario 3 – Creek Restoration (New Bridge at Pacific Way)**
We then modeled different configurations for a new bridge along Pacific Way that would not increase 100-year water levels at upstream structures. We developed three bridge configurations that met this criterion, which are shown schematically in Figures 9 and 10. Two configurations raise the roadway above the 100-year flood; the third raises the road but allows overtopping for flows above the 5-year event. The first configuration is a 266-foot span bridge with a deck elevation of 21.5 feet NGVD (approximately 10 feet above existing grade), and the second is a longer, 300-foot span with a lower deck at 18.0 feet NGVD.

We also evaluated other configurations that would allow some flooding of the road. We looked at the maximum elevation that we could raise the full length of the road without increasing 100-year flood levels at the Pelican Inn. Model sensitivity testing indicated that upstream water levels were more sensitive to a higher road than a shorter span bridge.

We found that the road raised to elevation 15.5 feet (based on the 5-year water level) and an approximately 50-foot long bridge (16.5-foot deck elevation) met the design criterion of not increasing flood elevations during a 100-year event. However, it should be noted that this configuration would raise water levels for the 10-year flow as shown on Figures 11 and 13. The 10-year water levels in the vicinity of the Pelican Inn would be raised approximately 0.5 to 1 foot. The higher 10-year water levels would be below the back steps and finished floor of the building.

The road would be overtopped during flows greater than the 5-year event. Predicted water depths above the raised road for the 10- and 100-year events are 3 and 12 inches, respectively (Table 7). This bridge configuration was tested further to see if the road could be raised higher. However, we found that raising the road to the 10-year water level would require a significantly longer span (similar to the first two configurations).

It should also be noted that culverts should be installed under the raised road to drain floodplain areas beyond the new channel berms and improve fish passage. A 3- to 5-foot diameter culvert could be installed on either side of the bridge. The culverts are expected to improve drainage during frequent storms, but could likely be blocked with flood debris during large (i.e. greater than 10-year) events.

**Scenario 4 – Creek Restoration (Relocate Pacific Way)**
Because the backwater effects of the bridge diminish with distance upstream, we looked at whether the bridge could be significantly smaller if it were located approximately 80 feet downstream (Figure 9).

Under this hypothetical scenario, the road would be located outside the County's right-of-way. As shown in Table 3, a bridge with a 21.5-foot deck elevation could be reduced in 200 feet, as compared to 266 feet under Scenario 3. A 280-foot bridge with a deck elevation of 17.0 feet NGVD (approximately 6 feet above existing grade) would also meet the design criterion.

**Scenario 5 – Modified Design (Widen Existing Bridge)**

We also modeled the Modified Design scenario which includes widening the existing bridge, dredging the upstream channel and realigning the downstream channel (Figure 4). For this scenario we assumed that the road would need to be raised to reduce the frequent road flooding. Except for the bridge location, this scenario is analogous to the raised road configuration for the full Creek Restoration (Scenario 3, Bridge 3), and produced similar results (see Figures 11 through 14).

Similar to Scenario 3, we found that a raised road at elevation 15.5 feet and a 50-foot long bridge (16.5-foot deck elevation) would meet the design criterion. This scenario also raises water levels in the vicinity of the Pelican Inn for the 10-year flow (Figures 11 and 13). The depth of road overtopping is slightly higher for this scenario than Scenario 3. In a 5-year event there would be approximately 2 inches water depth on the road; for 10- and 100-year flows the water depth would roughly one inch higher than under Scenario 3.

It should also be noted that installation of additional culvert(s) under the raised road would be even more important under this scenario because drainage will collect in the valley low point near the Pelican Inn. Because the culvert(s) drain a larger area, more frequent maintenance may be required than under Scenario 3.

**COUNTY AND NPS MEETING (October 7, 2005)**

The hydraulic modeling results summarized above were presented to representatives from NPS and Marin County in a stakeholder meeting on October 7, 2005. There was interest in further refining the bridge configuration with the 50-foot span and raised road (Scenario 3, Bridge 3). Although this scenario did not increase the 100-year water level, it increased the 10-year level by 0.5 to 1.0 foot compared to existing conditions.

NPS requested that PWA perform additional modeling to identify a bridge configuration that does not raise the water level for the 100-year as well as more frequent storm events. We varied the following parameters: bridge length (primary variable), bridge elevation and raised road elevation. We also modeled the following flow events: 5-, 10-, 50- and 100-year. The results are as follows:

**Table 4 – Sensitivity Analysis Results for "Raised Road" Design**

| Description | Bridge Length | Bridge Deck Height | Road Height | Water Level on Floodplain Adjacent to Pelican Inn (feet NGVD) | | | |
|---|---|---|---|---|---|---|---|
| | (feet) | (feet) | (feet) | Q5 | Q10 | Q50 | Q100 |
| **Existing Conditions** | 24 | 15.16(1) | ~10-15 | 14.8 | 15.1 | 16.5 | 17.1 |
| **Creek Restoration (Alternative 2)** | | | | | | | |
| Bridge 3 | 50 | 16.50 | 15.50 | 15.5 | 16.0 | 16.8 | 17.1 |
| Test Run #18 | 150 | 16.50 | 15.50 | 14.6 | 15.7 | 16.8 | 17.2 |
| Test Run #19 | 150 | 16.50 | 15.00 | 14.6 | 15.3 | 16.6 | 17.0 |
| Bridge 4 | 150 | 16.25 | 14.50 | 14.7 | 15.1 | 16.4 | 17.0 |

(1) The maximum bridge elevation as reported in NPS's August 2005 survey results. Previous surveys show the soffit at an elevation of 12.59 ft.

Results for Existing Conditions and the 50-foot bridge (Bridge 3) are as presented above. Under this additional modeling effort, we first tried to widen the bridge to 100 feet, which still increased the 10-year water level. We then widened the bridge to 150 feet (run #18), which decreased the 5- and 10-year water level, but slightly increasing the 100-year level (Table 4). We think this 0.1-foot increase in the water surface is more due to a change in the model configuration, rather than the increased bridge length (described more below). Nonetheless, we proceeded with modifying the bridge configuration until predicted water levels for the four modeled events were less than existing conditions. Lengthening the bridge to 150 feet and lowering the bridge and road surface to elevation 16.25 and 14.5 feet NGVD, respectively, met this criterion. The plan and elevation views of this new bridge configuration (Bridge 4) are shown schematically on Figures 43 and 35, respectively.

Please note that the model configuration for the 150-foot bridge (Runs #18, 19 and Bridge 4) is different than that used for the 50-foot bridge (Bridge 3) because the bridge span is significantly wider than the 35-foot channel. To reflect both a bridge opening and raised road (effectively a weir) on the floodplain, we needed to revise how the channel and floodplain limits are defined in the model. It was not appropriate to apply this same modification to the Existing Conditions model, and therefore the results are not as comparable.

**VALUE ANALYSIS WORKSHOP (January 19 - 20, 2006)**

NPS and the County held a Value Analysis workshop on January 19 - 20, 2006 to help identify the preferred conceptual bridge design. The general consensus was that preferred bridge location is within the existing road right-of-way and spanning the realigned channel (Scenario 3). Therefore Scenarios 4 (outside the road right-of-way) and Scenario 5 (Modified Design) have not been modeled further.

**Bridge with Minimal Road Raising (Bridge 5)**

Following the workshop, NPS requested that we evaluate an additional bridge configuration that lowered the bridge deck and reduced the extent of raising the road. This additional configuration (Bridge 5) includes a 50-foot bridge span with a deck elevation of 15 feet NGVD. The road is raised only as needed to transition to the bridge deck (at 6% slope per the County). Bridge 5 is shown schematically in plan and profile on Figures 9 and 36, respectively.

Bridge 5 was modeled assuming the relocated creek location were approximately 150 feet from the Pelican Inn, similar to the other modeled bridge configurations. In addition, we qualitatively evaluated the advantages and disadvantages of locating the creek and bridge even closer to the Pelican Inn. The intent of moving the bridge would be to reduce the extent of fill needed to raise Pacific Way, thereby reducing new obstructions to floodplain flows. We developed schematic representations of this scenario to look at the consequences of moving the creek northward. Figures 37 (plan view) shows the channel moved to within 10 feet of the Pelican Inn parking lot; Figure 38 shows an elevation view at this creek location. (Please note that the configuration shown in Figures 37 and 38 was not modeled.)

It is useful to compare the Bridge 5 elevations shown on Figures 36 and 38 for the two different creek alignments. As shown on Figure 38, moving the bridge northward does not significantly reduce the amount of road fill required. However, the amount of floodplain obstruction would be somewhat reduced because some fill (approximately 7% of total embankment cross-sectional area) would be placed downstream of existing fill for the Pelican Inn. (The reduced floodplain obstruction is shown graphically in Figure 38 where the green and yellow lines overlap). Another limited advantage would be that since the bridge would be located closer to the valley low point, which could reduce the number and/or size of drainage culverts needed under the raise road (as discussed under Scenario 3 above). However, this creek location is undesirable from a fish habitat perspective. Locating the creek adjacent to the parking lot does not provide a sufficient riparian buffer, which would result in loss of shade and cover, increased human disturbances and potential water quality degradation from parking lot runoff.

**Summary of Bridge Configurations**

The basic bridge configurations considered during the Value Analysis were: a 50-foot span (with and without a raised road), a 150-foot span with raised road, and a maximum length bridge (266 to 300-foot span). These bridge configurations are summarized in Table 5 and shown in elevation on Figures 10, 35 and 36.

**Table 5 – Summary of Bridge Configurations for Creek Restoration (Scenario 3)**

| Bridge Configuration | Deck Elevation (feet NGVD) | Length (feet) | Road Elevation (feet NGVD) | Increase Water Levels Upstream? (Table 6) | Predicted Road Flooding (See Table 7) | Geomorphic/ Ecological Function* (See Table 8) |
|---|---|---|---|---|---|---|
| 1 | 21.5 | 266 | ~15 to 21.5 | No | Rarely | ●●●●● |
| 2 | 18.0 | 300 | ~15 to 18 | No | Rarely | ●●●●● |
| 3 | 16.5 | 50 | 15.5 | Yes | Moderate | ●● |
| 4 | 16.25 | 150 | 14.5 | No | Moderate | ●●●● |
| 5 | 15.0 | 50 | ~11 to 15 | No | Frequent | ● |

* ●●●●● (5) is considered the highest relative rating for ecological/geomorphic function. See Table 8 below.

Predicted Water Levels

Table 6 shows predicted flood elevations near the Pelican Inn for the five bridge configurations. As shown in Table 6, Bridge 3 (50-foot span with raised road) will increase water levels at Pelican Inn (by less than one foot) for the 5-, 10- and 50-year events. All other bridge configurations either meet or reduce water levels compared to Existing Condition for the modeled flow events. (Note that Bridges 1 and 2 were not modeled for the more frequent flow events.)

**Table 6 – Summary of Predicted Water Levels for Bridges 1 through 5**

| Description | Bridge Length | Bridge Deck Height | Road Height | Water Level near Pelican Inn(1) (feet NGVD) | | | |
|---|---|---|---|---|---|---|---|
| | (feet) | (feet) | (feet) | Q5 | Q10 | Q50 | Q100 |
| **Existing Conditions** | 24 | 15.16 (2) | ~10 to 15 | 14.8 | 15.1 | 16.5 | 17.1 |
| Bridge 1 | 266 | 21.5 | ~15 to 21.5 | N/A(3) | N/A | N/A | 17.1 |
| Bridge 2 | 300 | 18.0 | ~15 to 18 | N/A | 14.7 | N/A | 17.1 |
| Bridge 3 | 50 | 16.5 | 15.5 | 15.5 | 16.0 | 16.8 | 17.1 |
| Bridge 4 | 150 | 16.25 | 14.5 | 14.7 | 15.1 | 16.4 | 17.0 |
| Bridge 5 | 50 | 15.0 | ~11 to 15 | 14.2 | 14.9 | 16.5 | 17.1 |

(1) Water level near the Pelican Inn structure. See Section D, Figure 4.

(2) The maximum bridge elevation as reported in NPS's August 2005 survey results. Previous surveys show the soffit at an elevation of 12.59 ft.

(3) N/A = modeling results not available.

We understand that bridge configurations 2, 4 and 5 were considered the preferred alternatives for further evaluation. To help compare flooding impacts, the 10- and 100-year water surface profiles for these three configurations are shown on Figures 39 through 42. In general, the proposed bridge configurations lower the 10-year water level by roughly one-foot upstream of Pacific Way (Figures 39 and 40) compared to existing conditions. The predicted lowering of water levels is less pronounced during the 100-year flow conditions; water levels for proposed conditions are roughly 0 to 6 inches below existing conditions (Figures 41 and 42).

(Note that Bridge 2 appears to result in higher water levels near Pacific Way than Bridges 4 and 5, even though this bridge configuration creates less of a floodplain obstruction. This may be because the model configuration for Bridge 2 has fewer cross-sections near the bridge, therefore there are fewer data points for the profile. The additional cross sections were used for Bridges 4 and 5 to simulate the elevated road. Bridge 2 could not be modeled with additional cross sections since the bridge spanned nearly the entire floodplain and there is a minimum distance allowed between cross sections and bridges.)

Road Flooding

For configurations 1 and 2, the bridge would span the floodplain and be above the predicted 100-year water surface, so the bridge would rarely be overtopped. For configurations with shorter spans, the road would flood periodically. Table 7 shows the approximate duration of road inundation for Bridges 3 through 5 (as predicted by the MIKE-11 model). (Raising the road further would increase upstream flooding, and is therefore not acceptable.)

**Table 7 - Average Water Depths for Bridges 3 to 5**

| Flow Event: | 5-Year | | | 10-Year | | | 100-Year | |
|---|---|---|---|---|---|---|---|---|
| Bridge Configuration | WSE(1) (feet NGVD) | Depth at Road(2) (inches) | Approx(4) Duration (hours) | WSE(1) (feet NGVD) | Depth at Road(2) (inches) | Approx(4) Duration (hours) | WSE(1) (feet NGVD) | Depth at Road(2) (inches) |
| **3)** 50-ft bridge & raised road (el. 15.5 ft) | ~15.5 | N/A(3) | 0 | 15.8 | 3 | 11.5 | 16.6 | 12 |
| **4)** 150-ft bridge & raised road (el. 14.5 ft) | 14.7 | ~3 | 5.5 | ~15.1 | ~5 | 11.5 | ~17 | ~30 |
| **5)** 50-ft bridge & ramped road (el. 11-15 ft) | 13.1 | 25 | 27 | 13.6 | 31 | 27 | 15.9 | ~60 |

(1) Average water surface elevation across the raised road. Water levels vary by up to 0.4 feet across the 50-foot wide road embankment.

(2) Maximum depth (in inches) at road, based on averaging the maximum water depths along the entire road profile.

(3) N/A = not applicable. No overtopping of the road.

(4) Approximate duration that any water would overtop the road, including periods of shallow flooding. The model cannot account for the conditions that may extend flooding duration such as tidal effects.

Of the five configurations, Bridge 5 results in the most frequent flooding because portions of the road will not be raised. Under this bridge configuration the road would flood (by roughly 12 inches) during the 2-year event (800 cfs). (However, predicted conditions in a 2-year flow are more approximate, since they are much more sensitive to the assumed channel dimensions, which are still preliminary.)

Ecological/Geomorphic Function

We have also provided a brief qualitative assessment of how the proposed bridge configurations would affect the geomorphic and ecological function of the channel and floodplain. As shown in Table 8 we rated each bridge configuration based on the following three characteristics:

1. Unsustainable Channel Migration – likelihood of channel avulsion outside of the bridge limits due to a) bridge blockage (by woody debris, accumulated sediment, etc.) and/or b) low resistance to channel headcutting (road that provides limited grade control function, by not having a raised embankment, non-erosive paving material, etc.).
   ? Highest rating (5): Long/high bridge span.
   ? Lowest rating (1): Short/low bridge span; at-grade road (low resistance to new channel formation).

2. Floodplain Connectivity – degree of a) longitudinal floodplain connectivity (provides wildlife corridor crossing Pacific Way) and b) channel-floodplain connectivity in the vicinity of the bridge.
   ? Highest rating (5): Long bridge span.
   ? Lowest rating (1): Short bridge span; raised road.

3. Natural Channel Function – degree to which a) channel adjustments (bank erosion and migration) are allowed without requiring armoring, and b) sediment deposition is allowed without requiring dredging or other channel maintenance (e.g. LWD removal).
   ? Highest rating (5): Long bridge span.
   ? Lowest rating (1): Short bridge span.

In general, a longer bridge spans (Bridges 1, 2 and 4) are rated highly for relative geomorphic and ecological function. The 50-foot bridge has low floodplain connectivity and channel function, with or without the raised road. However, raising the road should reduce the likelihood of the channel avulsing to either side of the bridge. For this reason, the 50-foot bridge with the raised road (Bridge 3) is considered to have higher geomorphic function than without the raised road (Bridge 5). The ratings in Table 8 are consolidated into one overall rating in Table 5 above.

**Table 8 Basis for Brief Evaluation of Geomorphic/Ecological Function**

| Bridge Configuration | Deck Elevation (feet NGVD) | Length (feet) | Road Elevation (feet NGVD) | Channel Stability | Floodplain Connectivity | Natural Channel Function |
|---|---|---|---|---|---|---|
| 1 | 21.5 | 266 | ~15 to 21.5 | ●●●●● | ●●●●● | ●●●●● |
| 2 | 18.0 | 300 | ~15 to 18 | ●●●●● | ●●●●● | ●●●●● |
| 3 | 16.5 | 50 | 15.5 | ●●● | ● | ● |
| 4 | 16.25 | 150 | 14.5 | ●●●● | ●●●● | ●●●●● |
| 5 | 15.0 | 50 | ~11 to 15 | ● | ● | ● |

## HYDRAULIC MODELING ACCURACY

The above results are appropriate for planning-level comparisons of design and existing conditions. Modeling assumptions are based on the current conceptual-level of creek restoration design. Future design refinements, such as actual bridge configuration, bridge width, road elevations, channel dimensions and channel slope, should be incorporated into the model as needed to confirm design criteria are met.

The accuracy of predicted water surface elevations are still limited because calibration data is only available for low flow conditions (i.e. limited overbank flow). Although we have refined our assumption regarding floodplain roughness, this estimate has not been calibrated.

Finally, the model was not initially set up for Scenario 5, the Modified Design, and has not been as refined as rigorously for this scenario. If this scenario is pursued further, we recommend that design assumptions and the model be further refined to reflect anticipated conditions.

## SEDIMENT TRANSPORT MODELING

Sediment transport modeling was performed using MIKE-11 to (a) compare deposition patterns between existing and design conditions, (b) identify specific locations that are depositional and (c) help optimize the bridge configuration to minimize deposition.

In the October 7th, 2005 meeting, project stakeholders selected the following three cases in the for additional sediment transport modeling:

- Existing Conditions
- Creek Restoration and Bridge 3 (50-foot bridge and raised road)
- Creek Restoration and Bridge 4 (150-foot span bridge and raised road)

It should be noted that although not selected for sediment transport modeling, other bridge configurations may be considered further.

**Modeling Approach**
PWA first calibrated the sediment transport model for existing conditions using existing available field data, as described below. Following model calibration, both long-term and large event scenarios were modeled for existing conditions and the two proposed bridge configurations. Pre- and post-simulation bed level profiles were compared to identify the erosional and depositional reaches of the channel.

Following sediment transport modeling, we routed three flood events (e.g. the 5-, 10- and 100-year) for both pre- and post-simulation bed conditions and compared flood elevations. This evaluation of how sediment deposition would affect flood levels was performed for existing conditions and one design scenario.

**Model Setup**
PWA utilized the Engelund and Hansen sediment transport function available in MIKE 11 to model bedload (suspended load was determined to be insignificant). The Engelund and Hansen total load transport function is applicable to the range of substrate grain sizes found in Redwood Creek (Yang and Huang, 2001).

To focus efforts in modeling sediment transport and to provide model stability, only the main branch of Redwood Creek was allowed to experience erosion and deposition. The floodplains and linked branches could receive sediment from the main channel, but were not allowed to function as a sediment source to the main channel. This simplification is reasonable since most of the bedload would remain within the channel during an event less than 100 years in frequency.

**Hydrology**
Two different flow events were modeled as an attempt to capture the full range of potential transport scenarios. We simulated long-term bed level changes by modeling 5 years of "typical" flow data. Actual flows from December 2004 were used since this month contained the two-year event and another event with a peak about half that of the two-year flow. The hydrograph shown on Figure 15 was repeated five times to represent five years of "typical" flow.

We also modeled a larger single event that would provide more significant sediment loads and higher potential for bed erosion and deposition. The stream gage at Highway 1 provided data from an event on December 27, 2004, which was approximately a two-year event. This event lasted for two days and was followed by about eight days of higher than normal baseflows. The hydrograph from this 10-day event was roughly doubled, yielding a hydrograph representing approximately a 6-year occurrence interval (Figure 16).

**Sediment Data**

Sediment sampling data was obtained from Environmental Data Solutions and included several bedload discharge measurements and bed material grain size distributions (Stillwater, 2004). Based on the bedload measurements, a rating curve was developed to create sediment supply curves that accompanied each hydrograph used in the modeling. As a way to model different sediment sizes separately, the bedload was broken into four separate size classes, each with their own supply curves. The model used each of these four supply curves and accounted for each of these bedload classes independently.

**Model Calibration**

The existing conditions model was calibrated based on changes to the channel thalweg elevation (from 2004 and 2005 thalweg surveys) and measured flow data. We compared thalweg profiles taken from survey data in August 2004 and February 2005 (Figure 8). Major flow events between these periods were modeled and the calibration parameters were adjusted until a reasonable fit was found with the February 2005 profile. Because the 2004 survey had fewer data points than the 2005 survey, it was not possible to match the post-simulation thalweg exactly. However, for calibration purposes additional cross-sections were included in the model to better match the 2005 data points. See Figure 17 for the calibration results.

**Boundary Effects**

Sediment transport modeling results at the upstream and downstream ends appear to be artificially influenced by model boundary conditions and should be disregarded.

For all simulations, the model consistently predicts erosion at the upstream model boundary (between Stations 3000 and 3500). We used the 50-foot bridge model to test whether the predicted erosion was due to model instability at the upstream boundary. We extended the boundary 650 feet upstream and reran the model. Figures 24 and 26 show results for the same model with the standard and extended upstream boundary condition, respectively. As shown in these figures, extending the boundary condition reduced the maximum erosion depth from approximately 1.5 to 0.5 feet, indicating that this erosion, or at least the predicted magnitude, is likely a modeling artifact.

For the hydraulic modeling scenarios, the downstream boundary is typically mean higher high water (MHHW) to represent tidal conditions. However, for sediment transport modeling, use of a high tide caused backflow during periods of low flow (between storms events in the long-term simulation). To stabilize the model the starting water surface was lowered to elevation 0.0 feet NGVD, which tended to overstate downstream erosion. For this reason the results at the downstream end of the model (roughly Station 0 to 500) are not considered valid.

**SEDIMENT TRANSPORT RESULTS**

The sediment transport modeling results for five years of “typical” flow are presented on Figures 18, 19 and 20. These plots compare the pre- and post-simulation channel profiles for the three cases modeled.

The difference in thalweg elevation from pre- and post-simulations can be used to infer general patterns of deposition and erosion. Figure 21 compares the change in thalweg elevation for existing and design conditions (50- and 150-foot bridge).

The modeling indicates that under existing conditions, the channel bed is expected to generally be more erosional than depositonal in the long-term (Figure 18). However, this prediction does not correlate well with the significant sediment accumulation observed since the early 1990s, as shown on Figure 22 (PWA, 2003). Redwood Creek experienced roughly 1 to 4 feet of channel deposition downstream of Pacific Way between 1992/3 and 2002 (prior to dredging by NPS).

Because the “five-years of flow” model simulation did not correspond well with observed results, we also modeled a single event to see if reasonable long-term sediment predictions were beyond the capabilities of the model. We modeled an event with roughly a 6-year return period (Figure 16). The sediment transport modeling results for the single 6-year event are presented on Figures 23, 24 and 25. A comparison of bed change for the three cases modeled is provided on Figure 27. These simulation results correlated better with design expectations that the restored channel would have higher sediment transport capacity resulting in a more stable channel bed.

Sediment transport results for the three models are discussed below, followed by some general conclusions.

**Existing Conditions**

For Existing Conditions (Alternative 1 – No Action) the modeling results for the long-term and single event simulations are shown on Figures 18 and 23, respectively. Under existing conditions the most notable bed changes are around the existing bridge. For the single event, there is a zone of significant deposition a few hundred feet upstream of the bridge, while in the long-term the zone of accumulated sediment extends approximately 100 feet downstream of the bridge. In both cases, erosion is predicted just downstream of deposited sediment (presumably due to the “hungry water” effect). The exact location of the deposition appears to be affected by the duration of the simulation; the longer the simulation, the more the zone of deposition extends downstream.

**Creek Restoration (50-foot span Bridge)**

For design conditions (Alternative 2 – Creek Restoration) we performed sediment transport modeling for the 50-foot span bridge (soffet el. 14.5 feet) with the road raised to el. 15.5 feet (Bridge 3). The long-term and single event modeling results for the 50-foot span bridge are shown on Figures 19 and 24, respectively. For the single event (Figure 24), the model predicts that the “design channel” will be relatively stable, with no areas of significant deposition or erosion. For the long-term simulation (Figure 19), more extreme patterns of deposition or erosion emerge, as discussed below.

The model predicts that the channel bed under the creek restoration will be slightly depositional upstream of the bridge and erosional just downstream. The limited erosion (2 inches) predicted just downstream of the bridge (Station 2500) in the single event (Figure 24) appears to be significantly magnified (3.5 feet) in the long-term simulation (Figure 19). The cause for the predicted erosion, and therefore its likelihood, is not clear based on our analysis of maximum velocity, shear stress and flow width for this single event (shown on Figures 28, 29 and 30, respectively). This large scour prediction may be influenced by how the bridge is modeled. (The modeled channel "limits" [different than channel dimensions] are normally 35 feet wide, but expand to 50 feet at the bridge to capture its full span. The predicted scour may be partly caused by the contraction of the channel limits back to 35 feet just downstream of the bridge.)

The model also predicts channel bed deposition in the reach through Green Gulch pasture. This deposition may be due to decreased channel conveyance through this reach as discussed above under Model Refinements.

**Creek Restoration (150-foot span Bridge)**

We also performed sediment transport modeling for the same design conditions but with the 150-foot span bridge (soffet el. 14.25 feet) and road raised to el. 14.5 feet (Bridge 4). The long-term and single event modeling results for the 150-foot span bridge are shown on Figures 20 and 25, respectively. As shown on Figures 21 and 27, the predicted bed changes for design conditions with the 150-foot bridge and similar to those for the 50-foot bridge, except just downstream of the bridge. For the long-term simulation, both deposition and less severe erosion are predicted for the 150-foot bridge, compared to the high erosion predicted for the 50-foot bridge. Again, the exact cause of this erosion, and therefore whether conditions would actually be improved with a longer bridge, is unknown. (However, it should be noted that the 150-foot bridge was modeled with consistent channel limits, unlike the 50-foot bridge. This provides some indication that the predicted scour for the 50-foot bridge is indeed a modeling artifact.)

**Predicted Water Levels**

Following sediment transport simulations, we also routed flood flows through the model for pre- and post-simulation bed conditions. We then compared the results to determine how much effect predicted "long-term" changes (i.e. five years) to the channel bed would affect flood levels near existing structures. Figures 31 and 32 show comparative 5-year flood levels for existing conditions and design conditions (150-foot bridge), respectively. Figures 33 and 34 show 100-year flood levels for existing conditions and design conditions, respectively. As shown on Figure 32, for the design conditions the predicted deposition upstream of the bridge would increase the 5-year water surface by approximately 2 to 4 inches. The change in water level is much less pronounced for the 100-year flow (Figure 34); however, the model predicts an approximately 4-inch increase in water surface just upstream of the Pelican Inn.

**Conclusions**

Our general conclusions regarding sediment transport modeling results are as follows:

- The single event modeling results appear to be less susceptible to distortion by the transport model, and therefore more reliable than the long-term simulation for drawing general conclusions.

- The sediment modeling results should be considered general predictions of depositional and erosional patterns, rather than qualitative predictions of changes to thalweg elevations.

- Although the existing conditions model was calibrated using actual field measurements, the long-term model predictions are not consistent with actual long-term observations. Potential factors may be because the model calibration data was only available for a limited channel reach (roughly 200 feet), and because the model does not adequately capture tidal influences.

- The existing conditions model predicts a zone of significant sediment deposition in the vicinity of the Pacific Way Bridge. The location of the deposition, including whether it is upstream or downstream of the bridge, varied for different simulations.

- In general, based on results for a single event, the channel under design conditions appears to be more stable than the existing channel, having no areas of significant deposition or erosion.

- For design conditions, the model predicts that there will be some sediment deposition upstream of the bridge. The sediment deposition is predicted to be distributed relatively evenly throughout the upstream reach.

- The sediment transport model does not predict any significant difference in erosion and deposition trends between the 50- and 150-foot bridges, except within 200 to 600 feet downstream of the new bridge. The model predicts that the 150-foot bridge would cause less erosion than the 50-foot bridge within 200 to 600 feet downstream of the new bridge; however results for this area may be skewed by a modeling artifact.

- Sediment deposition upstream of the new bridge will have some effects on flood levels; however the modeling is not accurate enough to predict how quickly sediment will accumulate.

**Channel Maintenance**

In addition to sediment transport modeling results, the following general points regarding future channel maintenance can be made based on our understanding of the geomorphic function of Redwood Creek. The creek restoration design is expected to reduce channel deposition, and therefore the frequency of channel dredging, for the following reasons:

- The new channel will be graded with a more uniform gradient and configuration (i.e. cross-sectional dimensions) which should increase sediment transport capacity.

- The new channel will be located closer to the valley low point, which will help keep flows concentrated in the channel, thus increasing sediment transport capacity, and sustaining the channel gradient and configuration. (Currently flow leave the channel upstream of the bridge, and do not return to the main channel until downstream of Green Gulch pasture).

- The existing bridge with be replaced with a larger span bridge, oriented parallel to the flow direction, which will reduce backwater effects that cause sediment deposition.

The sediment transport modeling did not conclusively show to what degree a significantly longer bridge (e.g. 150-foot versus 50-foot span) would reduce sediment deposition. However, in general, increasing the bridge span (and deck height) increases upstream flood protection. Therefore, even if a larger bridge does not significantly impact sediment transport, it could still reduce the required frequency of maintenance dredging for flood protection. A larger bridge is also less susceptible to debris blockage, reducing the need for other channel maintenance activities, such as LWD removal.

**LIST OF FIGURES**

The following is a list of figures attached to this memorandum.

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| **Sediment Transport Modeling** | |
| 15 | Redwood Creek December 2004 Flow Data Used for Sediment Loading Simulation |
| 16 | Approximate 6-year Event on Redwood Creek Used for Sediment Loading Simulation |
| 17 | Sediment Transport Model Calibration for Existing Conditions |
| 18 | Five Years of “Typical” Sediment Loading, Alternative 1, No Action |
| 19 | Five Years of “Typical” Sediment Loading, Alternative 2, Creek Restoration and 50 foot Bridge |
| 20 | Five Years of “Typical” Sediment Loading, Alternative 2, Creek Restoration and 150 foot Bridge |
| 21 | Comparison of Bed Changes for Existing and Design Conditions (Five Years of "Typical" Sediment Loading) |
| 22 | Redwood Creek Thalweg: 1992 vs 2002 |
| 23 | Sediment Loading for Approx. 6-Year Event, Alternative 1, No Action |
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| 42 | Comparison of Water Levels on the Left Floodplain during the 100-year Event for Bridges 2, 4 & 5 |
| 43 | Schematic Plan for 150’ Span Bridge |
| 44 | Conceptual Cross-section: Alternative 2 Creek Restoration |

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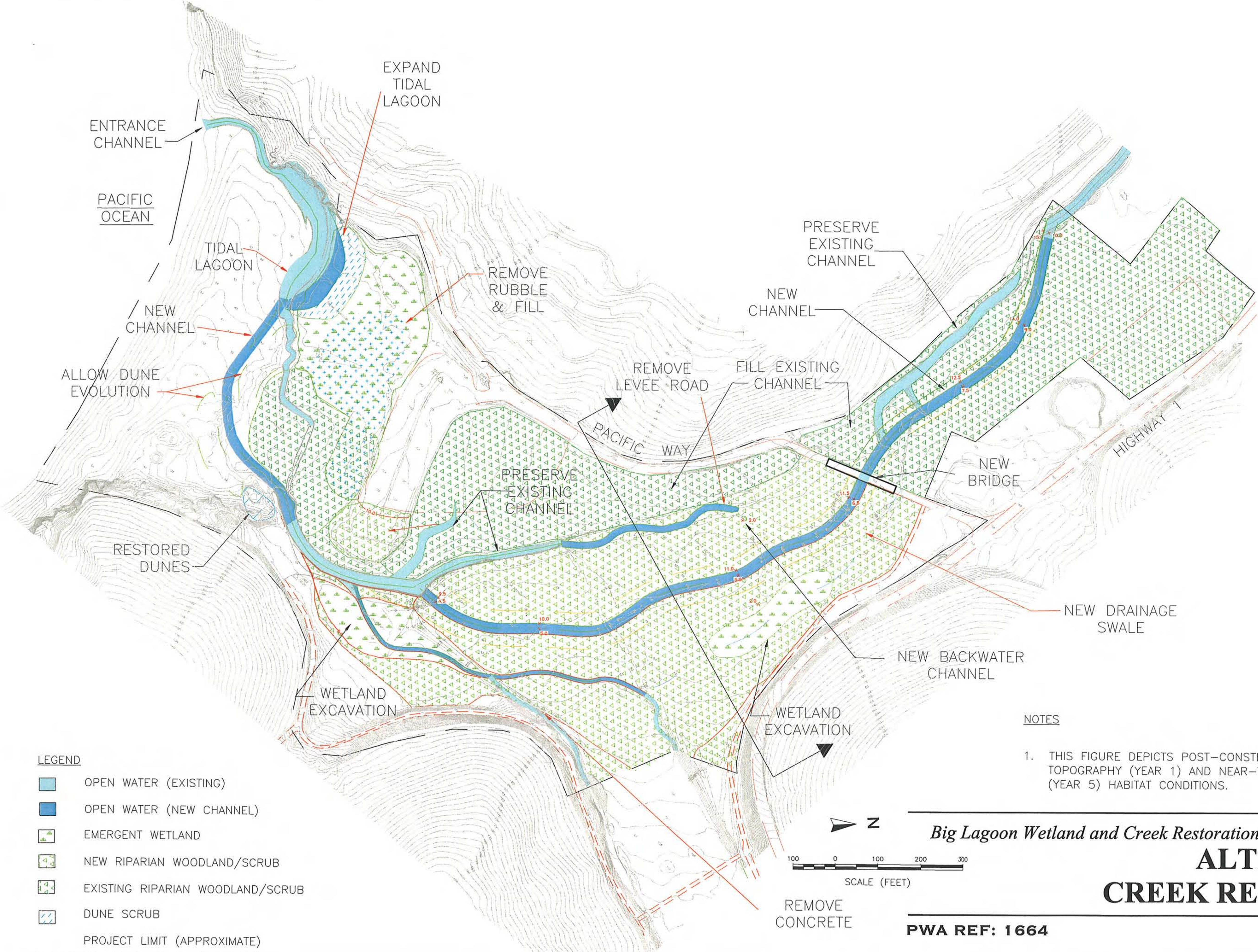
Table 2
Details of Model Runs for Bridge Analysis
Big Lagoon Wetland and Creek Restoration
PWA #1664.03

| | | | | Independent Variables | | | | | | | | | | Dependent Variables | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Run Number | Description | | | Bridge Dimensions | | | | | | Bridge Modeling Method | | Other Conditions | | 100-Year Flood Elevations (feet NGVD) | | | Other | |
| | | Scenario | Alternative | Opening Width (ft) | Soffit Elevation (NGVD) | Deck Elevation (NGVD) | Downstream Location | Lateral Location | Skewness | Normal Channel | Segmented (including floodplains) | New Cross Sections (C* & D*) | Leave Existing Channel (C-E) | Pelican Inn (17.65 NGVD) | D/S Home Lagoon Dr. (15.0 NGVD) | U/S Home Lagoon Dr. (14.7 NGVD) | Accessibility of Road | Dredging Required |
| 10 | Existing Conditions (No Action) | 1 | Alt 1 | 24 | 12.6 | 15.0 | At Road | Current Bridge | 0% | X | | X*** | | **17.11** | 17.60 | 18.39 | ~1.5 yr event | Yearly |
| 11 | Creek Restoration- No Bridge | 2 | Alt 2 | No Bridge | - | - | - | - | - | X | | X*** | X | **16.69** | 17.06 | 17.67 | No Bridge | None |
| 12 | Creek Restoration- New Bridge | 3 | Alt 2 | **250** | 19.5 | 21.5 | At Road | Center of FP | 0% | | X | X*** | X | **17.12** | 17.42 | 17.91 | 100 yr event | N.A. |
| 13 | Creek Restoration- New Bridge | 3 | Alt 2 | 280 | **16.0** | 18.0 | At Road | Center of FP | 0% | | X | X*** | X | **17.11** | 17.41 | 17.91 | 100 yr event | N.A. |
| 16 | Creek Restoration- New Bridge & Raised Road | 3 | Alt 2 | **50** | 14.5 | 16.5 | At Road | Center of FP | 0% | X | | X*** | X | **17.12** | 17.45 | 17.98 | 5 yr event | |
| 14 | Creek Restoration- New Bridge Downstream | 4 | Alt 2 | **200** | 19.5 | 21.5 | ~200' DS | Center of FP | 0% | | X | X*** | X | **17.15** | 17.45 | 17.95 | 100 yr event | N.A. |
| 15 | Creek Restoration- New Bridge Downstream | 4 | Alt 2 | 280 | **15.0** | 17.0 | ~200' DS | Center of FP | 0% | | X | X*** | X | **17.04** | 17.36 | 17.89 | 100 yr event | N.A. |
| 17 | Modified Design - Widen Bridge & Raised Road | 5 | N/A | **50** | 14.5 | 16.5 | At Road | Current Bridge | 0% | X | | X*** | | **17.08** | 17.47 | 18.11 | 5 yr event | |




NOTES

1. THIS FIGURE DEPICTS POST-CONSTRUCTION TOPOGRAPHY (YEAR 1) AND NEAR-TERM (YEAR 5) HABITAT CONDITIONS.

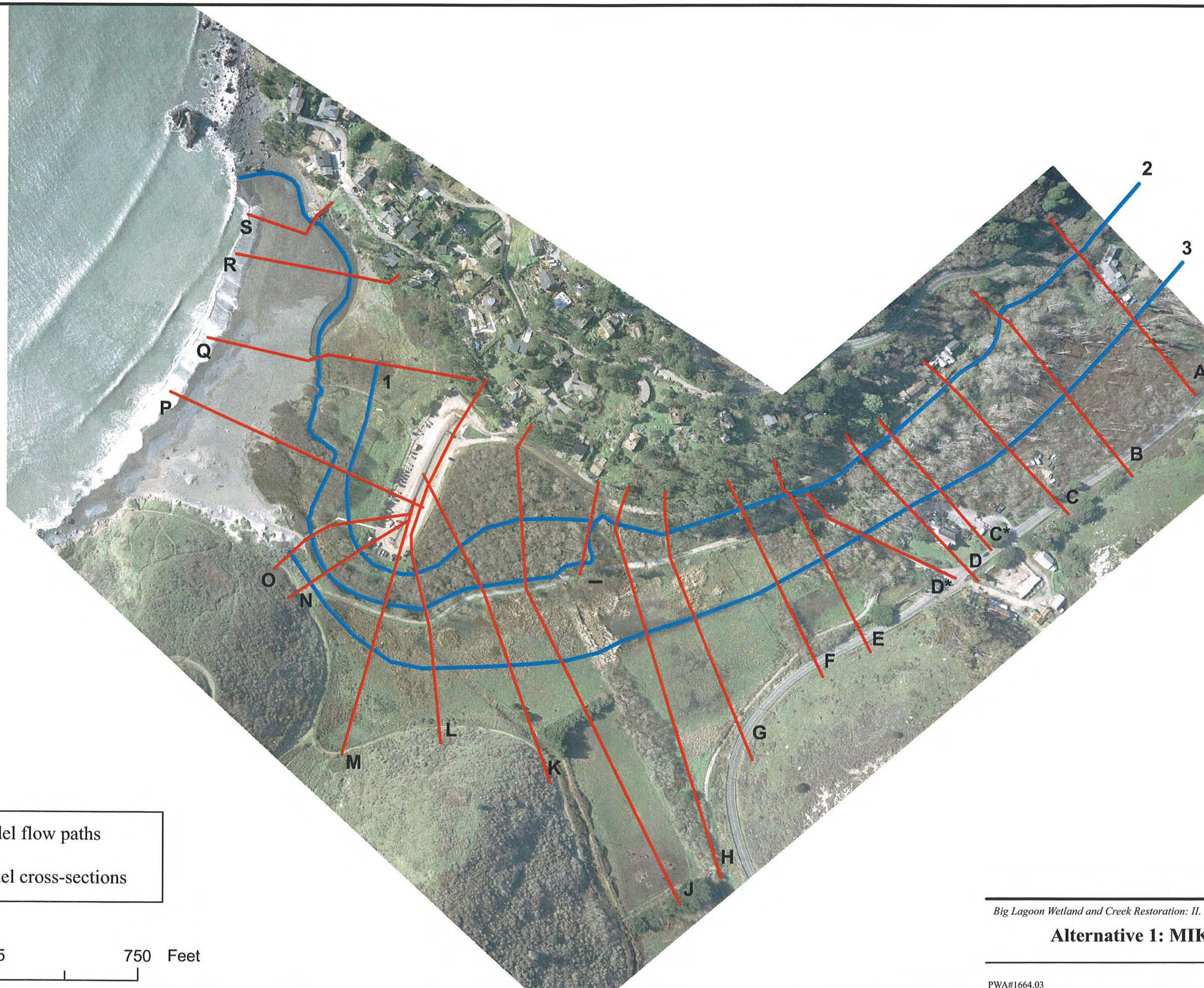
*figure 1*

*Big Lagoon Wetland and Creek Restoration: II. Feasability Report*

**ALTERNATIVE 2**
**CREEK RESTORATION**

PWA REF: 1664

PWA




Model flow paths

Model cross-sections

0 375 750 Feet

*figure* **2**

*Big Lagoon Wetland and Creek Restoration: II. Feasibility Analysis Report*

**Alternative 1: MIKE 11 Network**

PWA#1664.03

PWA

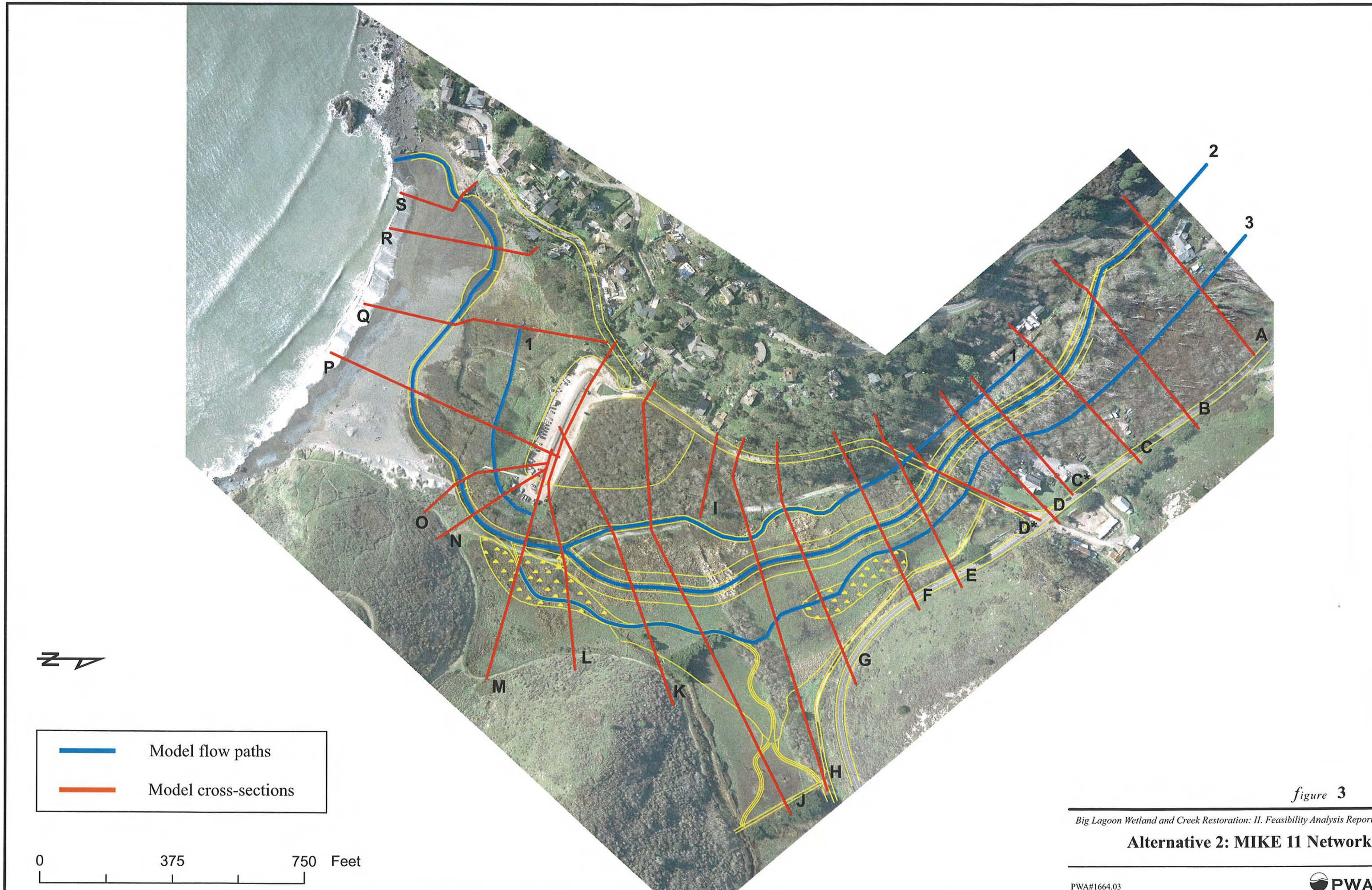



*figure* **3**

*Big Lagoon Wetland and Creek Restoration: II. Feasibility Analysis Report*

**Alternative 2: MIKE 11 Network**

PWA#1664.03

PWA

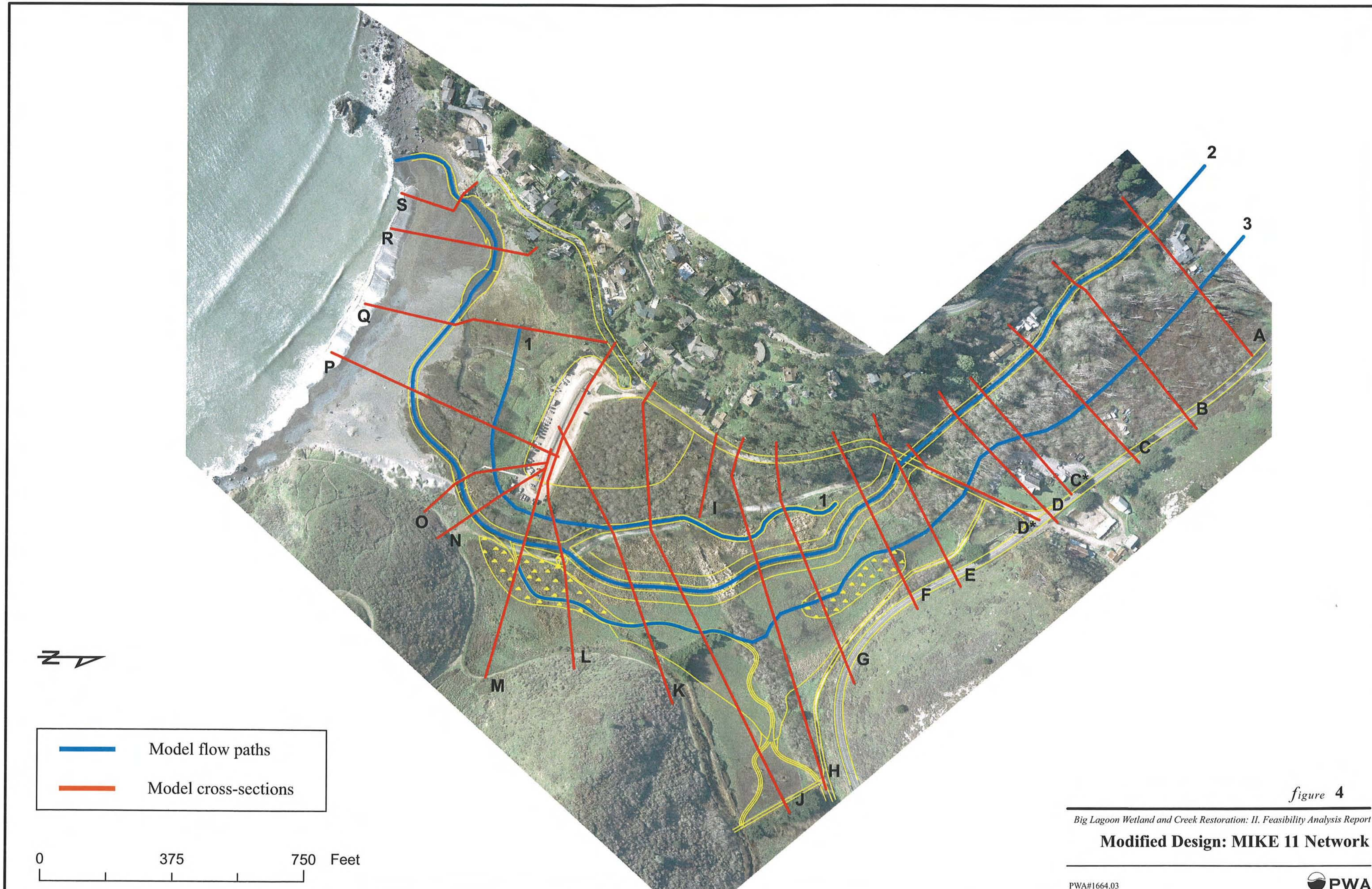



*figure* **4**

*Big Lagoon Wetland and Creek Restoration: II. Feasibility Analysis Report*

**Modified Design: MIKE 11 Network**

PWA#1664.03

PWA

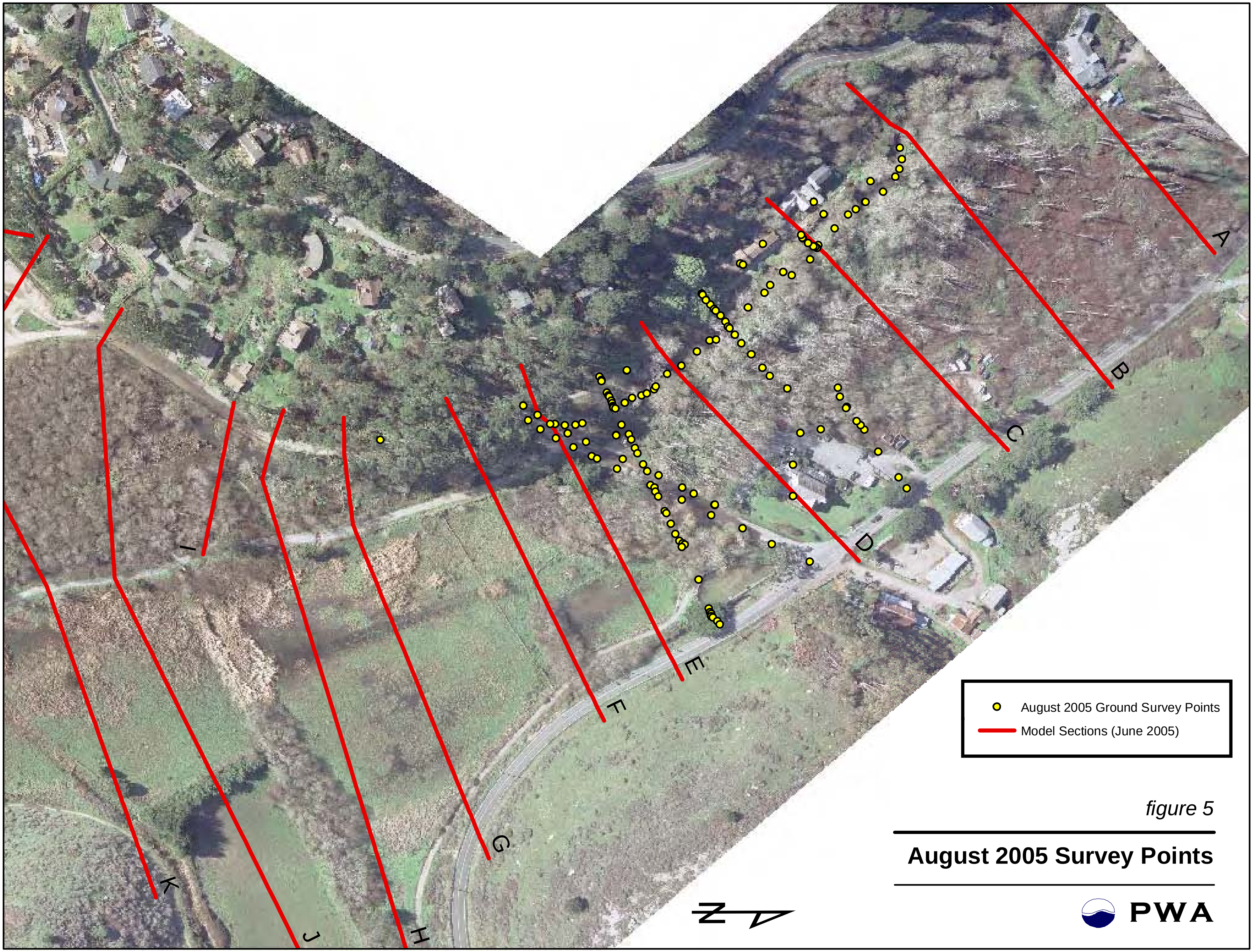
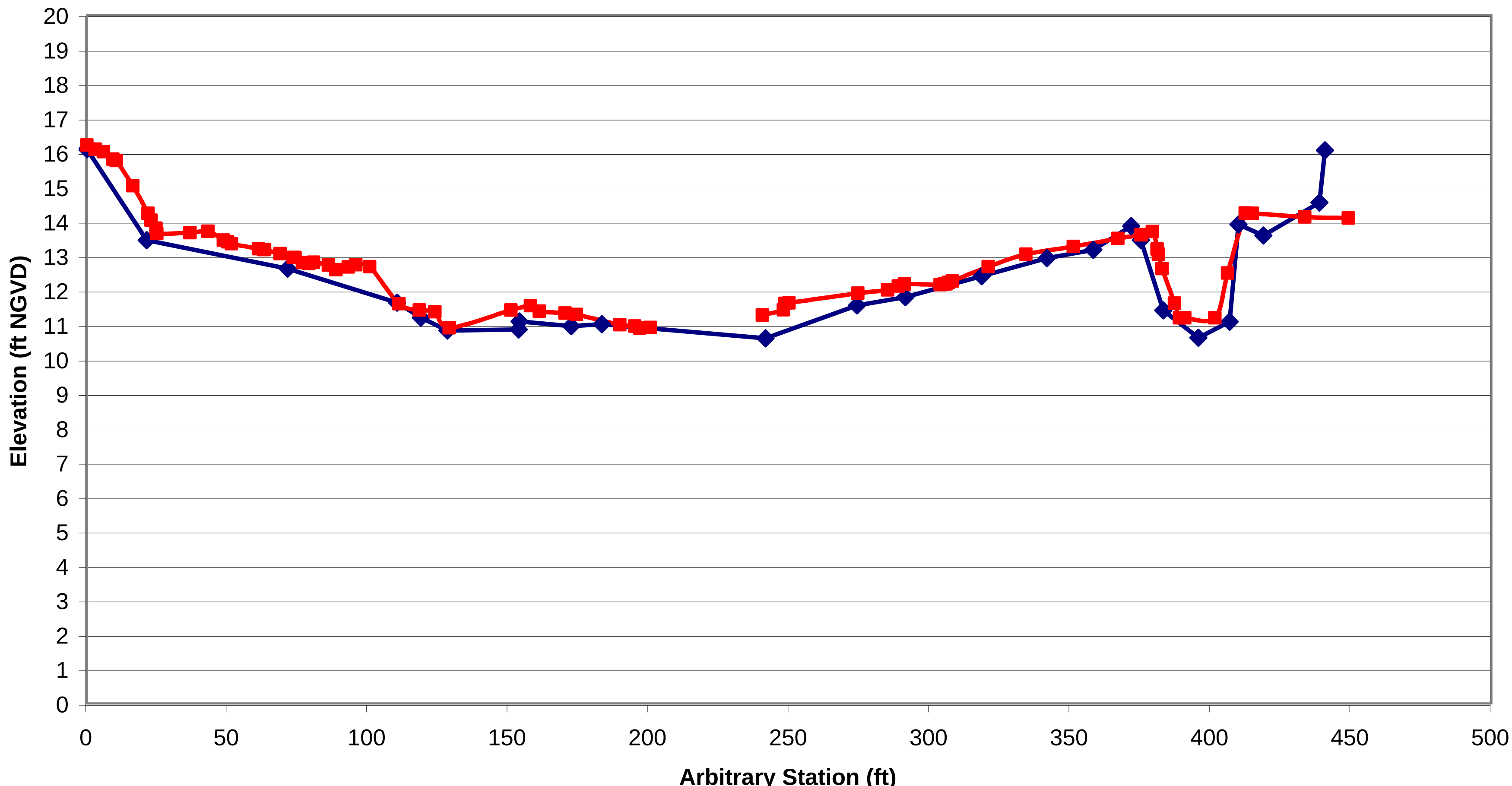



*figure 5*

**August 2005 Survey Points**

PWA




Notes: Using AutoCAD, a cross section was cut on the Towill, 2003 Digital Terrain Model (DTM) at the same location of the NPS August 2005 survey points. This figure compares the differences between the DTM and the survey points at the cross section labeled C*. The stationing is arbitrary.

NPS August 2005 Survey Points

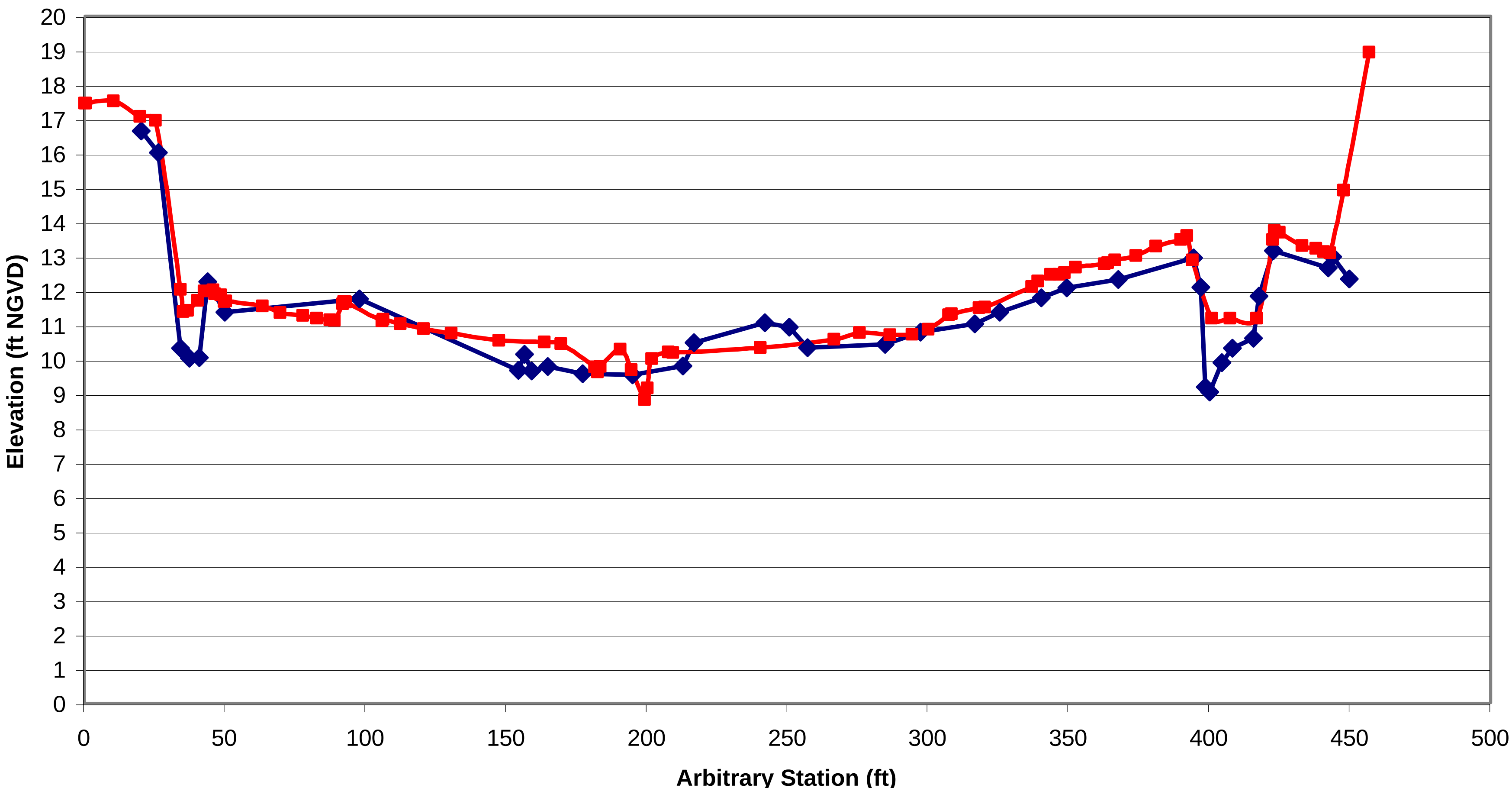
Cross Section Cut from Towill January 2003 DTM

*figure 6*

**Comparison of 2005 Ground Survey & 2003 Aerial Survey - Section C***

PWA

PWA #: 1664.03




Notes: Using AutoCAD, a cross section was cut on the Towill, 2003 Digital Terrain Model (DTM) at the same location of the NPS August 2005 survey points. This figure compares the differences between the DTM and the survey points at the cross section labeled D*. The stationing is arbitrary.

NPS August 2005 Survey Points

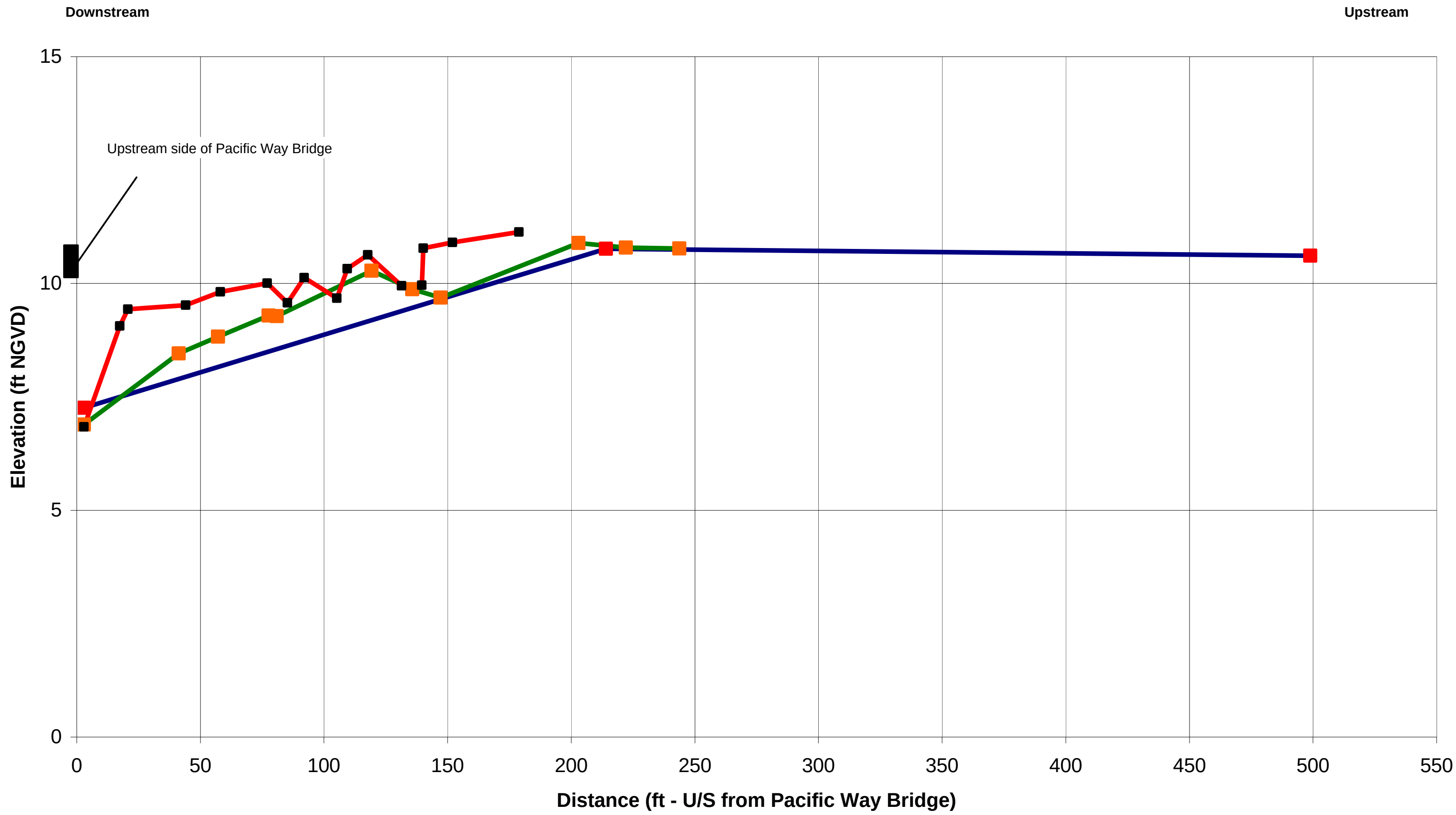
Cross Section Cut from Towill January 2003 DTM

*figure 7*

**Comparison of 2005 Ground Survey & 2003 Aerial Survey - Section D***

PWA

PWA #: 1664.03





Environmental Data Solutions

***Figure 8***

***Redwood Creek Thalweg Profile: Upstream Chord ofPacific Way Bridge***

***April, 2003, August, 2004 and February, 2005***

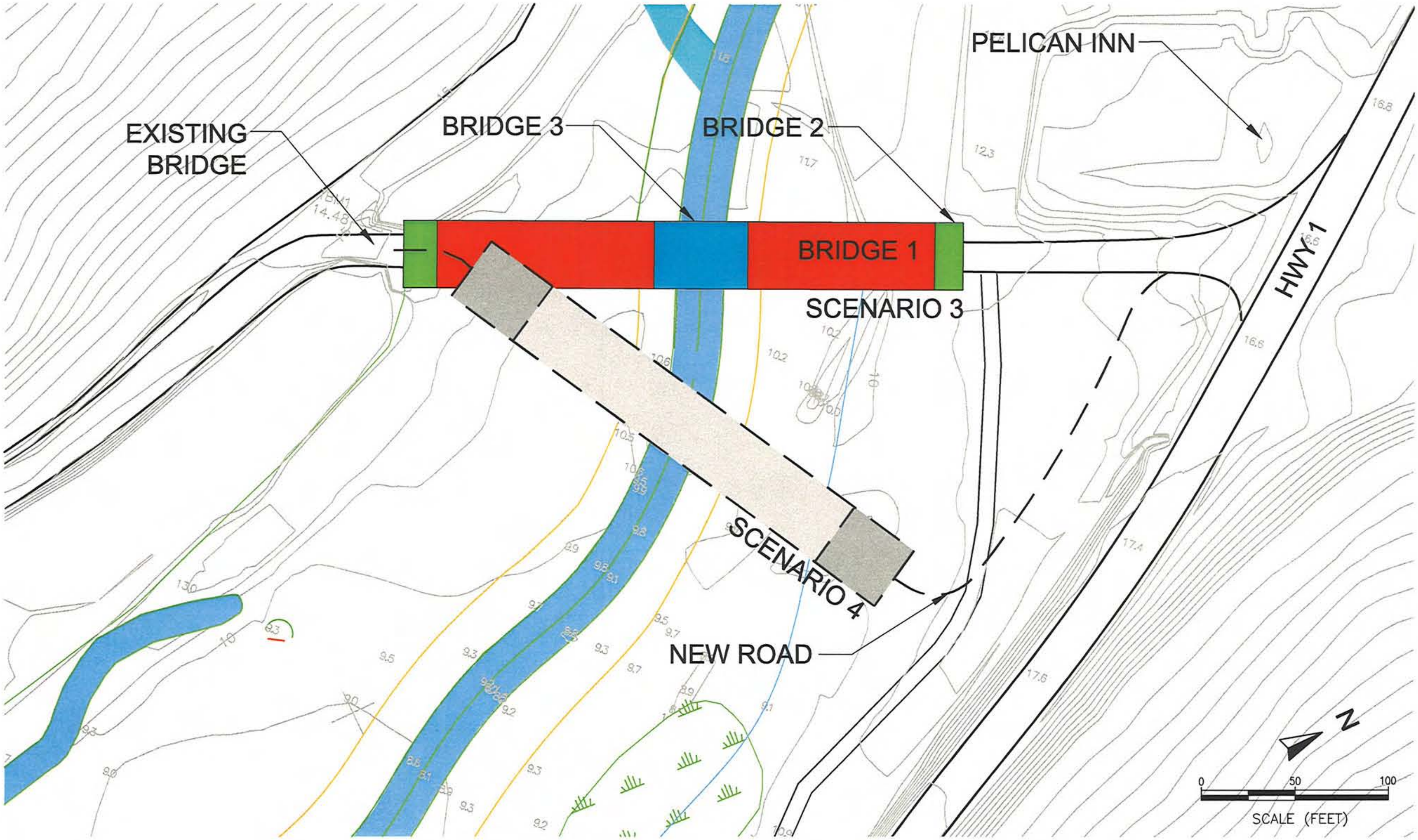



*figure* **9**

**Bridge Options for Scenarios 3&4**

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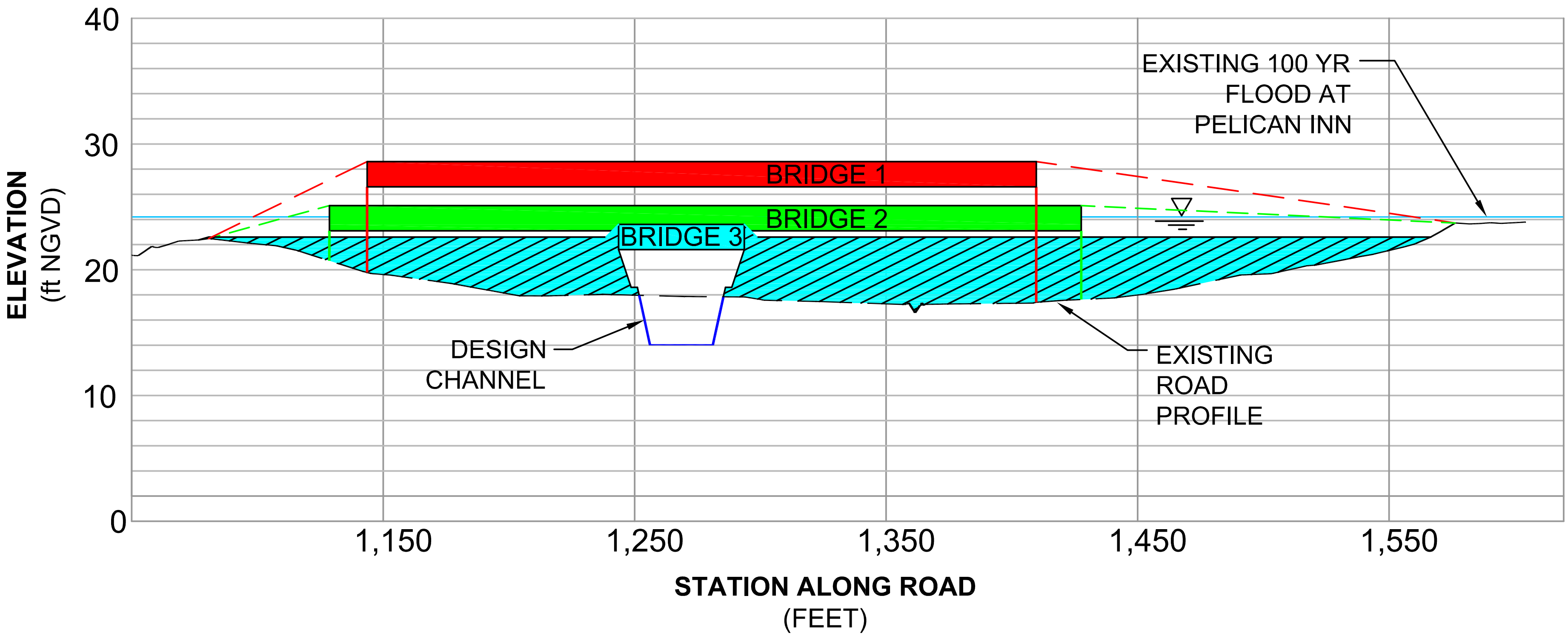
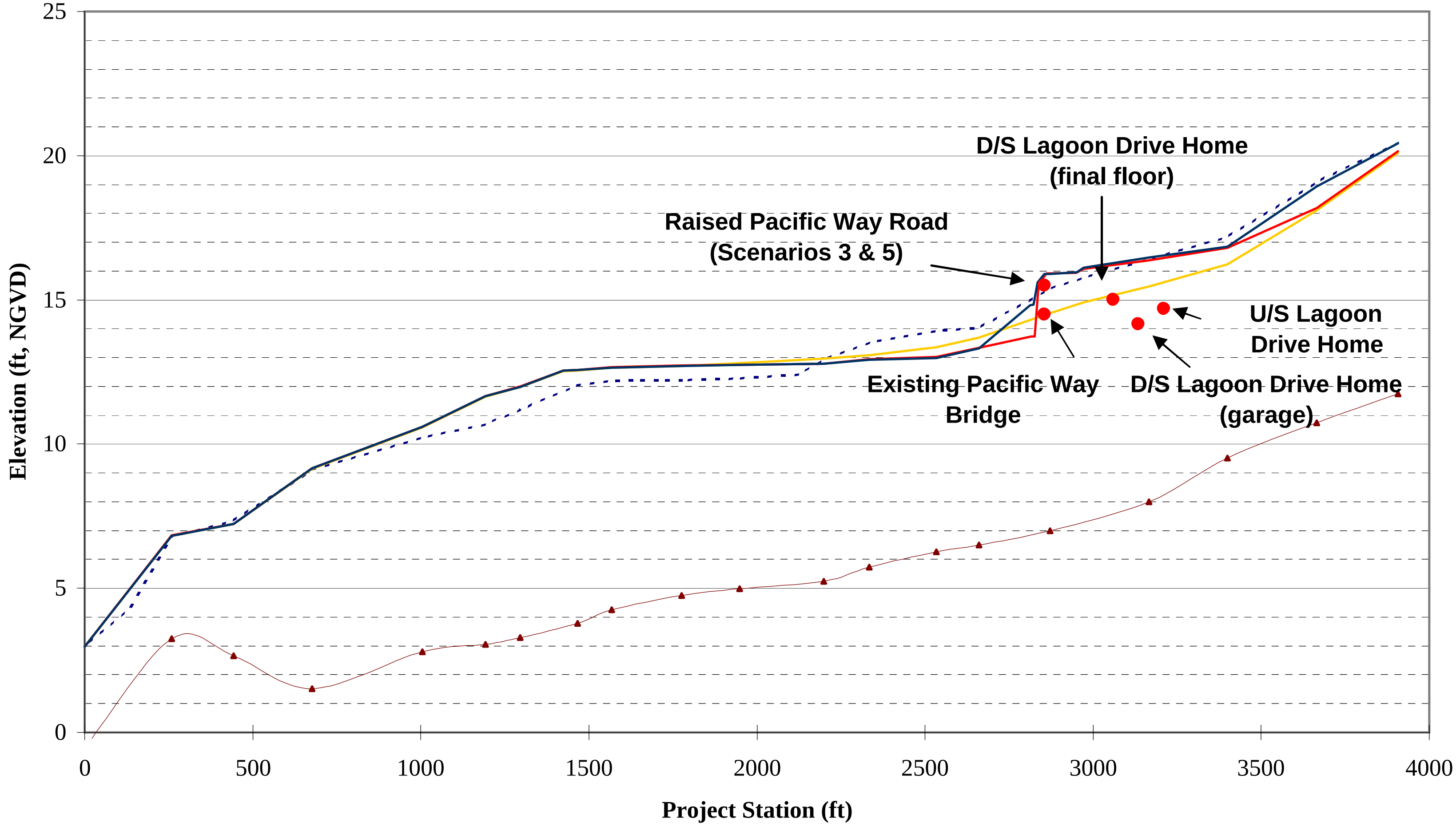



NOTE: Location of Bridge Alternatives Shown Relative to Existing Road Profile

*figure* ***10***

**Bridge Options for Scenario 3:
Creek Restoration and New Bridge**




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative. Scenario 3 is the raised road with the bridge in the center of the floodplain.

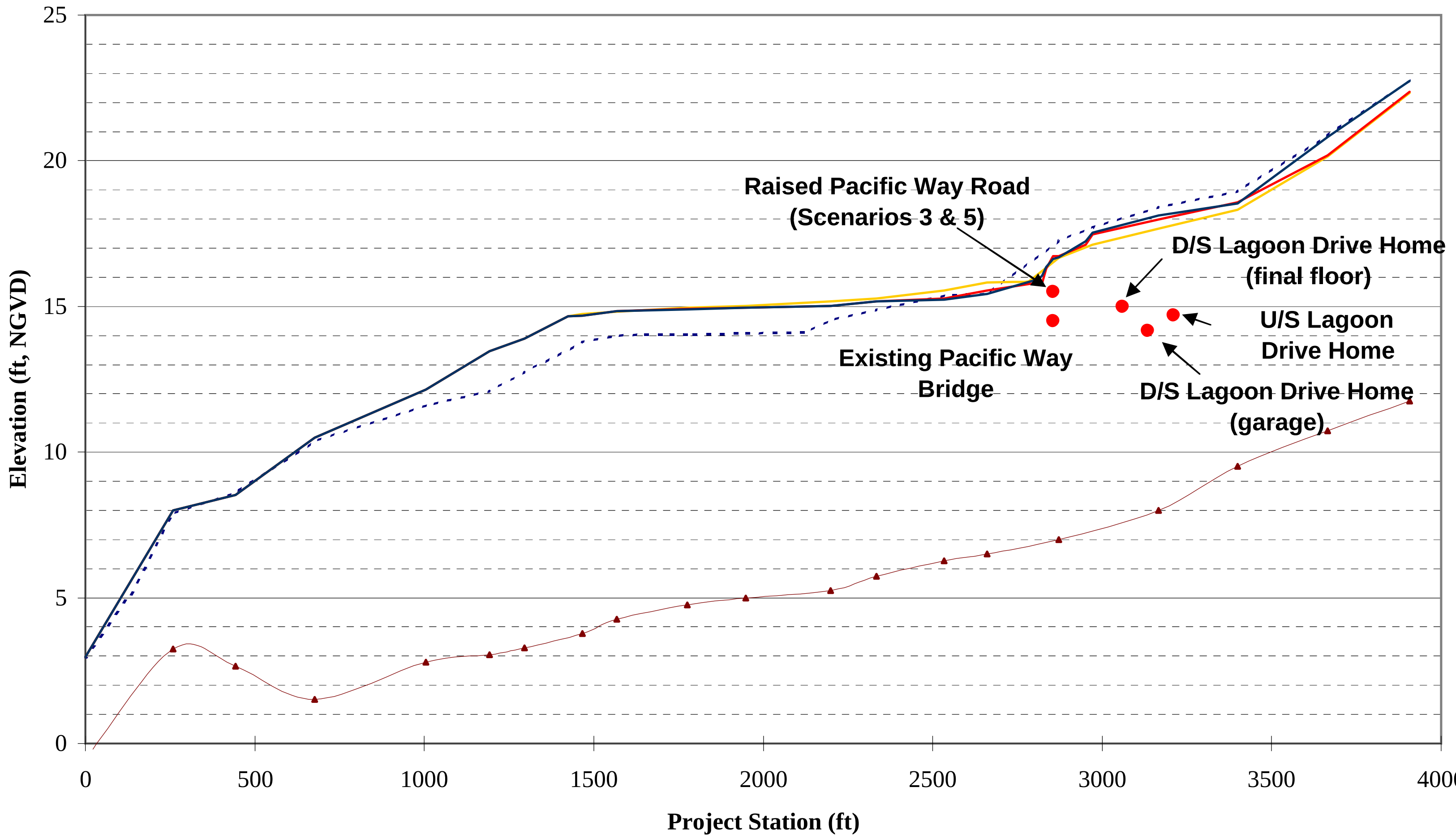
| | |
|---|---|
| Scenario 1: No Action | Scenario 2: No Bridge |
| Scenario 3: Alt 2 | Scenario 5: Modified Design |
| Alternative 2 Thalweg | Spot Elevations |

*figure 11*

**Comparison of Water Levels on the Righ Floodplain during the 10-Year Flow**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative. Scenario 3 is the raised road with the bridge in the center of the floodplain.

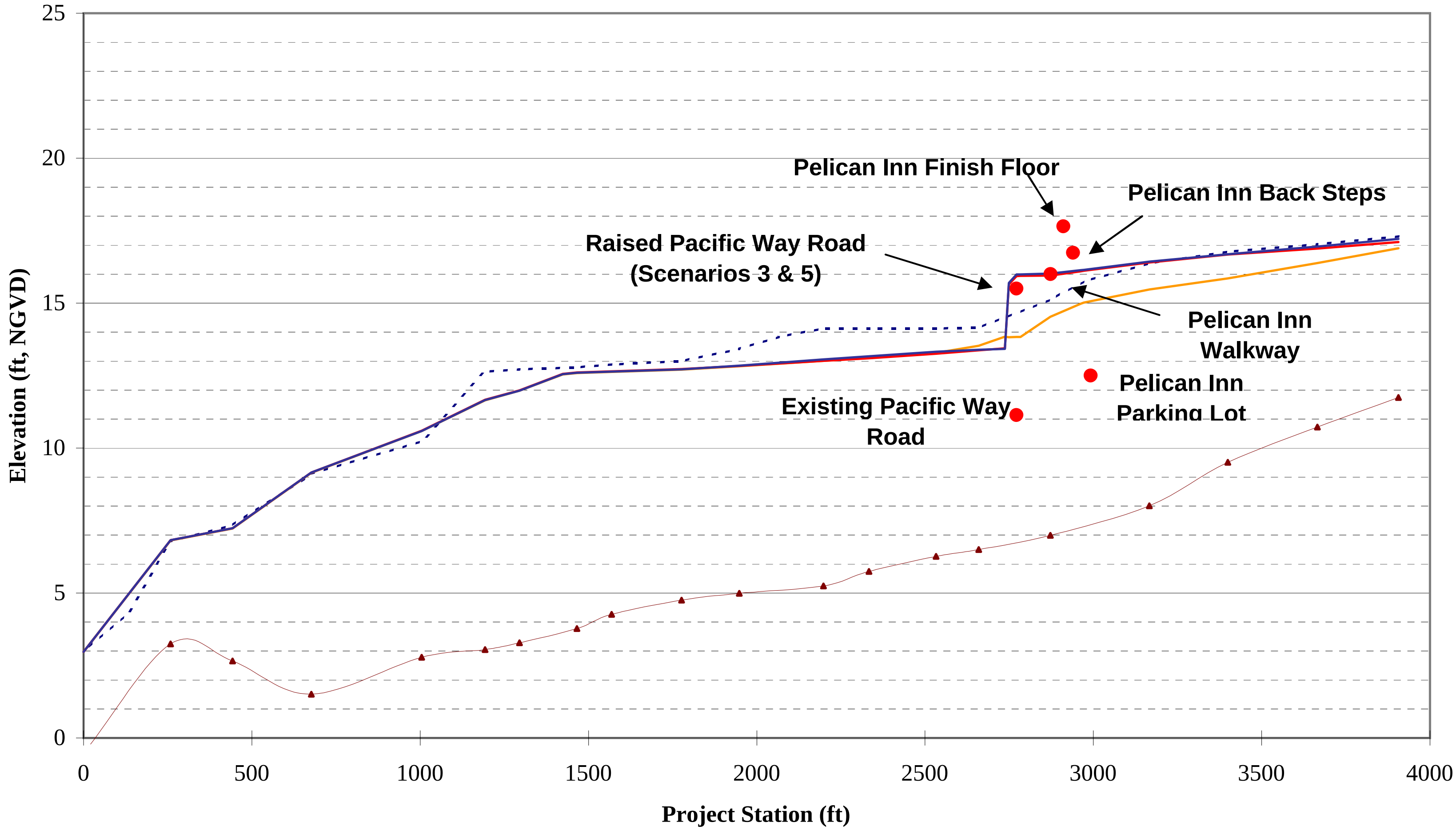
Scenario 1: No Action
Scenario 2: No Bridge
Scenario 3: Alt 2
Scenario 5: Modified Design
Alternative 2 Thalweg
Spot Elevations

*figure 12*

**Comparison of Water Levels on the Righ Floodplain during the 100-Year Flow**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative. Scenario 3 is the raised road with the bridge in the center of the floodplain.

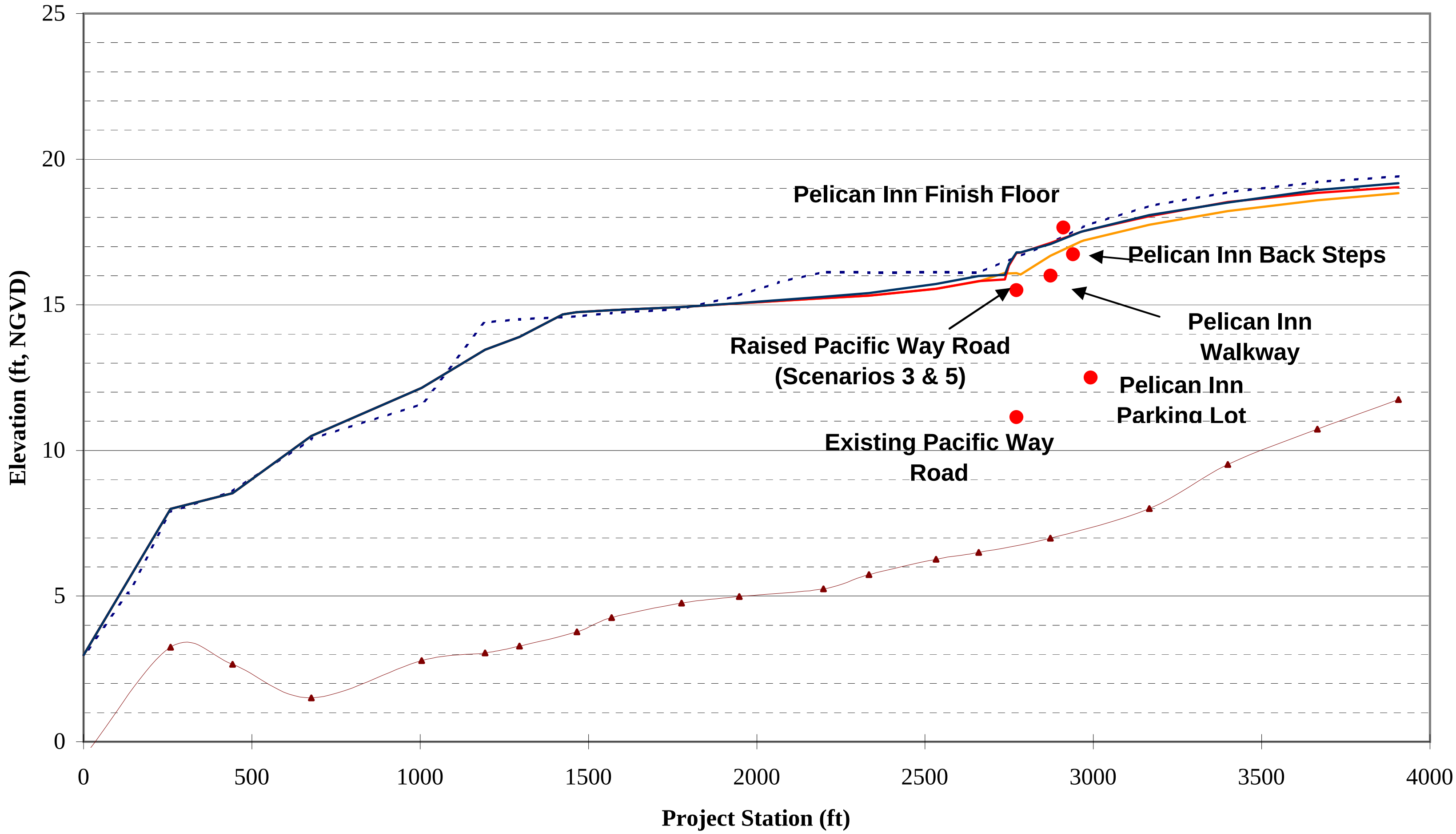
Scenario 1: No Action
Scenario 2: No Bridge
Scenario 3: Alt 2
Scenario 5: Modified Design
Alternative 2 Thalweg
Spot Elevations

*figure 13*

**Comparison of Water Levels on the Left Floodplain during the 10-Year Flow**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative. Scenario 3 is the raised road with the bridge in the center of the floodplain.

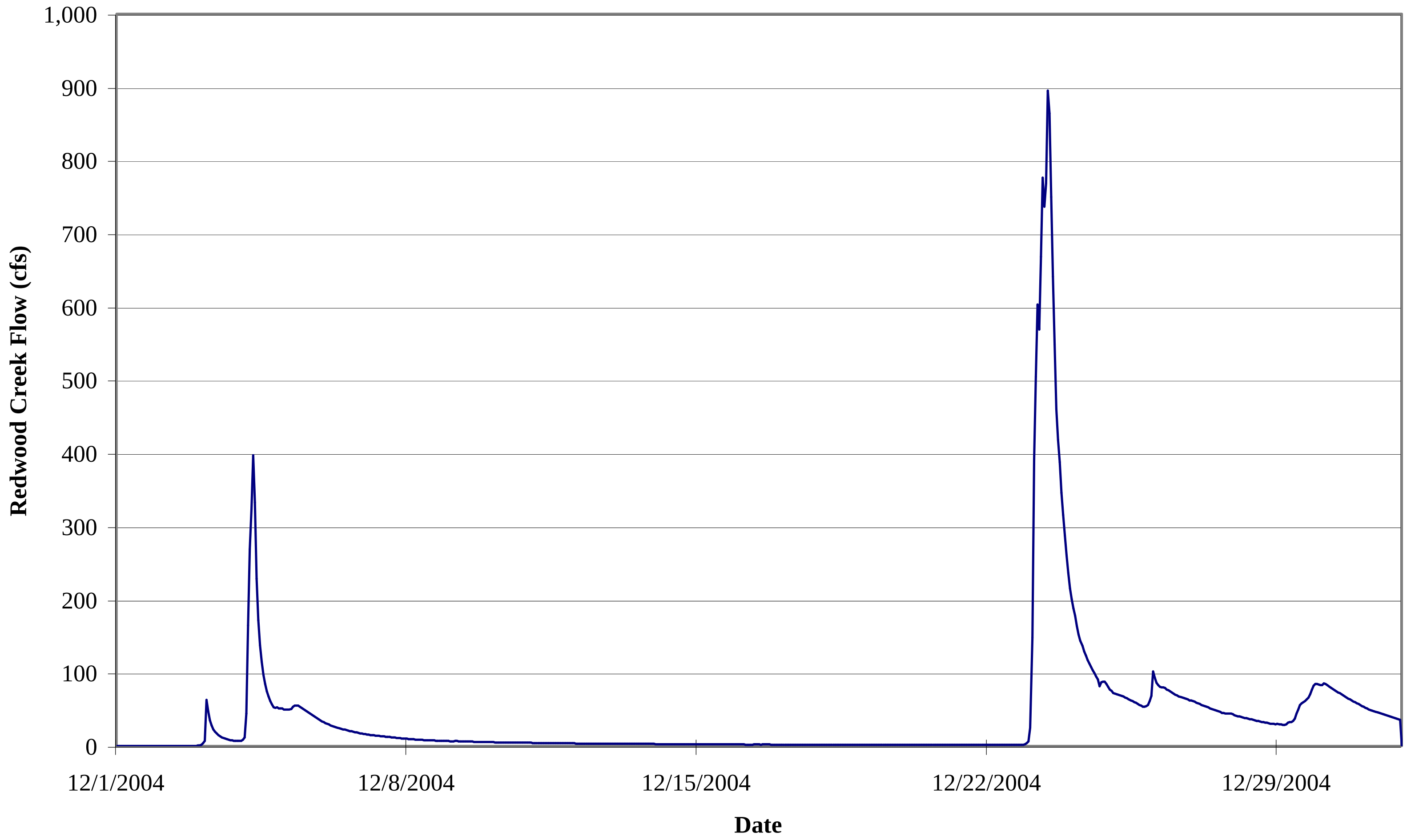
| | |
|---|---|
| Scenario 1: No Action | Scenario 2: No Bridge |
| Scenario 3: Alt 3 | Scenario 5: Modified Design |
| Alternative 2 Thalweg | Spot Elevations |

*figure 14*

**Comparison of Water Levels on the Left Floodplain during the 100-Year Flow**

PWA

PWA #: 1664.03



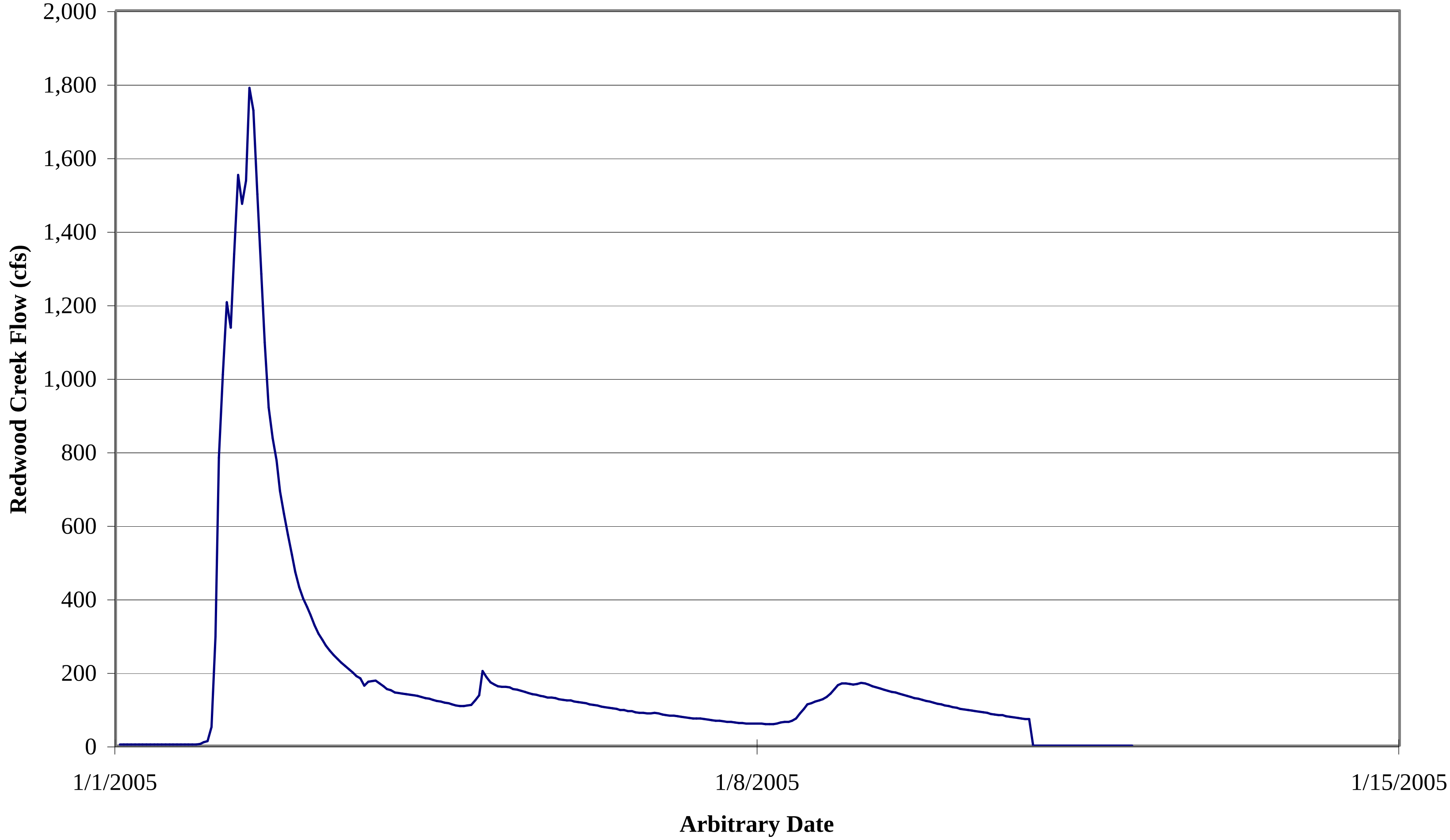

Flow values based on stage data at Highway 1 Bridge. For this period, the Qmax = 895 cfs, which is approximately a 2-Year event.

*figure 15*

**Redwood Creek December 2004 Flow Data for Sediment Loading Simulation**

PWA

PWA #: 1664.03




Flow values are double that of the Water Year 2005 Q2 event. For this period, the Qmax = 1790 cfs, which is approximately a 6-Year event.

*figure 16*

**Approx 6-Year Event on Redwood Creek Used for Sediment Loading Simulation**

PWA

PWA #: 1664.03

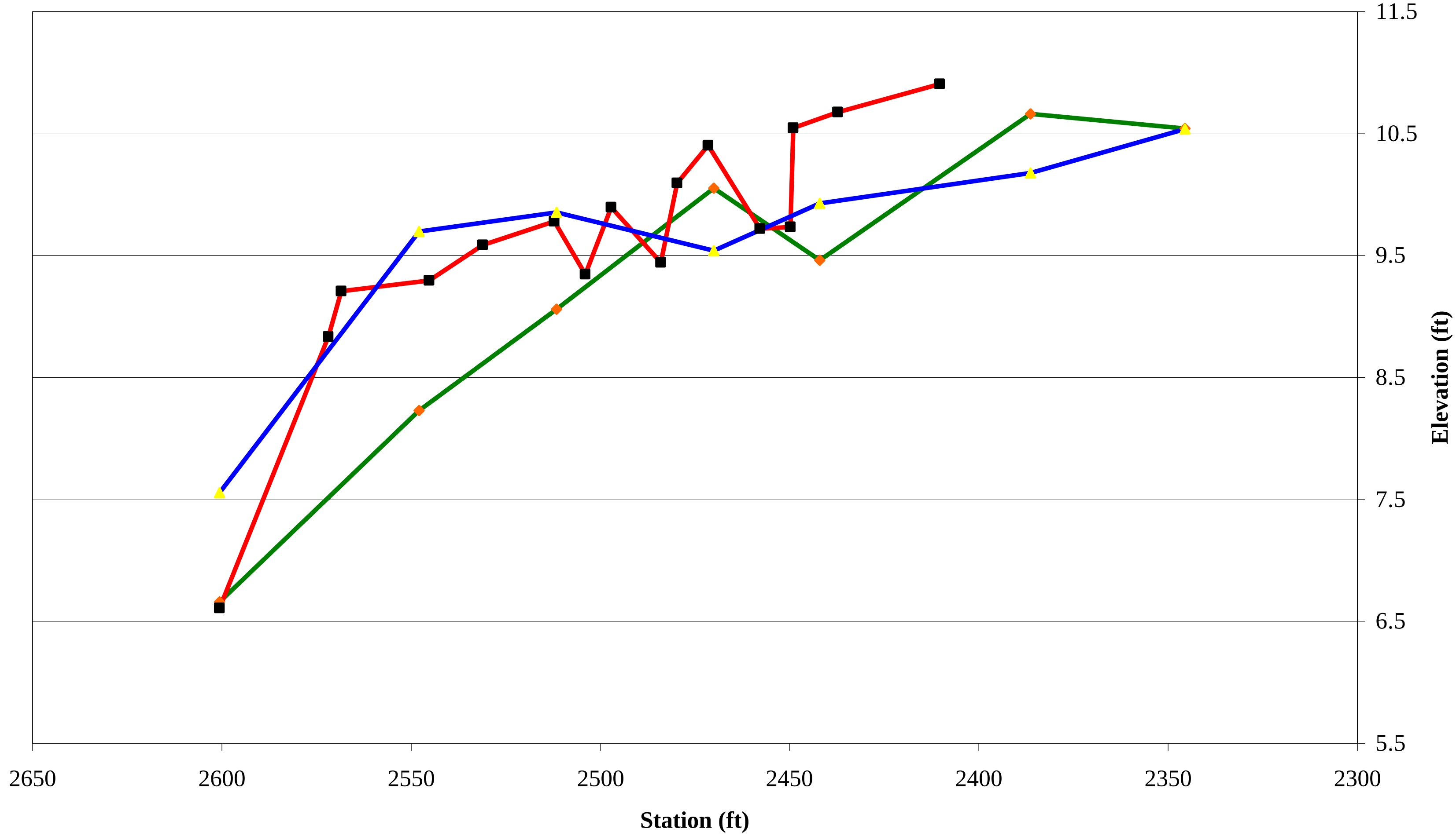
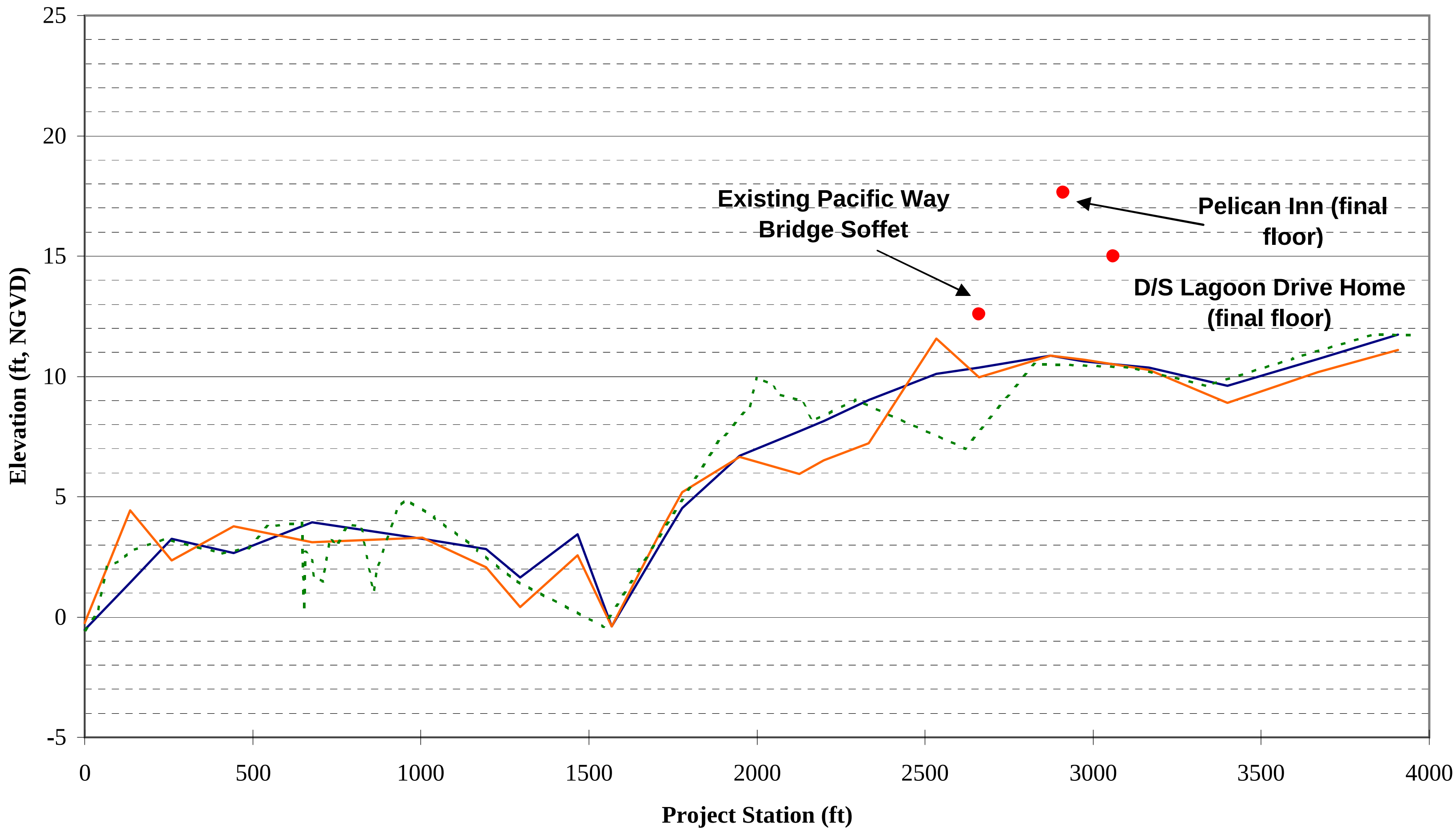



*figure 17*

**Redwood Creek Sediment Transport**
**Model Calibration for Existing Conditions**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

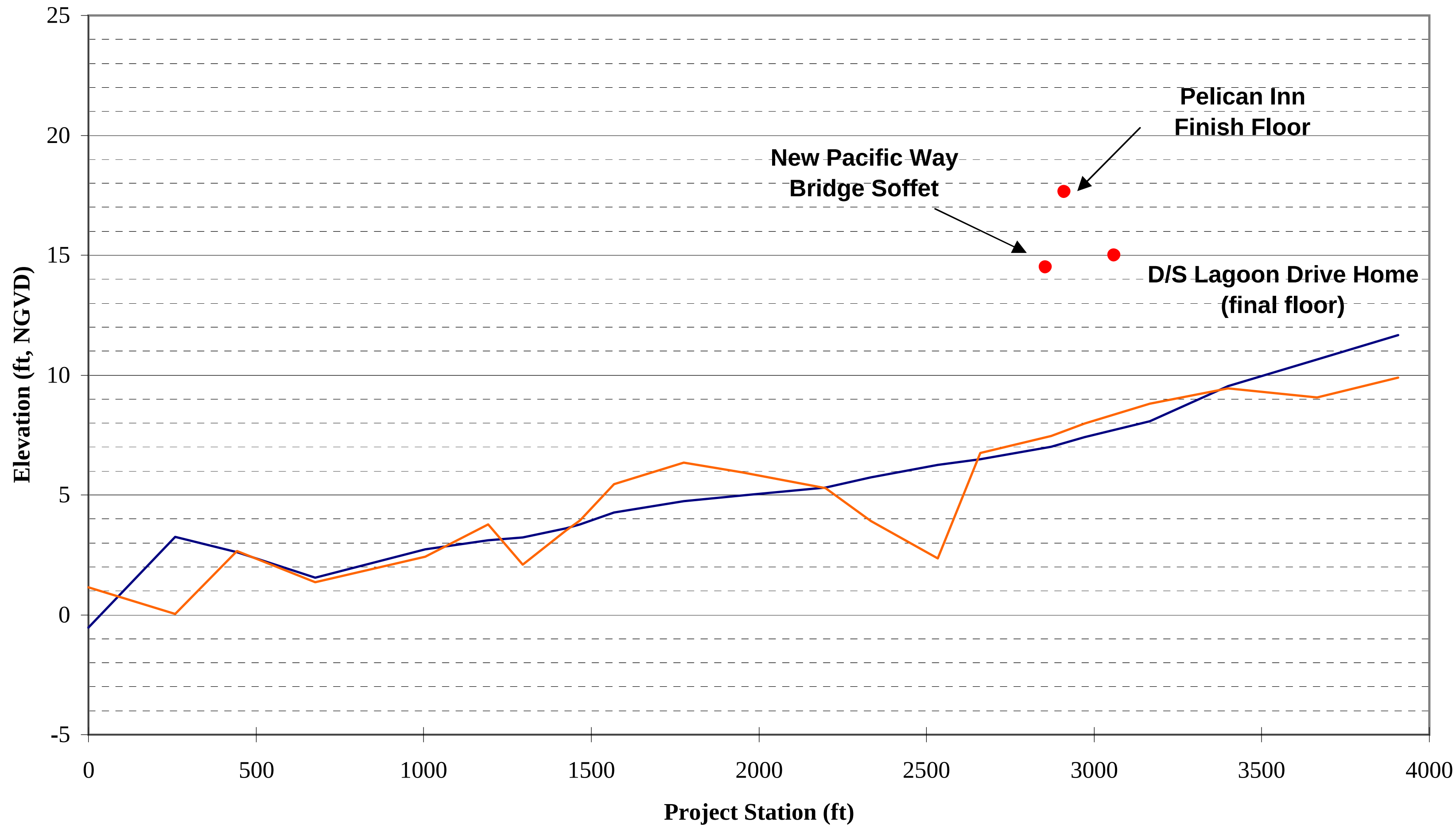
Initial Thalweg
Post-Simulation Thalweg
Post-Dredge (2003) Thalweg
Spot Elevations

*figure 18*

**Five Years of "Typical" Sediment Loading: Alternative 1- No Action**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

Initial Thalweg — Post-Simulation Thalweg — Spot Elevations

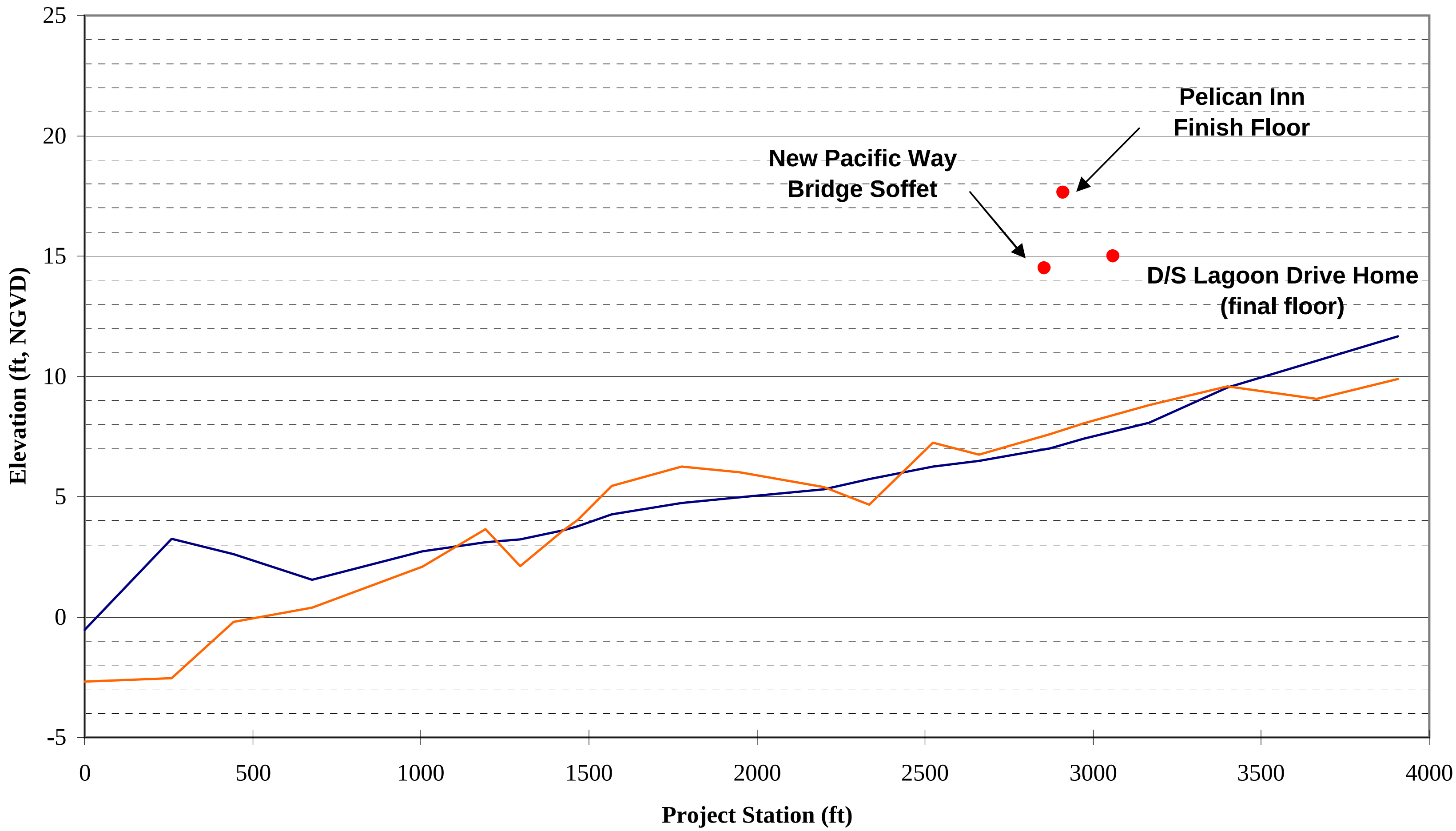
*figure 19*

**Five Years of "Typical" Sediment Loading**
**Alternative 2- Creek Restoration and 50 foot Bridge**

PWA

PWA #: 1664.03

M11Results_Sediment_50and150Bridge_bedlevelsonly_12-05.xls A2-50-LT 4/5/2006




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

Initial Thalweg | Post-Simulation Thalweg | Spot Elevations

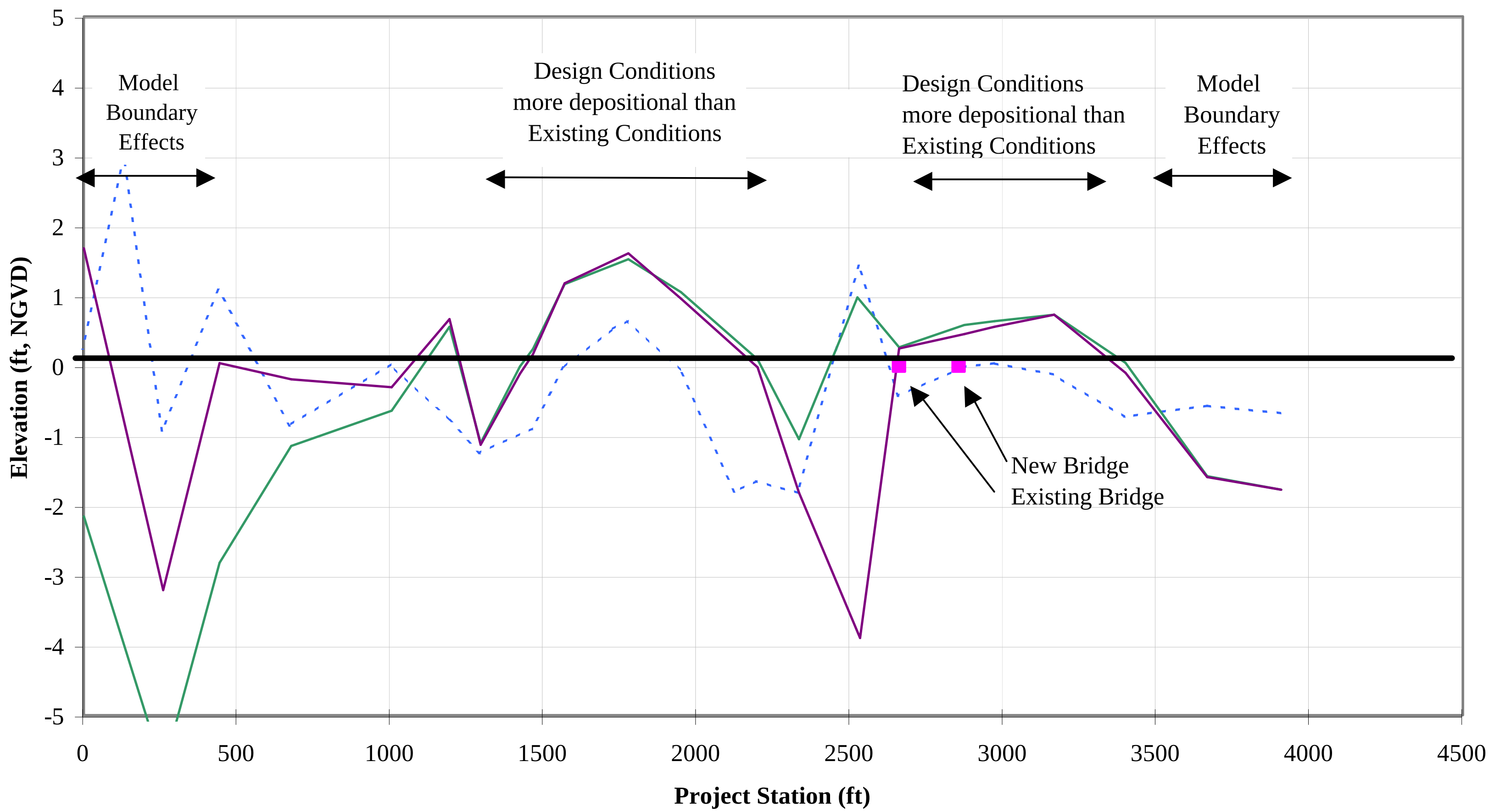
*figure 20*

**Five Years of "Typical" Sediment Loading**
**Alternative 2- Creek Restoration**
**and 150 foot Bridge**

PWA

PWA #: 1664.03

M11Results_Sediment_50and150Bridge_bedlevelsonly_12-05.xls A2-150-LT 4/5/2006




Notes: Chainages based on Alternative 1 MIKE network. Bed change is the difference between pre- and post-simulation thalweg elevation. Positive values indicate deposition and negative values indicate erosion.

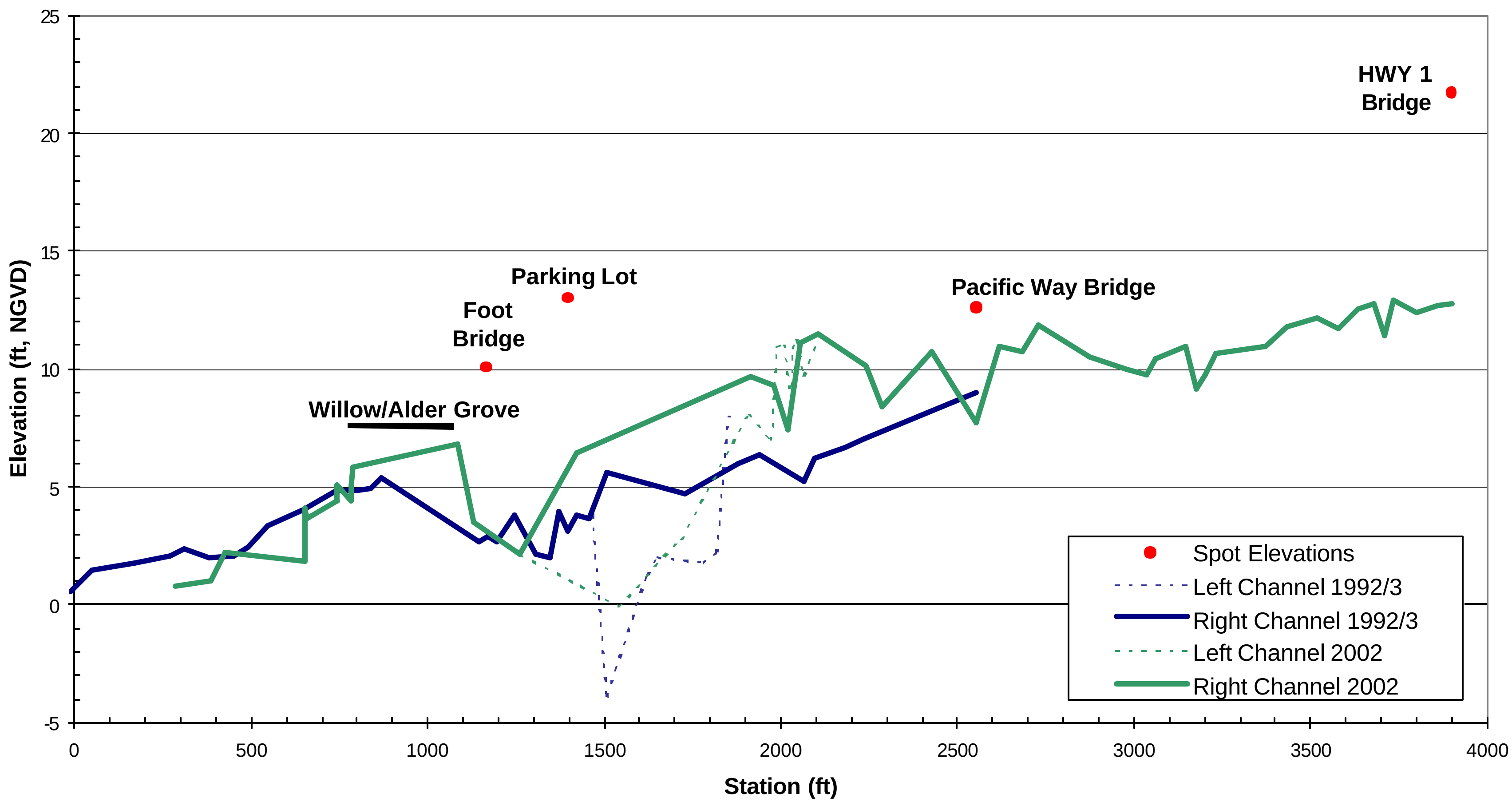
Bed Change - Existing Conditions (Alt 1)
Bed Change - Design Conditions (Alt 2, 150-ft Bridge)
Bed Change - Design Conditions (Alt 2, 50-ft Bridge)
Spot Elevations

*figure 21*

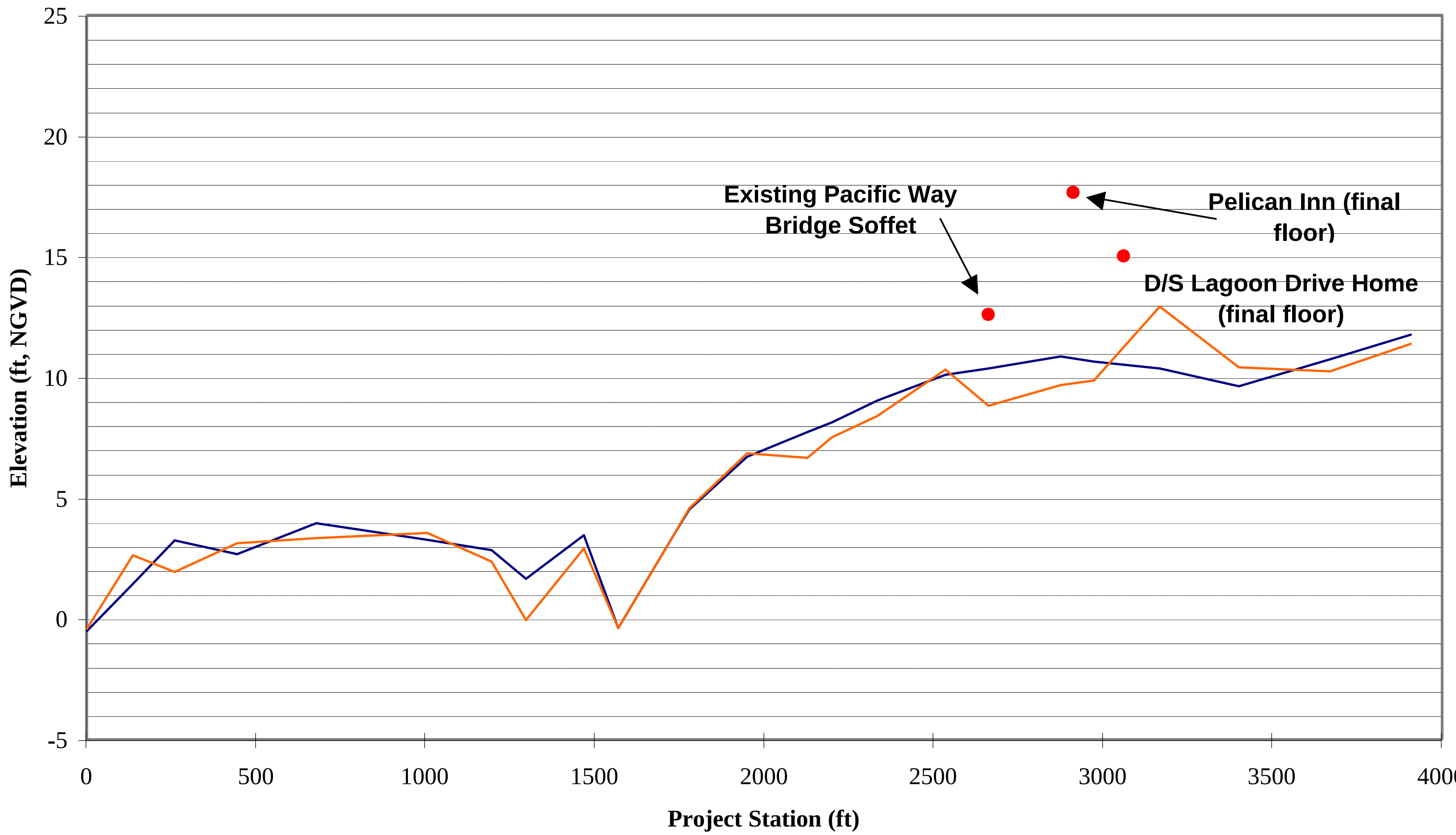
**Comparison of Bed Changes for Existing and Design Conditions (Five Years of "Typical" Sediment Loading)**

PWA

PWA #: 1664.03




| Sources: | *f igure* **22** |
|---|---|
| 1992 Survey, (PWA, 1994) | *Big Lagoon Wetland and Creek Restoration: I. Site Analysis Report* |
| 2002 Survey, (NPS, 2002) | **Redwood Creek Thalweg: 1992 vs. 2002** |
| Note: | PWA Ref #1664.02 |
| Between stations 1300 and 2000, Redwood Creek is a two channel system. | PWA |




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. Sediment loading based on synthetic hydrograph for one event (Qmax = 1790 cfs) and Redwood Creek sediment rating data (Stillwater, 2004)

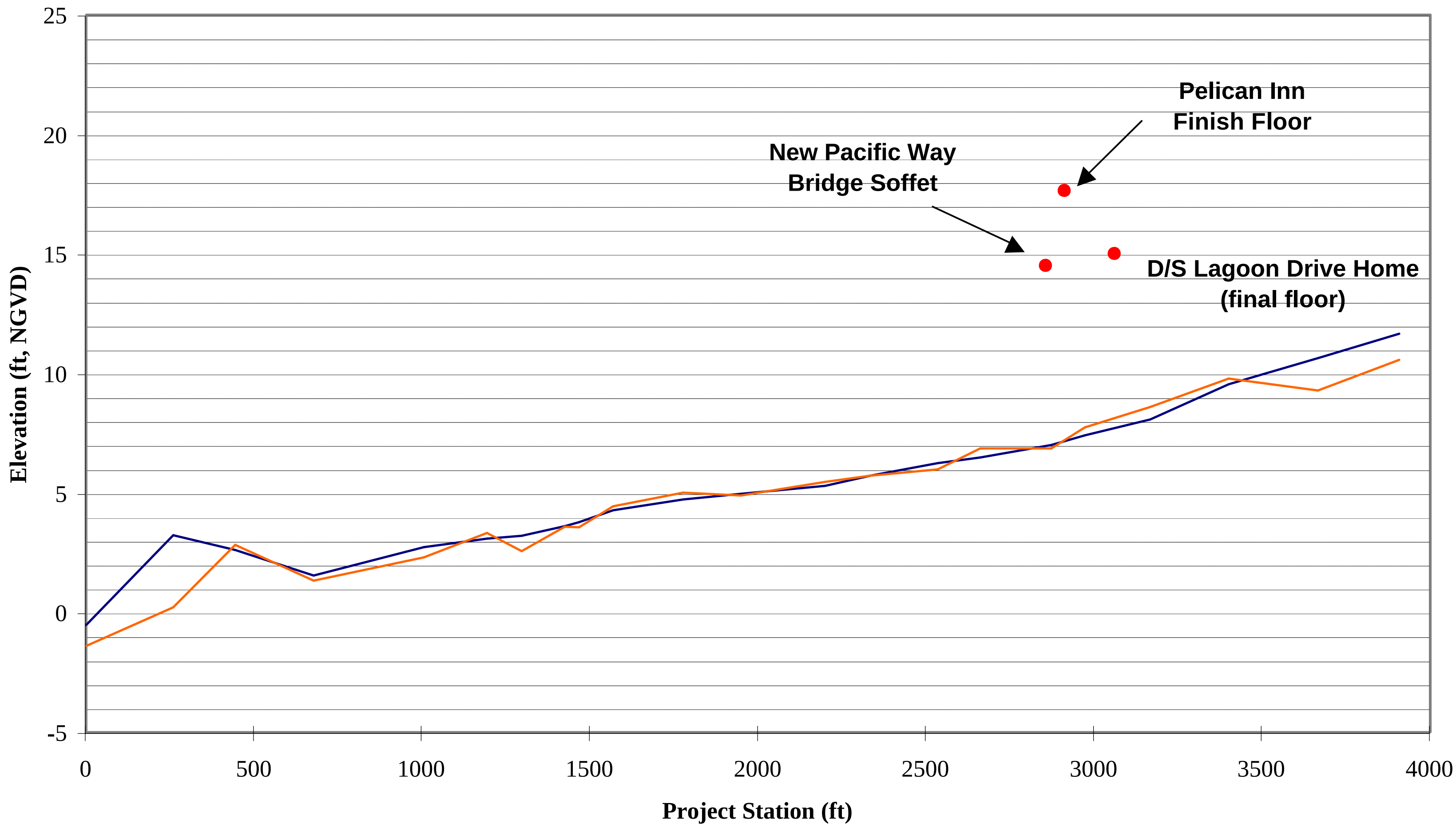
Initial Thalweg | Post-Simulation Thalweg | Spot Elevations

*figure 23*

**Sediment Loading for Approx. 6-Year Event: Alternative 1- No Action**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. Sediment loading based on synthetic hydrograph for one event (Qmax = 1790 cfs) and Redwood Creek sediment rating data (Stillwater, 2004)

Initial Thalweg — Post-Simulation Thalweg — Spot Elevations

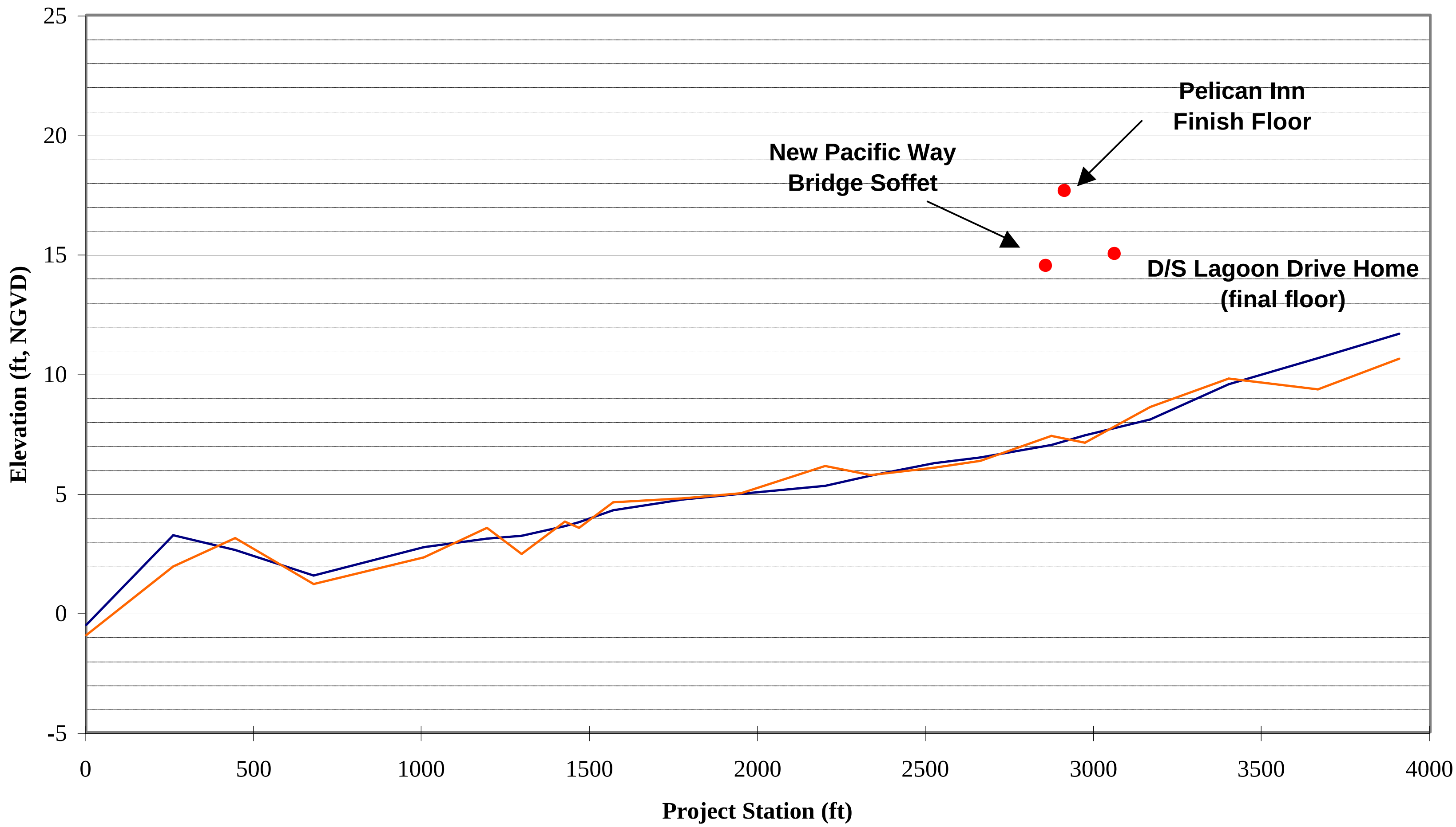
*figure 24*

**Sediment Loading for Approx 6-Year Event: Alternative 2- Creek Restoration and 50 foot Bridge**

PWA

PWA #: 1664.03

M11Results_Sediment_50and150Bridge_bedlevelsonly_12-05.xls A2-50-Q6 12/23/2005




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. Sediment loading based on synthetic hydrograph for one event (Qmax = 1790 cfs) and Redwood Creek sediment rating data (Stillwater, 2004)

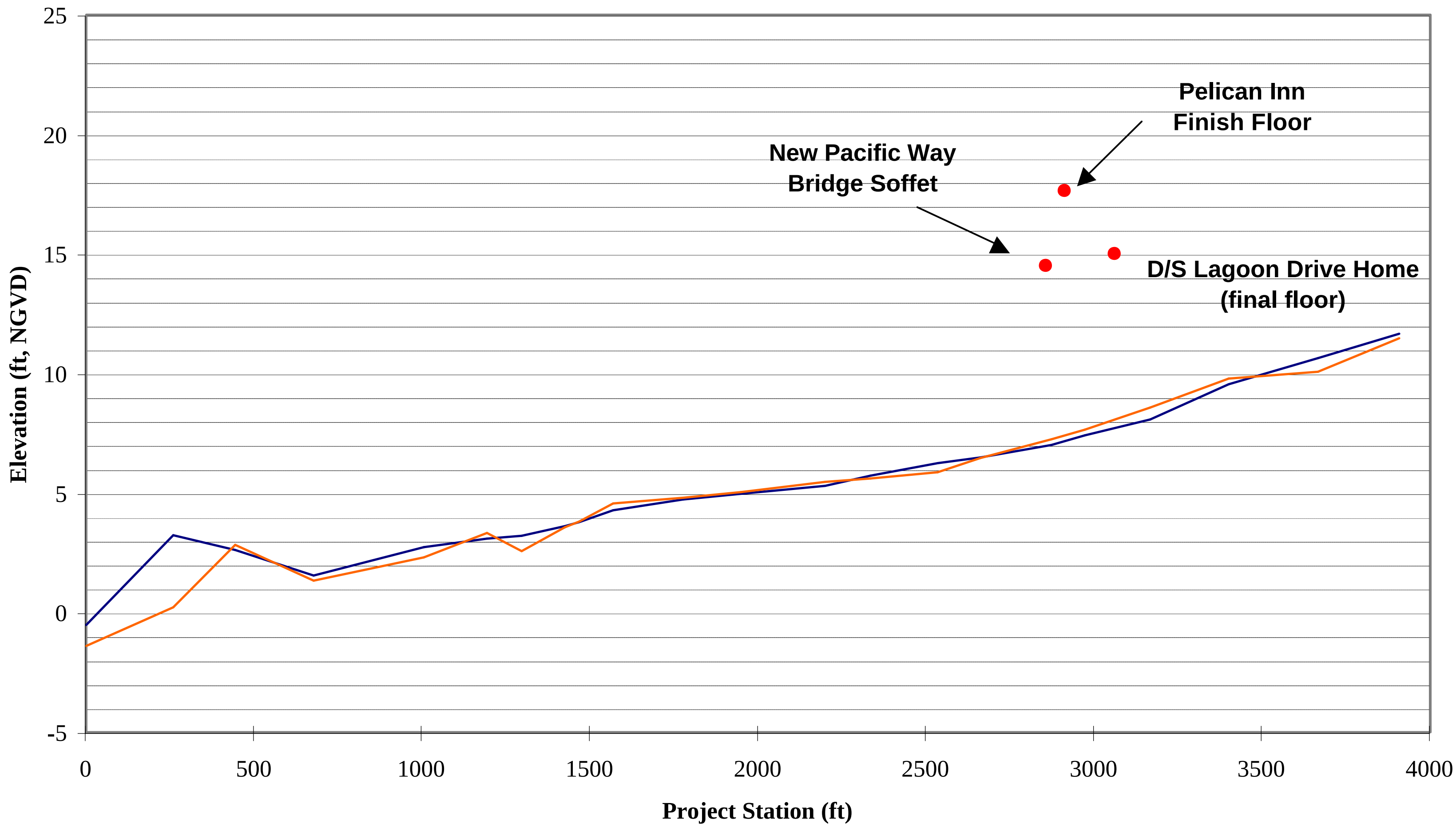
Initial Thalweg　Post-Simulation Thalweg　Spot Elevations

*figure 25*

**Sediment Loading for Approx 6-Year Event: Alternative 2- Creek Restoration and 150 foot Bridge**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. Sediment loading based on synthetic hydrograph for one event (Qmax = 1790 cfs) and Redwood Creek sediment rating data (Stillwater, 2004)

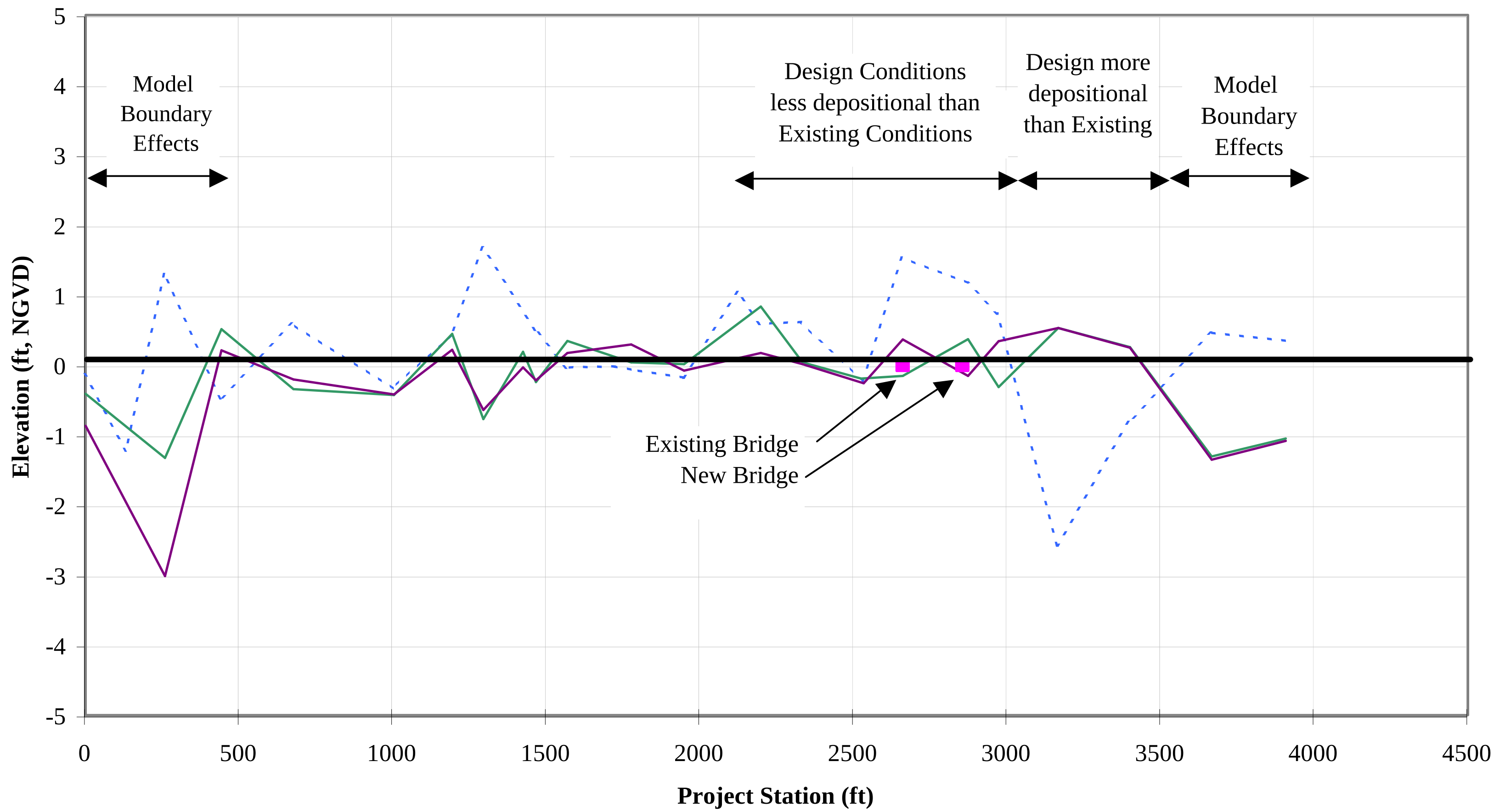
Initial Thalweg — Post-Simulation Thalweg — Spot Elevations

*figure 26*

**Sediment Loading for Approx 6-Year Event: Alternative 2- Creek Restoration and 50 foot Bridge (extended upstream boundary)**

PWA

PWA #: 1664.03




Notes: Chainages based on Alternative 1 MIKE network. Bed change is the difference between pre- and post-simulation thalweg elevation. Positive values indicate deposition and negative values indicate erosion.

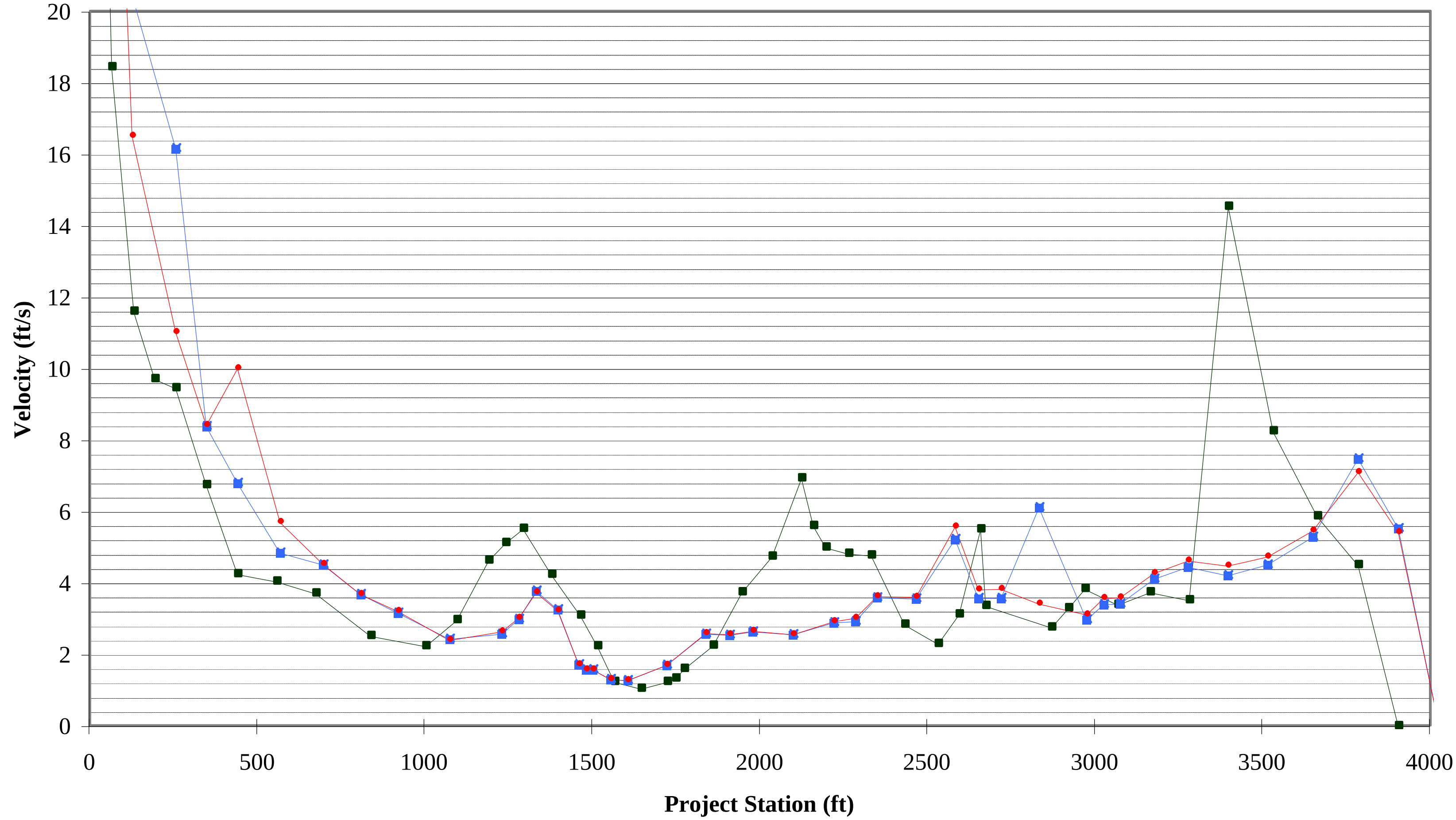
- Bed Change - Existing Conditions (Alt 1)
- Bed Change - Design Conditions (Alt 2, 150-ft Bridge)
- Bed Change - Design Conditions (Alt 2, 50-ft Bridge)
- Spot Elevations

*figure 27*

**Comparison of Bed Changes for Existing and Design Conditions (Approx 6 -Year Event Sediment Loading)**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network.

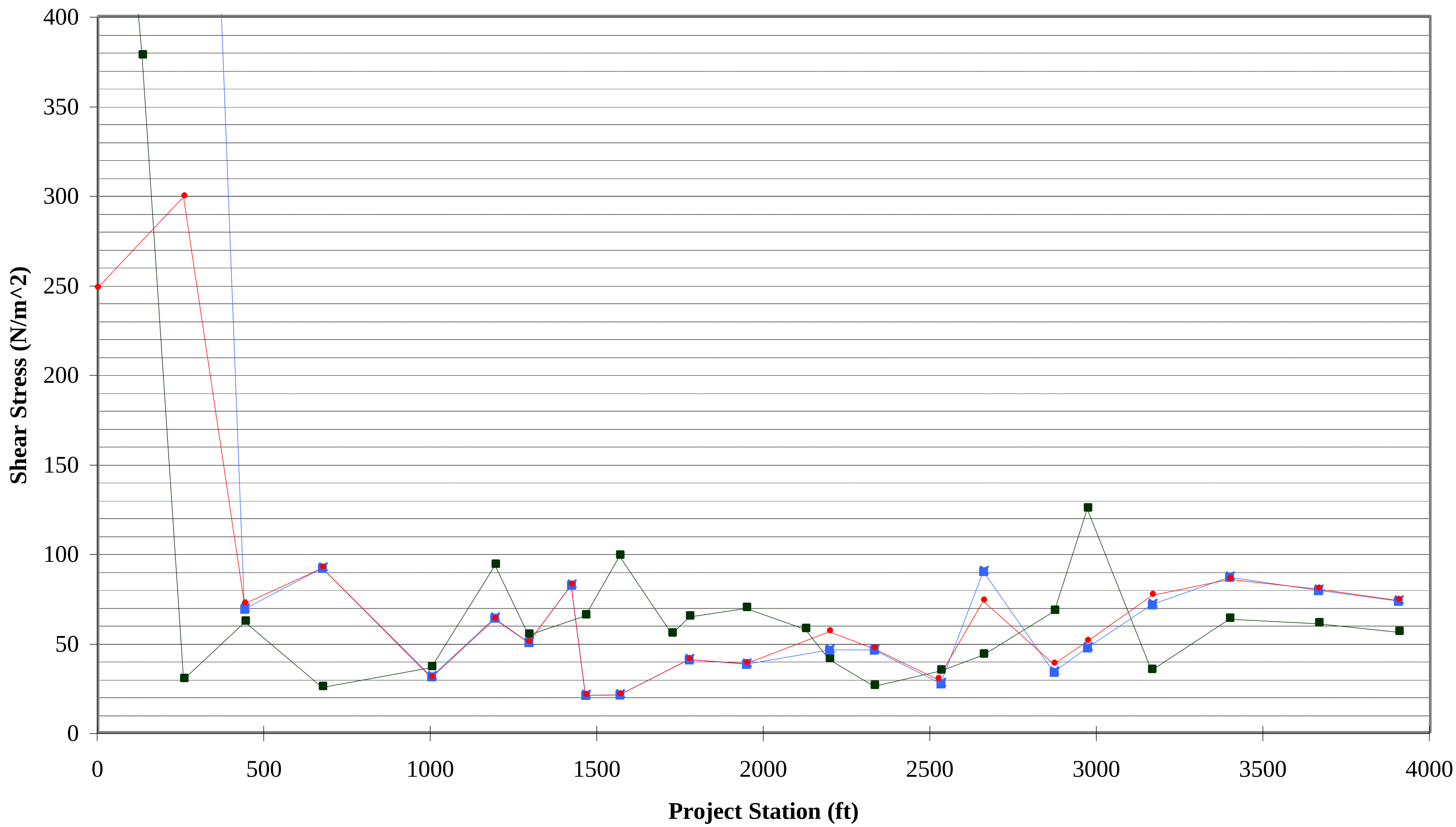
A1 Q6 A2 50' Q6 A2 150' Q6

*figure 28*

**Maximum Velocity Values for Sediment Transport Simulations**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network.

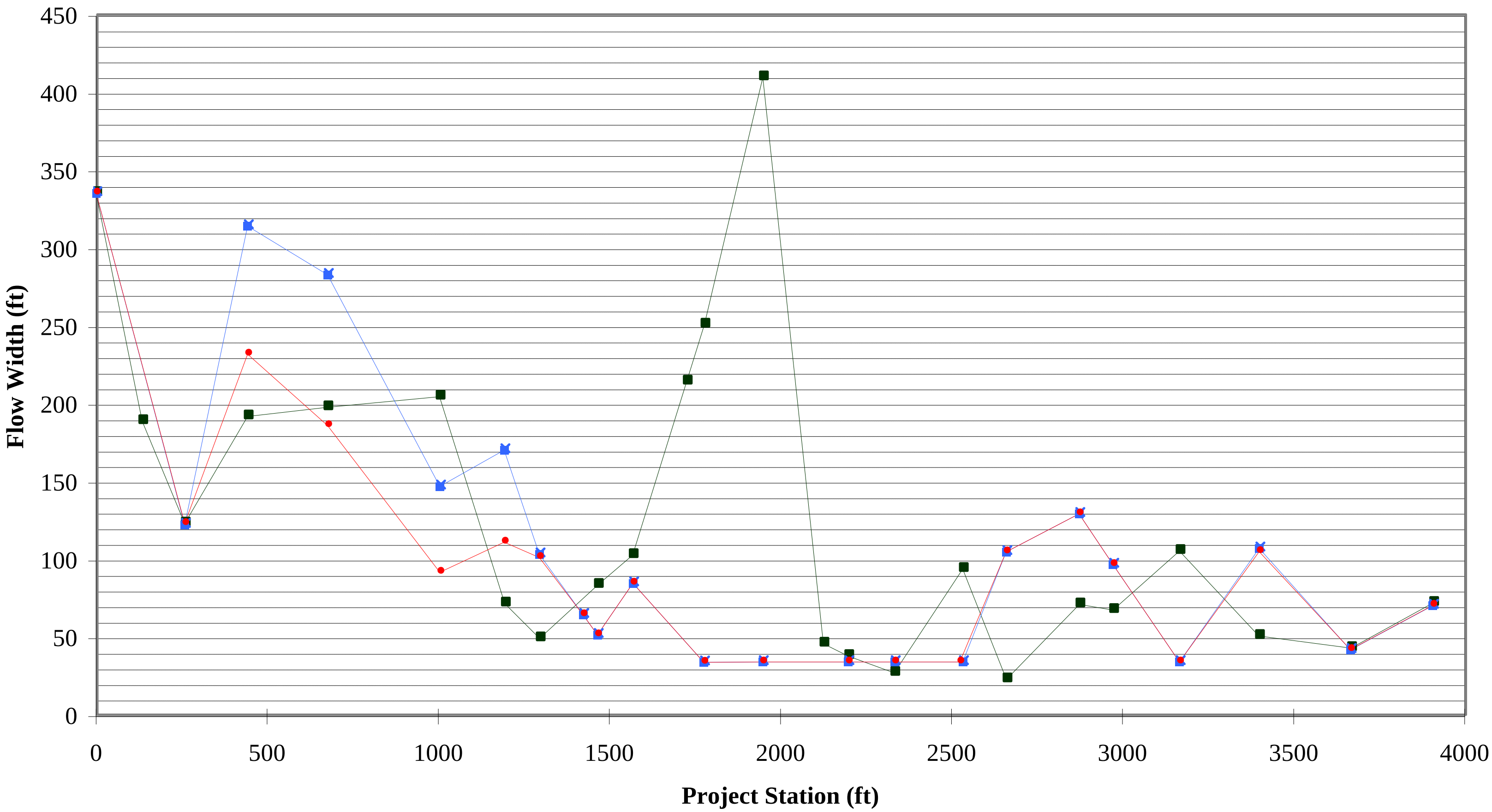


*figure 29*

**Maximum Shear Stress Values for Sediment Transport Simulations**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network.

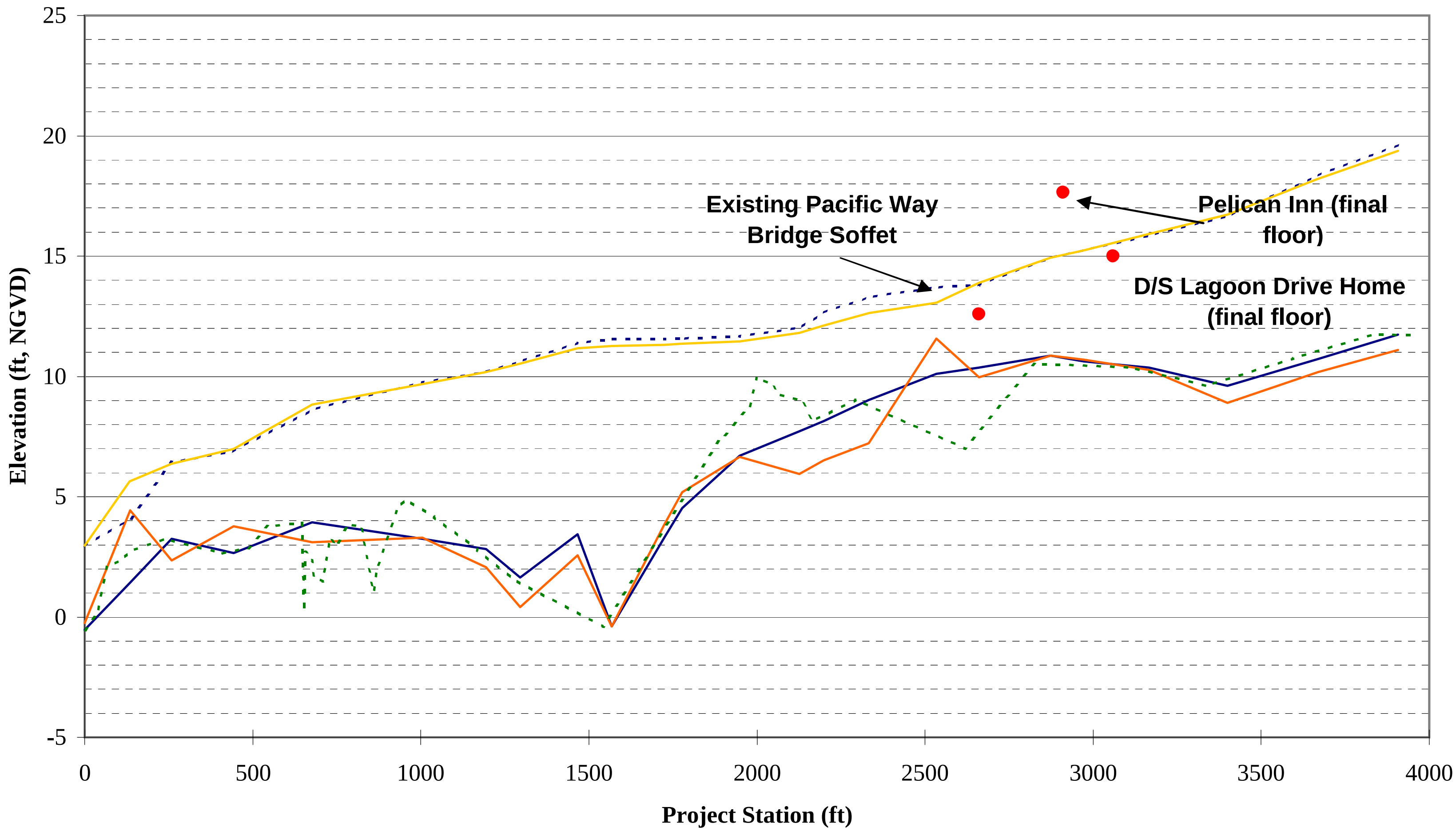
A1 Q6 | A2 50' Q6 | A2 150' Q6

*figure 30*

**Maximum Flow Width Values for Sediment Transport Simulations**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 10th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

| | |
|---|---|
| Initial Thalweg | Post-Simulation Thalweg |
| Post-Dredge (2003) Thalweg | Spot Elevations |
| Intial 5-Year Water Surface | Post-Sim 5-Year Water Surface |

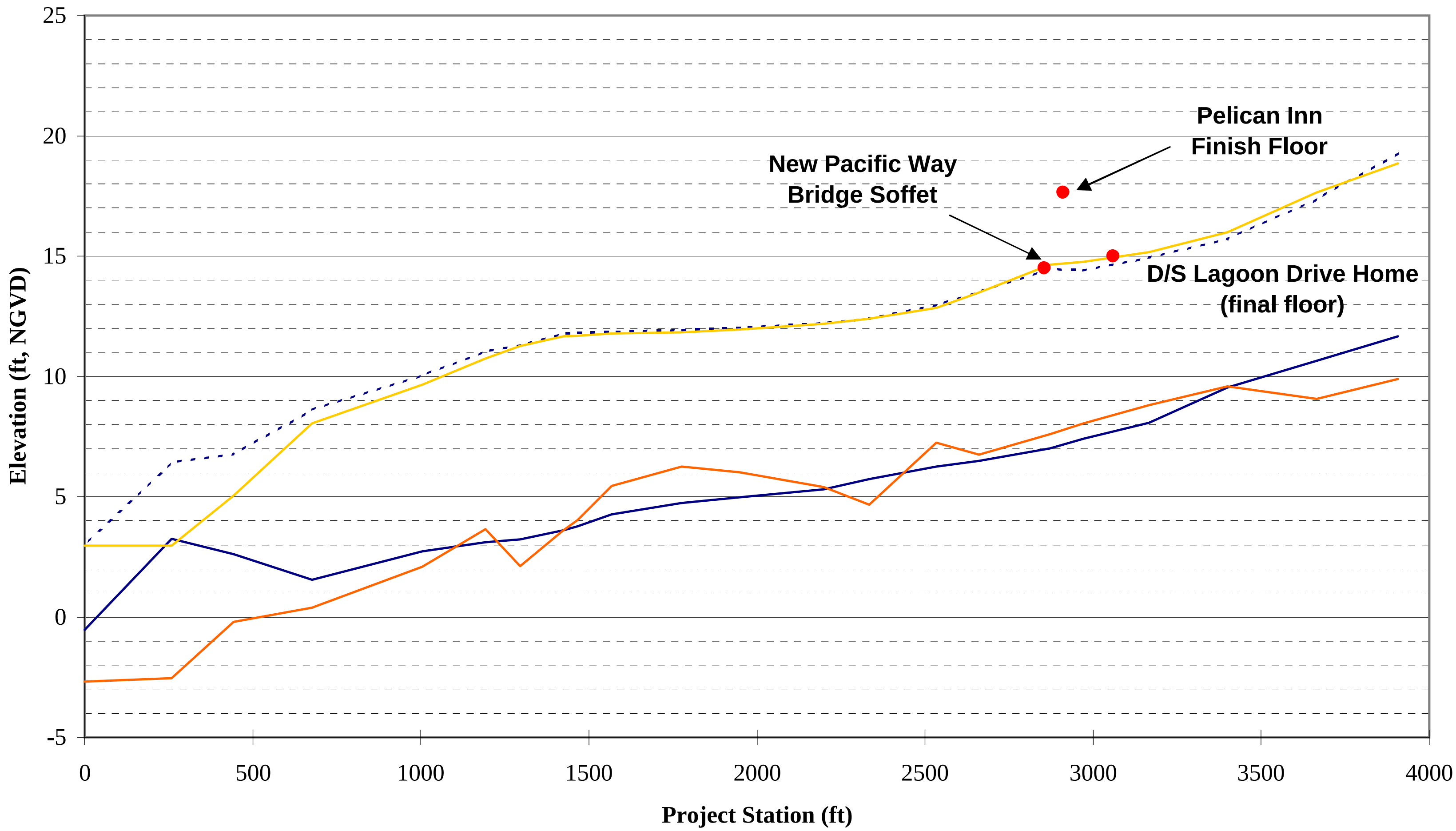
*figure 31*

**Five Years of "Typical" Sediment Loading with 5-Year Flood Levels: Alternative 1- No Action**

PWA

PWA #: 1664.03

M11Results_Sediment_150Bridge_bedandfloodlevels_11-05.xls A1-5-T 4/5/2006




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

| | |
|---|---|
| Initial Thalweg | Post-Simulation Thalweg |
| Initial 5-Year Water Surface | Post-Sim 5-Year Water Surface |
| Spot Elevations | |

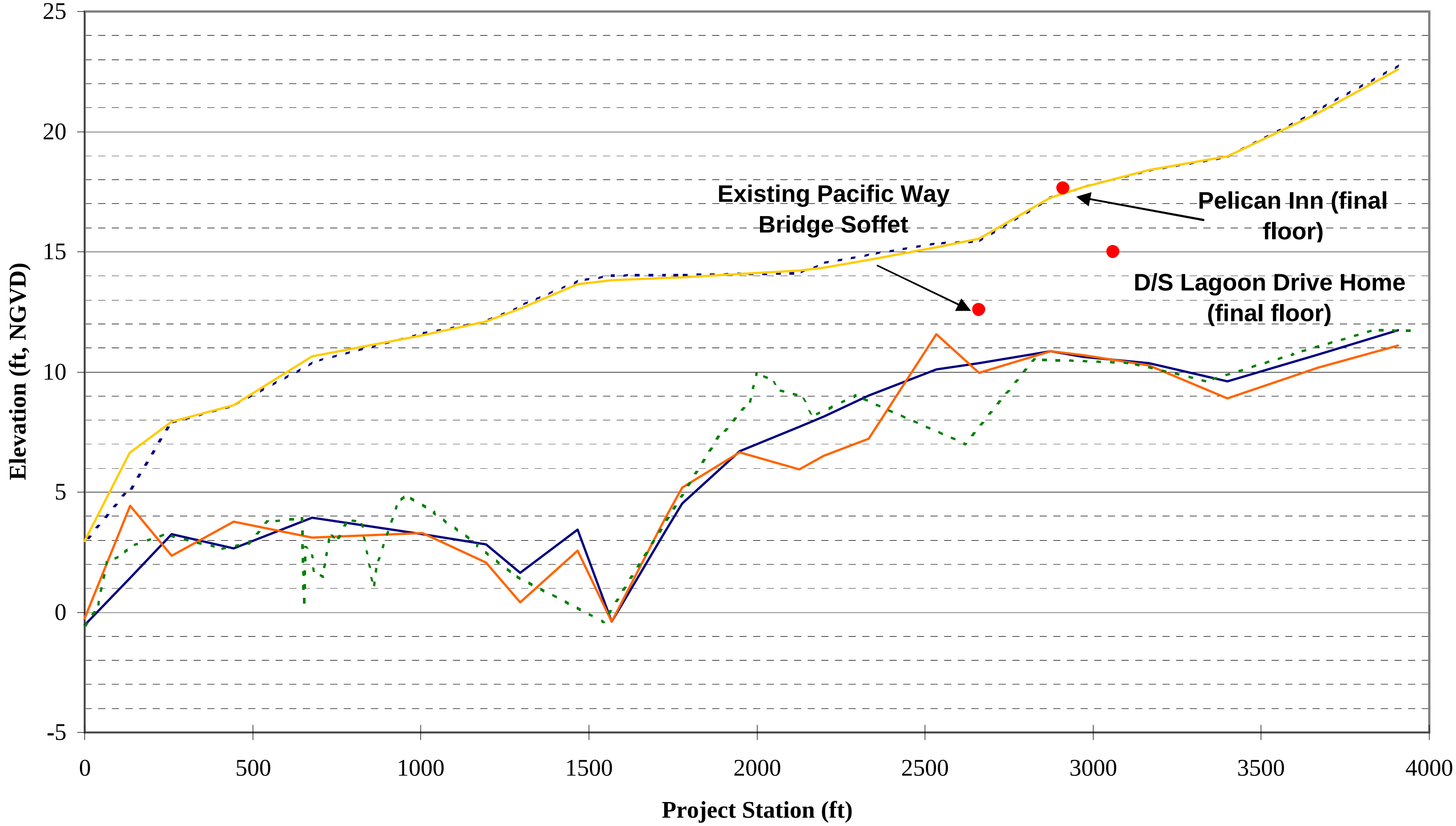
*figure 32*

**Five Years of "Typical" Sediment Loading with 5-Year Flood Levels:**
**Alt 2- Creek Restoration and 150 foot Bridge**

PWA

PWA #: 1664.03

M11Results_Sediment_150Bridge_bedandfloodlevels_11-05.xls Fig 32 A2-5-T 4/5/2006




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

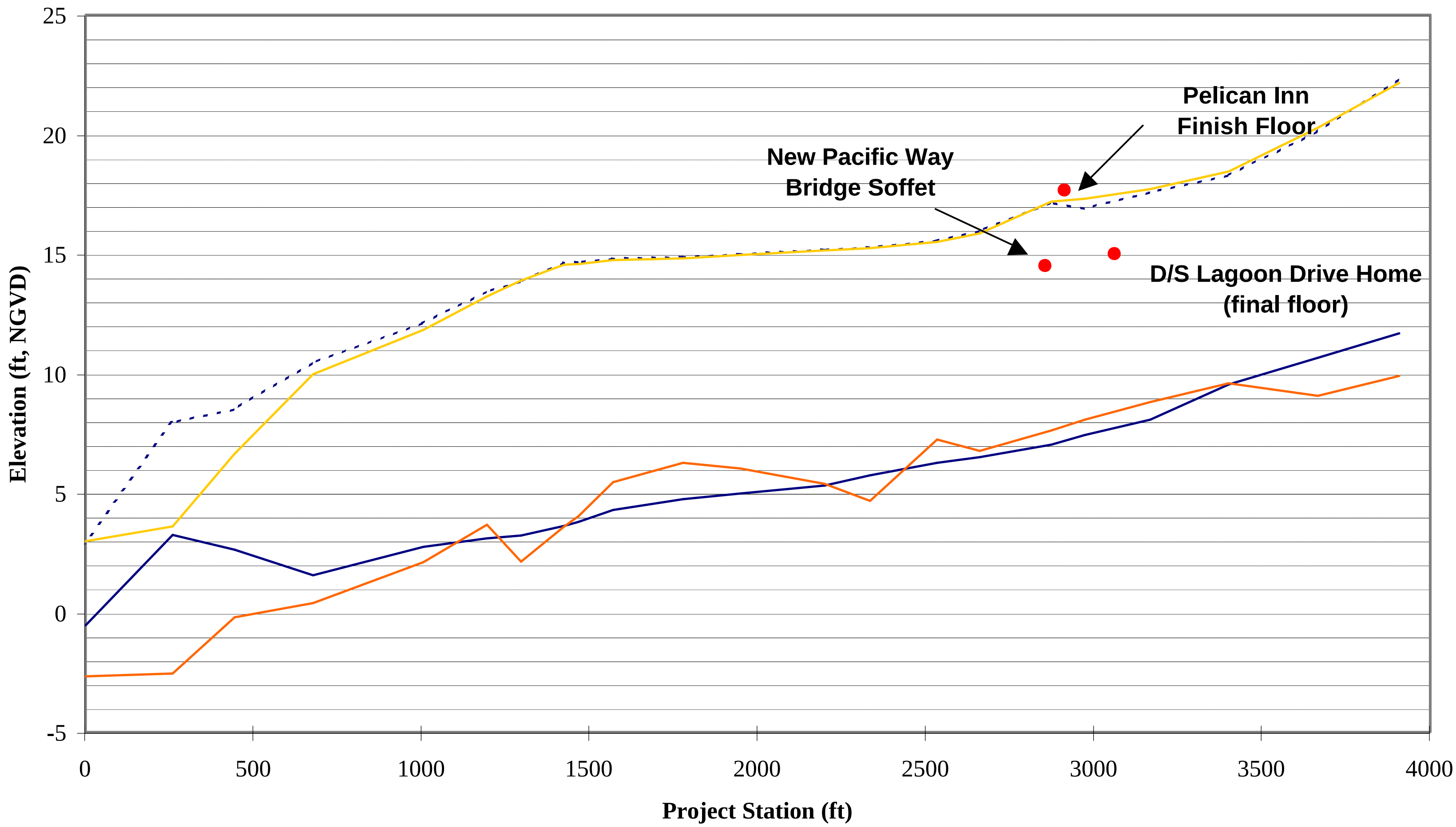
| | |
|---|---|
| Initial Thalweg | Post-Simulation Thalweg |
| Post-Dredge (2003) Thalweg | Spot Elevations |
| Initial 100-Year Water Surface | Post-Sim 100-Year Water Surface |

*figure 33*

**Five Years of "Typical" Sediment Loading with 100-Year Flood Levels: Alternative 1- No Action**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. "Typical" sediment loading based on Water Year 2005 hydrograph from Dec 1st to January 18th (Qmax = 895 cfs) and Redwood Creek sediment data (Stillwater, 2004).

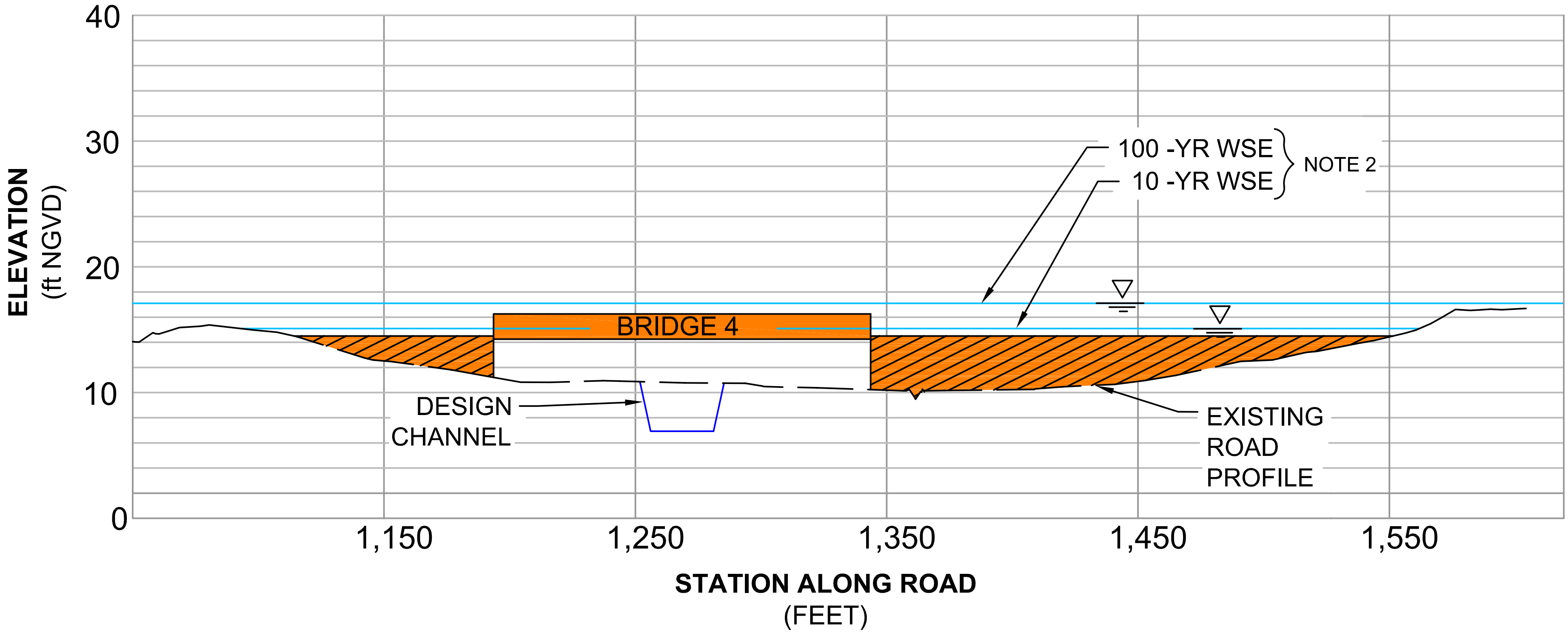
| | |
|---|---|
| Initial Thalweg | Post-Simulation Thalweg |
| Intial 100-Year Water Surface | Post-Sim 100-Year Water Surface |
| Spot Elevations | |

*figure 34*

**Five Years of "Typical" Sediment Loading with 100-Year Flood Levels: Alt 2- Creek Restoration and 150 foot Bridge**

PWA

PWA #: 1664.03

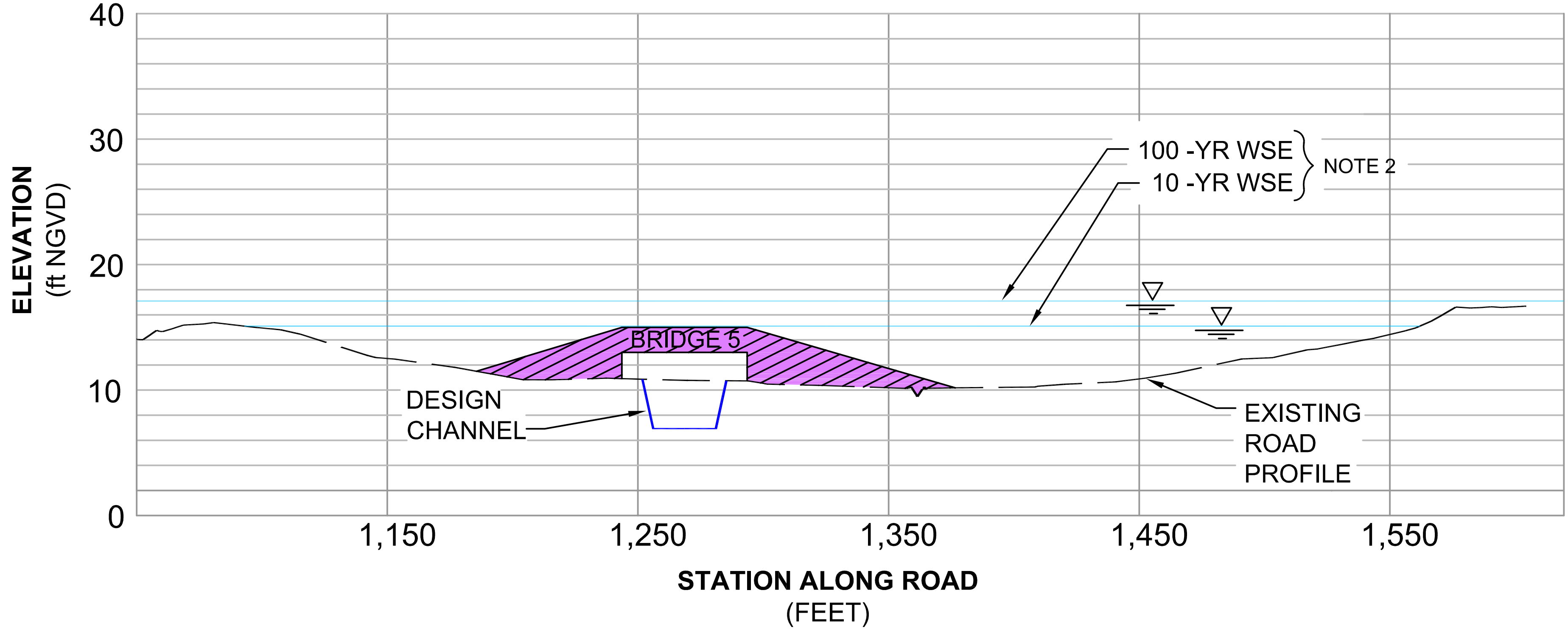



NOTES:
1. THIS IS A SCHEMATIC REPRESENTATION OF THE 150-FT SPAN BRIDGE (AS MODELED). THE ACTUAL DESIGN NEEDS TO INCLUDE TRANSITION FROM THE RAISED ROAD (EL. 14.5 FT) TO THE BRIDGE DECK (EL. 16.25 FT).

2. APPROXIMATE WATER SURFACE ELEVATION (WSE) ATTHE PELICAN INN UNDER EXISTING CONDITIONS.

*figure* **35**

# 150' Span Bridge (Option 4) for Scenario 3: Creek Restoration and New Bridge




NOTES:
1. BRIDGE 5 IS A 50-FOOT SPAN BRIDGE WITH THE ROAD RAISED ONLY AS NEEDED TO TRANSITION TO BRIDGE DECK (EL. 15.0 FT).

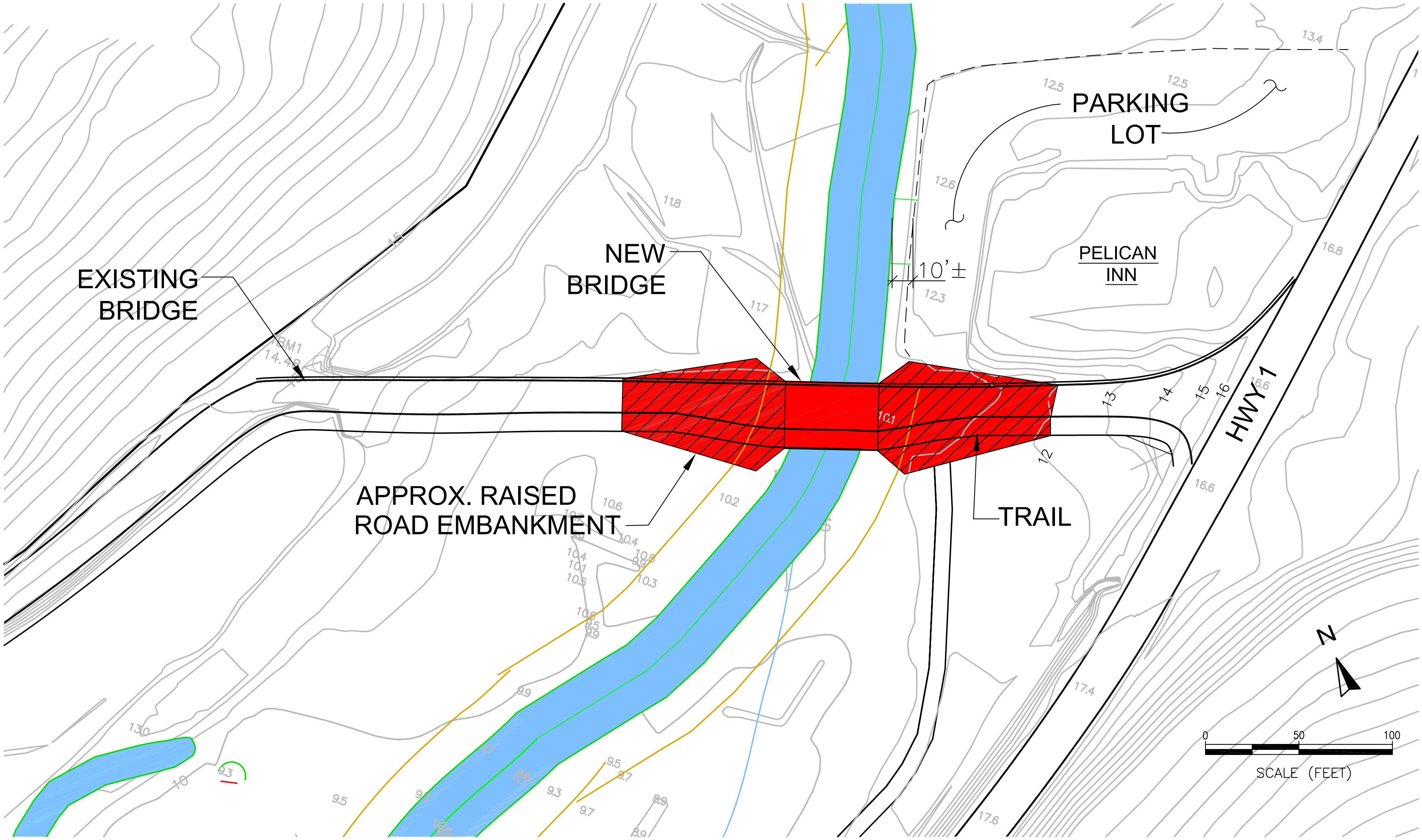
2. APPROXIMATE WATER SURFACE ELEVATION (WSE) AT THE PELICAN INN UNDER EXISTING CONDITIONS.

*figure* **36**

**50' Span Bridge (Option 5) for Scenario 3: Creek Restoration and New Bridge**

PWA

Q:\Projects\1664.02_BIG_LAGOON_COST_EST\MODEL\1664_BRIDGEoptions.dwg 4-05-06 02:29:52 PM e.wisnosky




NOTES:
1. HYPOTHETICAL SCENARIO WITH CREEK & 50' BRIDGE LOCATED AS CLOSE AS PRACTICAL TO THE PELICAN INN. (THIS CONFIGURATION WAS NOT MODELED) SEE FIGURE 38 FOR PROFILE.

*figure 37*

**Schematic Plan for 50' Span Bridge Located near Pelican Inn**

Q:\Projects\1664.02_BIG_LAGOON_COST_EST\MODEL\Bridge_Plan.dwg 4-10-06 12:17:20 PM e.wisnosky

PWA

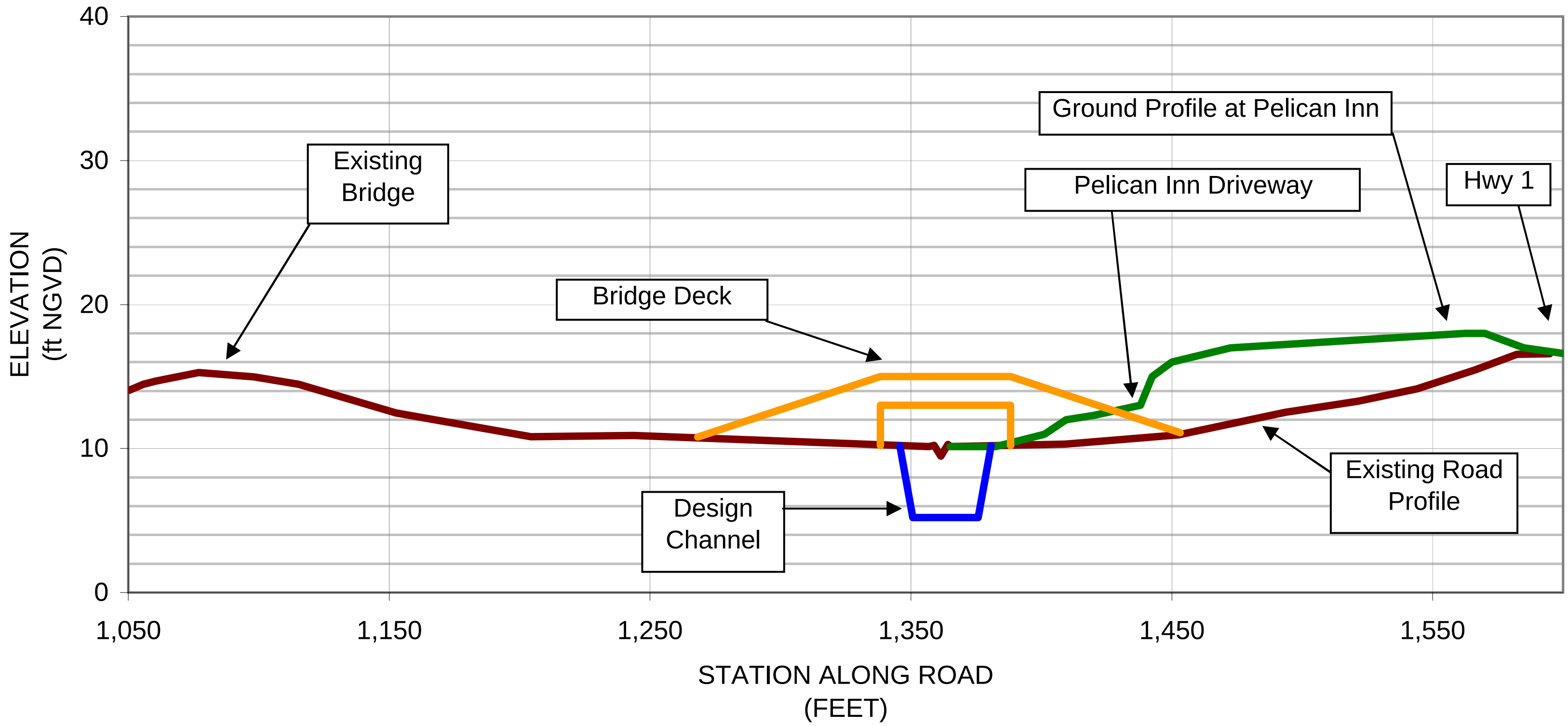
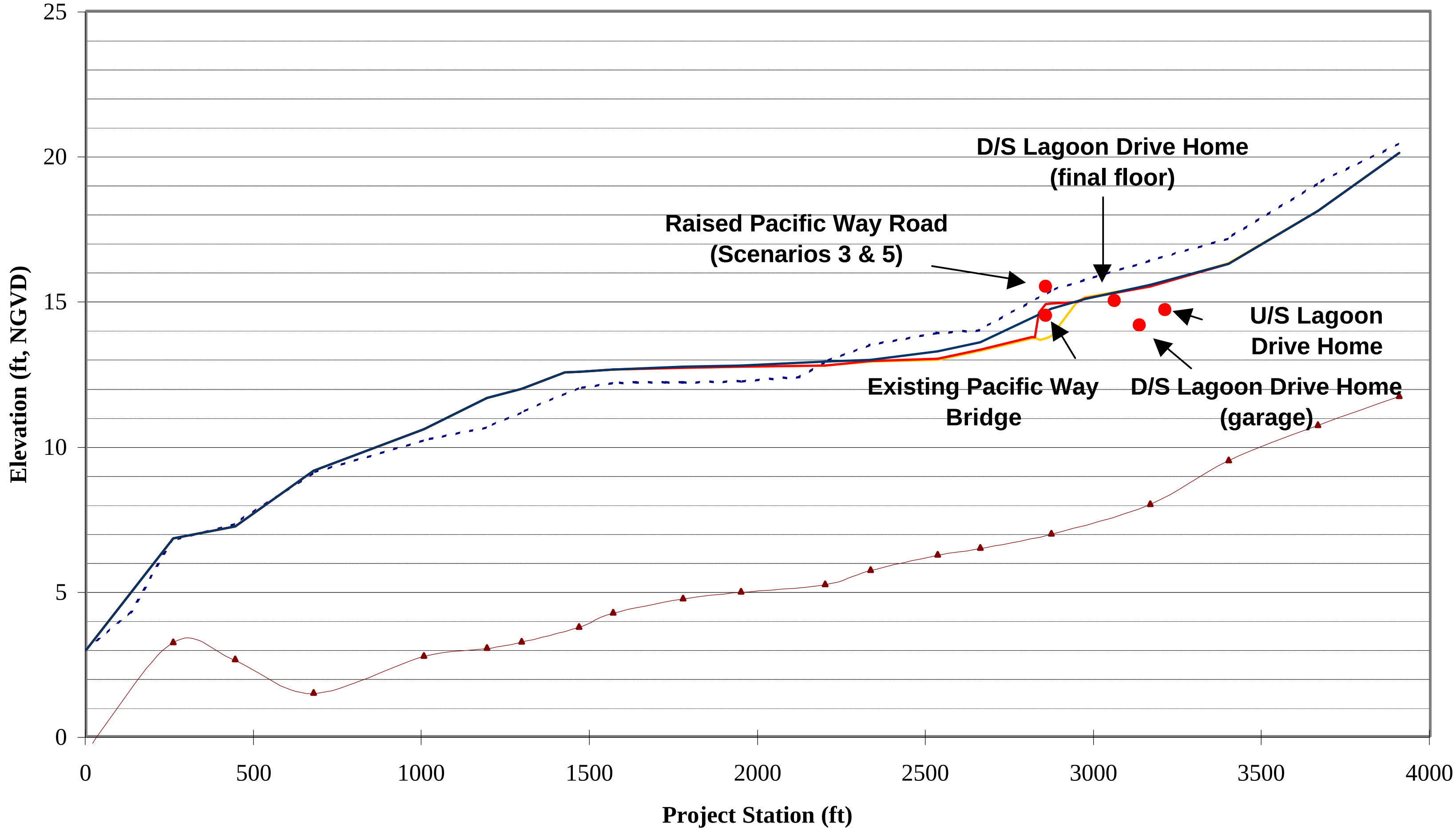



*figure* 38

Schematic Profle for Bridge 5 Located Near Pelican Inn

NOTE: 1. HYPOTHETICAL SCENARIO WITH CREEK & BRIDGE LOCATED AS CLOSE AS PRACTICAL TO THE PELICAN INN (TO MINIMIZE THE FLOODPLAIN OBSTRUCTION CAUSED BY THE ROAD EMBANKMENT). SEE FIGURE 37 FOR PLAN VIEW.

PWA



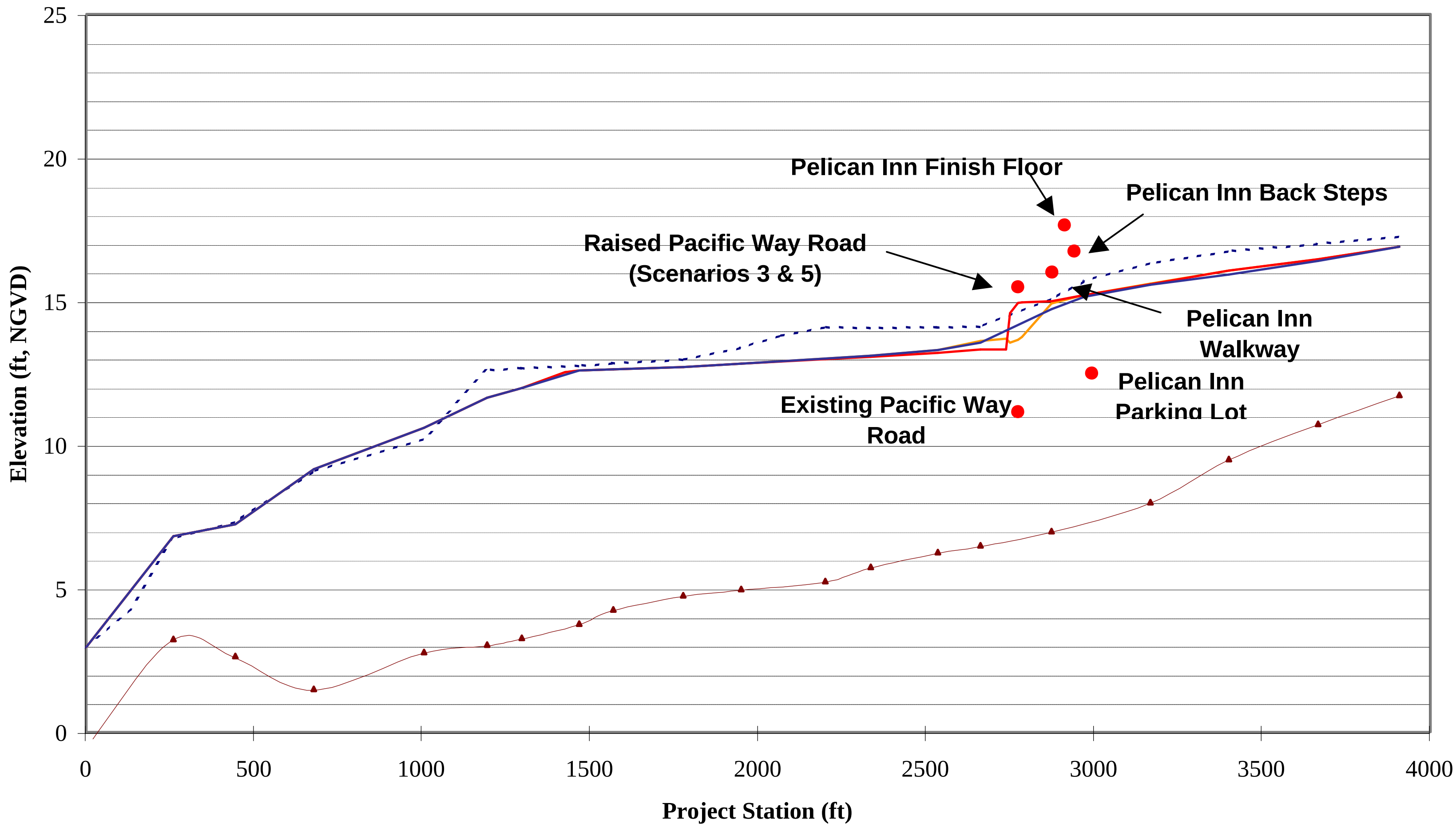

Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative.

*figure 39*

**Comparison of Water Levels on the Right Floodplain during the 10-Year Flow for Bridges 2, 4, and 5**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative.

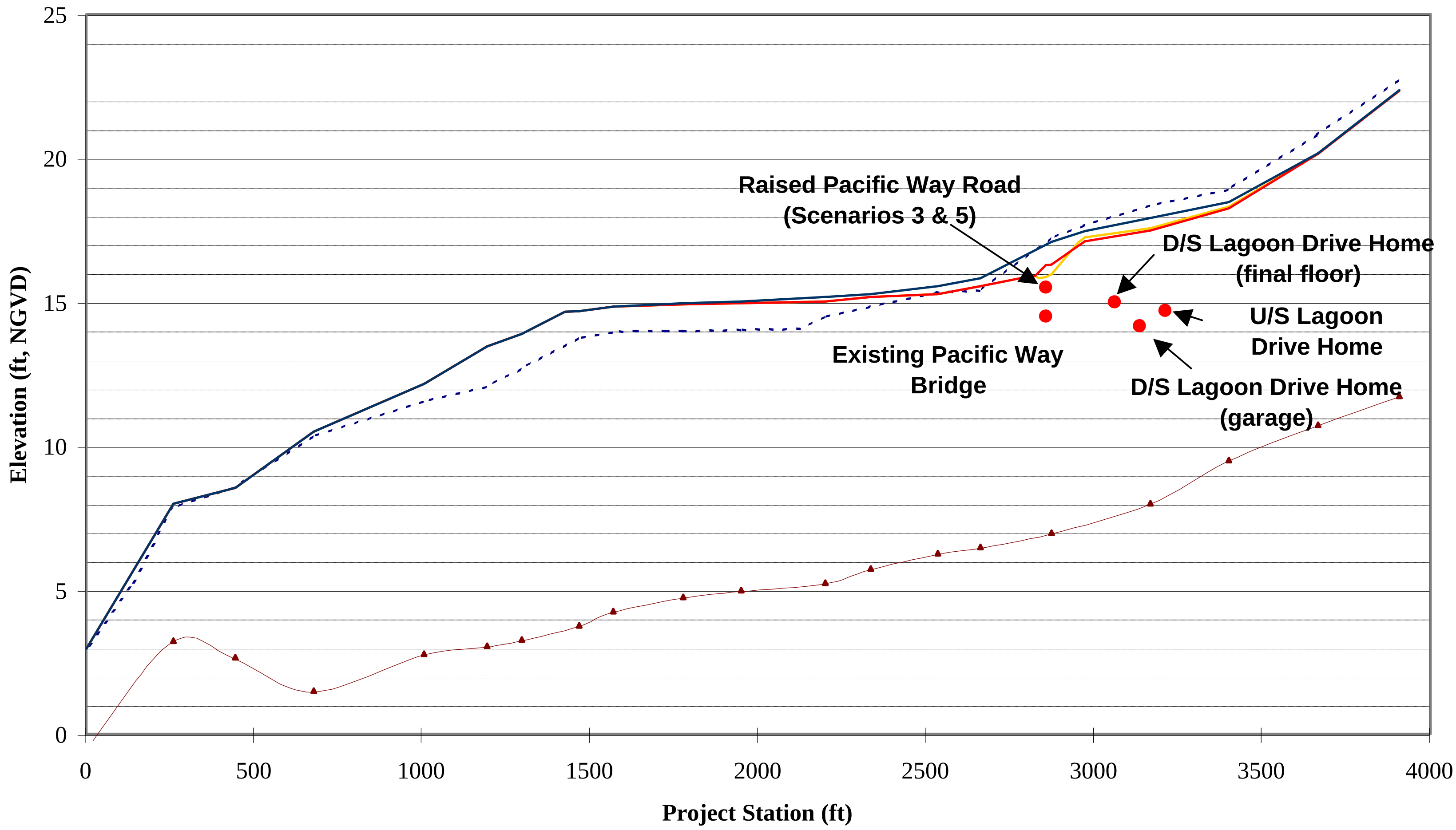
| | |
|---|---|
| No action, existing conditions | 50-foot bridge, w/o raised road |
| 150-foot bridge, w/ raised road | 280-foot bridge |
| Restored Creek Thalweg | Spot Elevations |

*figure 40*

**Comparison of Water Levels on the Left Floodplain during the 10-Year Flow for Bridges 2, 4, and 5**

PWA

PWA #: 1664.03




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative.

| | |
|---|---|
| No action, existing conditions | 50-foot bridge, w/o raised road |
| 150-foot bridge, w/ raised road | 280-foot bridge |
| Restored Creek Thalweg | Spot Elevations |

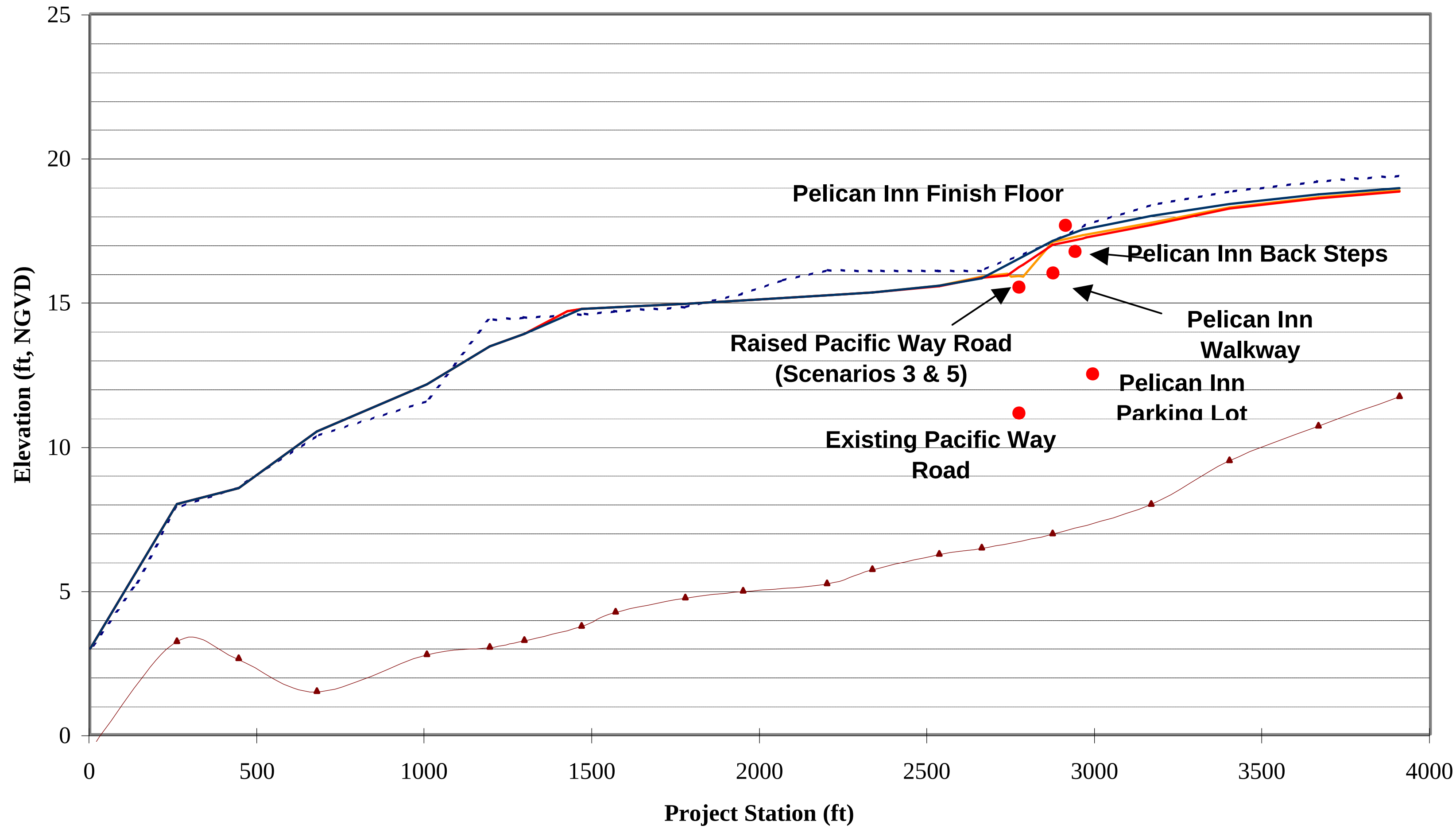
*figure 41*

**Comparison of Water Levels on the Right Floodplain during the 100-Year Flow for Bridges 2, 4, and 5**

PWA

PWA #: 1664.03

ResultsFebruary06Bridge.xls (RFP) (100) 2/22/2006




Notes: Alternative and spot elevation chainages based on Alternative 1 MIKE network. All cross sections are in the same locations for each alternative, however distances between cross sections may be different between each alternative.

| | |
|---|---|
| No action, existing conditions | 50-foot bridge, w/o raised road |
| 150-foot bridge, w/ raised road | 280-foot bridge |
| Restored Creek Thalweg | Spot Elevations |

*figure 42*

**Comparison of Water Levels on the Left Floodplain during the 100-Year Flow for Bridges 2, 4, and 5**

PWA

PWA #: 1664.03

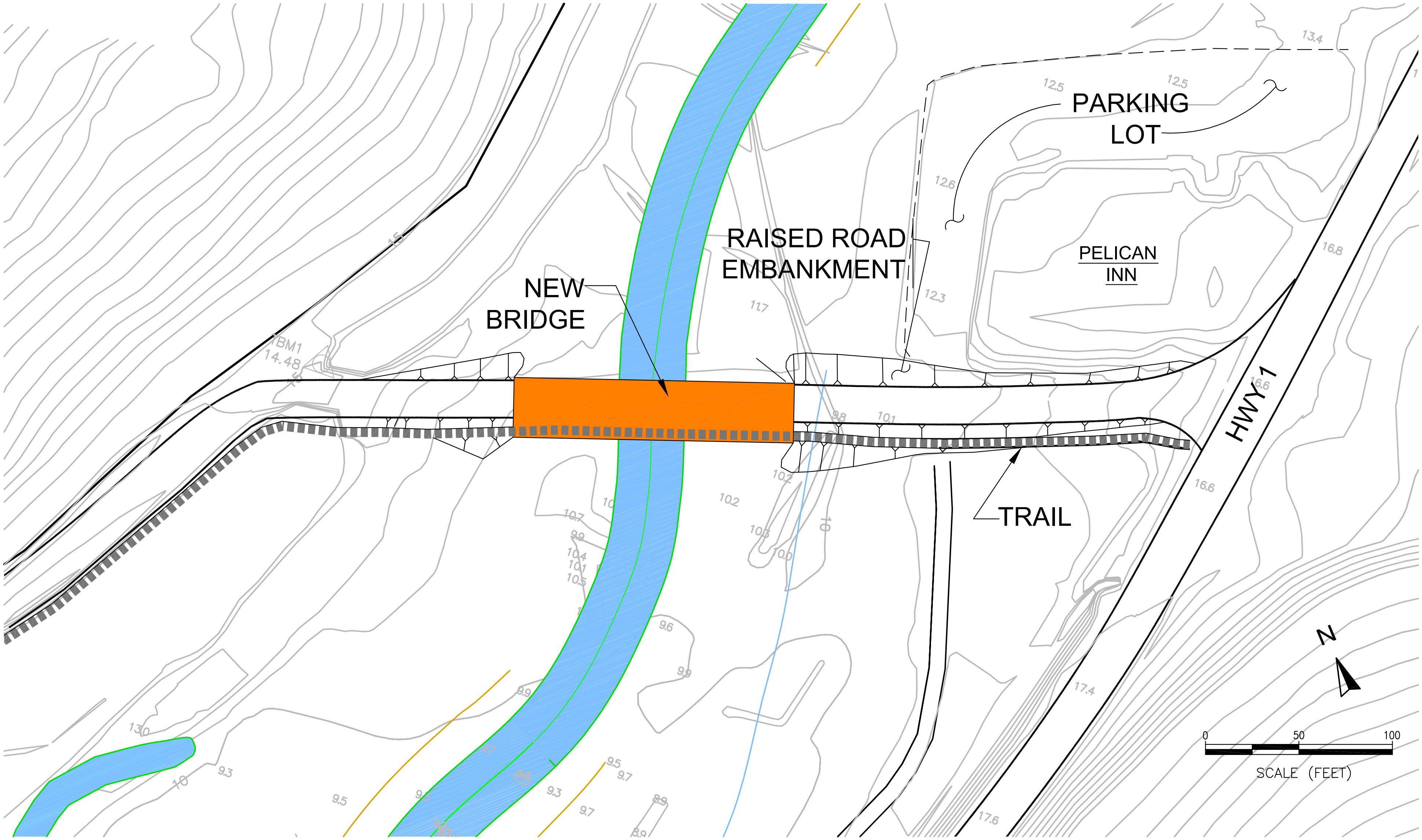


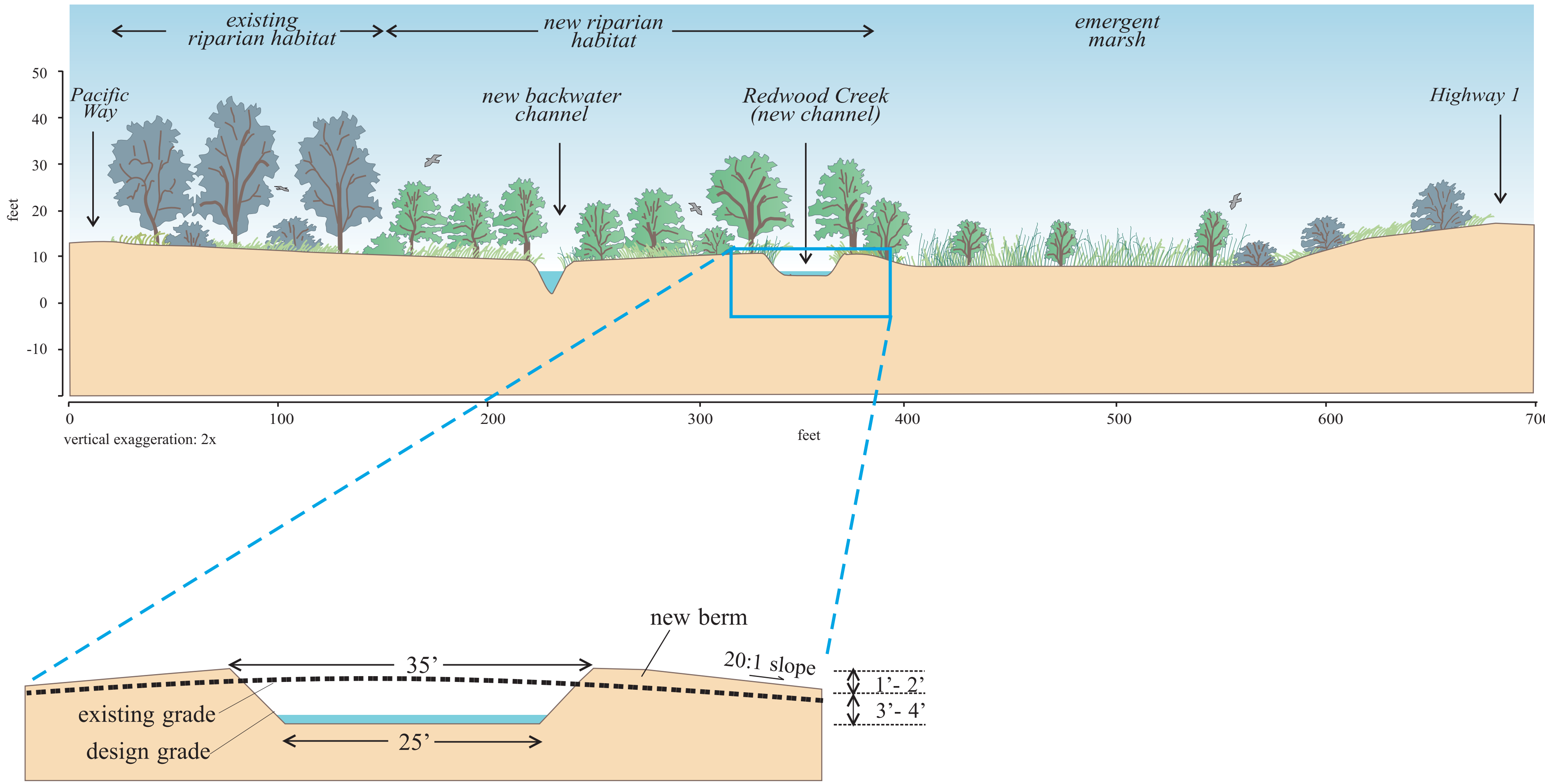

*figure* ***43***

**Schematic Plan for 150' Span Bridge**

NOTES:
1. SCHEMATIC REPRESENTATION OF 150' SPAN BRIDGE WITH ROAD RAISED TO ELEVATION 14.5 OR GREATER.

Q:\Projects\1664.02_BIG_LAGOON_COST_EST\MODEL\060406_Bridge_Plan.dwg 4-10-06 12:21:57 PM e.wisnosky

PWA




1:1 scale
(no vertical exaggeration)

Note:
See Figure 1 for approximate location of conceptual cross-section.

*figure 44*

CONCEPTUAL CROSS - SECTION

**Alternative 2**
**Creek Restoration**

PWA

*Proj. # 1664-3C_reporting, alt 2_revised 4-10-06.cdr*