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Rocky Gulch at Old Arcata Road
Channel and Floodplain Modification: Conceptual Design
Grant Agreement #205300

FINAL REPORT

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1 INTRODUCTION

1.1 Background

Rocky Gulch is a 1.55 square mile watershed that drains into North Humboldt Bay approximately 6 miles north of Eureka, CA (Figure 1). Rocky Gulch historically supported coho salmon (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) populations, but past timber and agricultural land uses caused extirpation of these populations by the early 1960's. Since 2001, state and federal resource agencies have provided grant funding for planning and restoration activities in Rocky Gulch, with the overarching goal of restoring anadromous fish access, habitat conditions, and naturally reproducing salmonid populations (coho salmon and steelhead) from Humboldt Bay to approximately the Rock Quarry located 1.5 miles upstream of Old Arcata Road.

McBain & Trush was awarded a grant in 2001 for the "Rocky Gulch Stream Assessment Project". The objectives of this project were to assess migratory access, habitat conditions, and restoration needs of Rocky Creek, prioritize restoration actions, and develop site-specific recommendations for habitat restoration. In addition, McBain & Trush coordinated with the landowners, resource agencies, and the local community to hear different restoration perspectives and ultimately achieve a shared vision for stream restoration in Rocky Gulch. The Stream Assessment Report (McBain and Trush 2002) recommended seven essential actions to restore salmonid populations to Rocky Gulch (Figure 2), including:

Task A: Replace the Rocky Gulch tidegate (completed 2004)

Task B: Enhance estuarine conditions in Rocky Gulch (initiated 2005)

Task C: Realign the lower Rocky Gulch channel to reduce confinement (completed 2005)

Task D: Set back dikes confining Rocky Gulch along Old Arcata Road (completed 2005)

Task E: Rehabilitate the channel around the old Williamson Ranch (Ginni Hassrick's property)

Task F: Replace the Old Arcata Road culvert

Task G: Replace the barrier culvert upstream of the Old Arcata Road culvert (scheduled for 2006)

Task H: Rehabilitate the stream channel surrounding the barrier culvert (scheduled for 2006)

A proposal for the "Rocky Gulch Salmonid Access and Habitat Restoration Project" (Tasks A-D) was submitted to the CA Department of Fish and Game (CDFG) in 2002 and was awarded in 2003. The engineering design and regulatory compliance phases were conducted from June 2003 to August 2005. A new tidegate was installed in December 2004 to restore adult salmon to access Rocky Gulch, allowing reestablishment of the population. In August 2005 the final permits were obtained for the stream habitat construction elements (Tasks B-D), on-the-ground construction activities began August 18th, and were completed by the middle of October. The Salmonid Access and Habitat Restoration project contained eight elements:

1. Installation of a new tidegate at the bottom end of Rocky Gulch to allow fish passage;
2. Excavation of aggraded sediments from approximately 1,100 ft of slough channel;
3. Reconstruction of nearly 2,800 ft of channel to eliminate unnatural 90 degree bends and re-meander straightened sections;
4. Relocation of the 2,500 ft section of dike that parallels Old Arcata Road to 50 ft back from the existing stream channel to create a floodplain, increase the riparian corridor, and increase floodway capacity;
5. Placement of dredged material to rehabilitate approximately 4,900 feet of dikes to protect adjacent agricultural lands;

6. Installation of 3,200 ft of riparian fencing, two armored cattle crossings and watering access sites, and one bridge;
7. Revegetation of native riparian and wetland plant species, and installation of erosion control features;
8. Development of procedures and protocols for future maintenance of the channel, and a riparian grazing agreement for the riparian areas.

The Barrier Culvert Project (Tasks G and H) was awarded funding in 2005, and will be implemented in 2006. There is at least 2,200 ft of high quality salmonid habitat upstream of the barrier culvert that is presently inaccessible to coho salmon and steelhead. Aquatic habitat above the culvert has been recovering since the mid-1960's timber harvests, and together with downstream habitat there appears abundant habitat suitable to sustain coho salmon and steelhead. The objective of the project is to replace the barrier culvert with a bridge to restore fish access upstream of the culvert. The project will also rehabilitate approximately 300 ft of stream channel upstream and downstream of the new bridge, build an inset floodplain, and expand flood capacity.

With completion of the lower Rocky Gulch restoration (2004-5) and the barrier culvert project (2006), only Tasks E and F remain of the recommended restoration actions in Rocky Gulch. These tasks include channel rehabilitation at the Old Williamson Ranch (owned by Ginni Hassrick) downstream of Old Arcata Road, and replacement of the culvert under Old Arcata Road.

McBain & Trush (M&T) and Jeff Anderson & Associates (JAA) were contracted to work with the landowners and agencies to assist in developing a design solution for the Old Arcata Road culvert and the surrounding properties. We were tasked to (1) extend surveys upstream and downstream of OAR and develop topography for hydraulic modeling and design, (2) extend the existing hydraulic model to incorporate the project reach, and (3) coordinate design recommendations with the landowners and Humboldt County to develop a project alternative and design details that satisfied landowners and HCPW, while improving salmonid habitat and migration conditions. HCPW retained the responsibility to develop culvert dimensions and construction plans for project implementation.

The properties surrounding the culvert are small (3-5 acre) privately owned parcels zoned for residential use (Figure 3). McBain and Trush and Jeff Anderson met with landowners Ginni Hassrick and Nathan Prather several times to discuss design alternatives. The failing retaining wall structure on the left bank upstream of the culvert was also discussed with landowner Lee Hover. This design memorandum presents design alternatives considered, presents our hydraulic modeling results, and then recommends a design that best balances landowner concerns, flood risks and impacts, and salmonid habitat issues.

Funding for this project was provided by the Five Counties Salmonid Conservation Program, with contracting assistance from Gary Flosi of CDFG. The contract was administered through the Humboldt County Public Works Department, with oversight by Chris Whitworth.

1.2 Project Site Description

The location of Rocky Creek relative to residential structures in the vicinity of the Old Arcata Road (OAR) culvert present a difficult problem and is a constraint to improving fish passage, habitat conditions, and flooding in this reach. Rocky Gulch passes under Old Arcata Road (OAR) at station 60+00 (i.e., 6,000 ft upstream of Humboldt Bay) through a pair of 3 ft and 1.5 ft diameter, 48 ft long concrete pipes (Figure 4). The present undersized culverts pass a total flood discharge up to approximately 100 cfs (estimated from hydraulic modeling as the 2 to 3-yr flood). At higher flows, floodwaters overtop the right bank, flow northwest across a pasture (floodplain), and collect in a secondary flood channel along the inboard ditch on the east side of OAR (Figure 3) . The pasture slopes gradually away from the channel and toward the inboard ditch, encouraging flood flow in a north-westerly direction. Streamflows collected in the secondary flood channel pass through a 1.5 ft diameter culvert at the foot of Rocky Creek Road before rejoining Rocky Gulch. Floods exceeding approximately a 5-yr recurrence interval overwhelm the ditch and secondary culvert capacity and flow overtops the road (Figure 5). A previous landowner constructed a berm along the right bank of the main channel for approximately 150 ft upstream of the culvert, in an attempt to route flood flow to the OAR culvert. This effort has been unsuccessful, primarily due to the undersized OAR culvert and the sloped topography.

The OAR culvert was assessed during a culvert passage survey conducted by Humboldt County (Taylor and Associates 2000), which reported the following:

> **Site #27:** Rocky Gulch; Old Arcata Road **Priority Ranking =** #22
> **Overall condition:** Poor, one culvert is overgrown and completely plugged with fine sediment. Entire
> channel flows through one 3' pipe (nearly full at low summer flow).
> **Sizing:** Extremely undersized, especially with one pipe completely overgrown. Floods Old Arcata Road
> on a regular basis.
> **Barrier Status:** Yes, excessive velocities occur in pipe at a moderate range of expected migration flows.

Downstream of OAR, the channel is severely undersized (approximately 8 ft wide). Building structures (garage on right bank, small rental house on left bank) encroach the channel at station 59+00, leaving 45 ft between garage and rental house. At this same location, two small culverts (1.5 and 3 ft diameters) (henceforth referred to as “the downstream crossing”) are embedded into the landscaping to allow foot traffic and lawnmower passage across the creek (Figure 6). A large plunge pool has formed at the outlet of these culverts. Below the plunge pool, the channel is narrow, confined, and scoured of most coarse sediment. A second private residential stream crossing at station 57+90 consists of an old redwood plank bridge. The channel then rounds a tight right corner and joins the upstream end of the reconstructed reach (completed in 2005). Cattle fencing spans the channel at the downstream property boundary. Winter floods in 2005 and 2006 caused bank erosion along the left bank in the reach between OAR and the downstream crossing, and thoroughly scoured the channel downstream of Station 58+50. With exception of the plunge pool, salmonid habitat quality in this reach is poor.

1.3 2D Modeling of the 100-yr Flood

We developed a 2D hydraulic model to demonstrate the 100-year flood discharge for existing conditions, to improve our understanding of flood conditions in the project area , and to demonstrate general flood flow paths and patterns around properties and infrastructure (i.e., direction of flow, volumes, velocities). Because of the limitations in the topographic data and budget to develop and calibrate the 2D model, the model results are only approximate, and should be used for information purposes only.

The 2D model used for this project was FESWMS-FST2DH (FHWA, 2002) [1]. To develop the model, the project area was discritized into material types based on land use and roughness characteristics, which were then mapped to each element of the finite element mesh within the SMS program. Based on field assessments and past modeling efforts in the vicinity, a Manning's roughness coefficient or *n* value was assigned to each material type. Table 1 lists each material type, representative *n* values, and turbulence coefficients used in the 2D model. Figure 7 shows a plan view of the finite element mesh developed for the project area and the material types overlaid onto the mesh. The mesh was extended upstream and

[1] FST2DH applies the finite element method to solve steady-state or time-dependent systems of equations that describe two-dimensional depth-averaged surface water flow and transport of non-cohesive sediment by surface waters. Mesh development and pre- and post- processing were conducted using the Surface-Water Modeling System (SMS 9.0) (Brigham Young University 2005).

downstream of the project site to limit boundary condition effects and better characterize flow distribution into the project site.

Table 1. Material types, Manning's roughness coefficients (n Values), and viscosity values for project area

Material Type	Manning's n Value	Turbulence (ft^2/s)
Channel	0.05 - 0.1	20
Pasture	0.08 - 0.1	50
Woods	0.1 - 0.12	50
Drainage Ditch	0.04 – 0.06	20
Road	0.04	20
Residential	0.1	50
Brush	0.1 - 0.12	50
Levee	0.08 - 0.1	50
Channel – low n value	0.03	20
Pasture overflow	0.08 - 0.1	50
Concrete culvert w/ gravel bed	0.02 – 0.03	20
Corrugated culvert w/ gravel bed	0.03	20

Under existing conditions, two important flow conditions should be noted. First, during floods larger than a 2-3-yr recurrence interval, more than half of the flood flow leaves the main channel upstream of OAR and flows in a northwest direction across the floodplain. This flow divergence occurs well upstream of the road crossing and will not be significantly altered by modifying the Old Arcata Road culvert, especially at flood flows greater than the 5-yr event. Second, out-of-bank flows occur along the left bank downstream of OAR, along the apex of the channel bend west of the house on the Hassrick property. Flood flow leaving the channel at this location is conveyed safely down the pasture without threatening any infrastructure, and returns to Rocky Gulch via a culvert and flapgate 300 ft upstream of the main Rocky Creek tidegate. Figures 8 and 9 show 2D model results for existing conditions for the 100-year flood event. Figure 8 is a plot of water depth and velocity vectors (scaled to magnitude), and Figure 9 shows water surface elevation and velocity vectors.

1.4 Summary of Existing Conditions

The existing OAR culvert is undersized, has become partially aggraded with fine sediments, and is a partial barrier to salmonid migration. The present undersized culvert configuration provides the downstream landowner (Ginni Hassrick) protection at lower flood recurrences by allowing only a portion of the discharge to pass through the culvert, but the channel downstream of OAR is narrow, unconfined, and encroached by vegetation and home structures, posing flood risks at higher flood recurrences. The undersized culvert also backwaters, and floodwaters leave the channel along the right bank, causing flooding on the upstream landowner's (Nathan Prather) property. Overbank flows flood across OAR at floods above approximately a 5-yr recurrence interval. The existing condition also constricts coarse sediment from routing through the culvert and replenishing the downstream reconstructed reach. Finally, the inboard ditch along OAR that drains floodwater through a secondary culvert back to Rocky Creek, may trap juvenile salmonids and other fish after floods recede.

2 TOPOGRAPHIC SURVEYS

Portions of the land within the project area had been surveyed in prior projects, but additional surveys were required. The Humboldt County Public Works (HCPW) Department collected topographic surveys on parcels adjacent to the culvert, and M&T crews collected topography, channel profile, and cross section data upstream to station 69+00 and downstream to the Rodoni property. The resulting topographic surface provided the basis for hydraulic modeling and conceptual designs (Figure 10). We also obtained and orthorectified the 2001 aerial photographs from the Humboldt Bay Harbor, Recreation, and Conservation District for use as a basemap (Figure 10).

3 HYDROLOGY

3.1 Methods

The U.S. Army Corps of Engineers Hydrologic Modeling System (HEC-HMS) was used to estimate flood discharges for the Rocky Gulch project area (USACOE 2000). HEC-HMS simulates the rainfall-runoff and routing processes for both natural and anthropogenic-controlled environments, and can be used for event or continuous modeling. HEC-HMS contains models for simulating water losses, runoff transformations, and open-channel routing, and different methods for the analysis and generation of meteorologic input data. For this analysis, the following models and methods contained in HEC-HMS were used: (1) infiltrative losses were modeled using the Natural Resources Conservation Service (NRCS) curve number method, (2) the transformation of excess rainfall into surface runoff was done with the NRCS unit hydrograph method using default settings, and (3) basin-wide precipitation was estimated using the NRCS 24-hour hypothetical design storms and 24-hour precipitation depths specified in the NOAA Atlas 2 for the Western U.S. Channel routing was not used in this analysis, but was incorporated into the time of concentration estimate. We developed simulated flood hydrographs for use in an unsteady 1D hydraulic model.

The Rocky Gulch project area was divided into three sub-watersheds consisting of the main Rocky Gulch creek, South Tributary, and North Tributary. Watershed boundaries and areas, creek lengths and slopes were determined from 7.5 minute USGS quad maps. General soil conditions were derived from Soil Vegetation Maps of California (USFS, 1975). NRCS curve numbers (CN) for each land use were determined from Chow et al. (1988), and the NRCS TR-55 Manual (1986).

Time of concentration (t_c) estimates for existing conditions in each sub-watershed were determined using the method described in the NRCS TR-55 manual. Since minimal stream gaging exists for Rocky Gulch, the lag time (t_{lag}) parameter used in the NRCS method was estimated from the calculated t_c using the suggested NRCS default ($t_{lag} = 0.6t_c$). Winter baseflow was included in the flood analysis for Rocky Gulch based on the flow duration curve. Winter baseflow was assumed equal to 3.1 cfs, which is approximately the 40% exceedence probability, and was distributed to each sub-watershed by drainage area ratios (Rocky Creek = 2.5 cfs, South Tributary = 0.5 cfs, and North Tributary = 0.6 cfs). Basin-wide precipitation input for HEC-HMS consisted of the NRCS 24-hour Type 1A hypothetical storm for the Pacific Northwest Region. Precipitation depths were determined from the NOAA 2 Atlas for the Rocky Gulch area. Table 2 summarizes the HEC-HMS input parameters for the Rocky Gulch project area. These data are available for the Q_2, Q_5, Q_{10}, Q_{25}, Q_{50}, and Q_{100} events, but not for the $Q_{1.5}$ event.

To evaluate the HEC-HMS results, flood frequency analysis was done using the USGS regional flood frequency relationships (Waananen and Crippen 1977), and the Lehre Method (Lehre 1997). The Lehre Method is an unpublished method adapted from Rantz (1964) which scales flood frequency estimates for a USGS stream gage. We used the discontinued USGS gage for Jacoby Creek (USGS 11480000 Jacoby C Nr Freshwater CA), a tributary to Humboldt Bay with a drainage area of 6.07 mi^2 above the gage, and a 10 year gaging record (1955-1964). The Lehre Method is based on Rantz (1964), but rather than using a regional regression equation derived from a number of stream gages, Lehre's (1997) adaptation relies solely on the USGS flood frequency estimates for the Jacoby Creek gage. In this method, peak flows for Rocky Gulch are scaled from Jacoby Creek flows using the ratios of both drainage area and mean annual discharge (1.80 cfs for Rocky Creek; 15.1 cfs for Jacoby Creek). Mean annual discharge for Rocky Gulch was estimated using mean annual precipitation depth (45 in) minus mean annual evapotranspiration depth (23 in), both from isohyetal maps in Rantz (1964). The result (excess rainfall depth) is then transformed to an outflow rate in cubic feet per second.

Table 2. HEC-HMS parameters for Rocky Gulch project area

Parameters	Unit	Rocky Creek	South Tributary	North Tributary
Watershed Area	(mi^2)	1.096	0.199	0.252
CN (weighted)		74.04	70.35	70.17
Percent Impervious	(%)	0.29	0.14	0.14
Initial Loss	(in)	0.701	0.843	0.850
Time of Concentration (tc)	(min)	156	88.4	76.3
Hydrograph Lag Time (tlag)	(min)	93.6	53.1	45.8
Winter Baseflow	(cfs)	2.5	0.5	0.6

3.2 Results and Discussion

The peak discharge estimates for the Rocky Gulch study area obtained from the HEC-HMS flood frequency analysis fell between the two regional estimates for all flood estimates except the Q_2 event (Table 3). We plotted the HEC-HMS peak discharges for the Old Arcata Road culvert (Rocky Creek and South Tributary combined) along with the USGS regional equations and Lehre method (Figure 11). Peak discharge hydrographs generated from the HEC-HMS analysis for the Old Arcata Road culvert were also plotted for the 2-yr, 10-yr, 25-yr, and 100-yr (Q_2, Q_{10}, Q_{25}, and Q_{100}) flood events (Figure 12).

The channel-forming discharge is the theoretical steady discharge that if maintained indefinitely, would produce the same channel geometry as the natural long-term hydrograph (Soar & Thorne, 2001). A single channel-forming discharge is useful in determining channel morphological characteristics and stable channel designs. For this study, the 1.5-yr recurrence flood was assumed equal to the channel-forming discharge (Leopold et al. 1964). Because the HEC-HMS results do not provide the 1.5-yr flood, we estimated this flood using a Log Pearson Type III distribution of the HEC-HMS flood frequency data (Figure 13). The 1.5-yr flood had a discharge value of 80 cfs for Rocky Gulch at Old Arcata Road (includes the South Fork, but not the North Fork). The 24-hr precipitation depth required to produce a peak discharge at Old Arcata Road of 80 cfs was 3.3 inches. The resulting 1.5-yr flood hydrograph is also shown on Figure 12.

Table 3. Peak discharge estimates for Rocky Gulch project area

Event	Precip. Depth[1] (in)	Rocky Creek (cfs)	South Tributary (cfs)	North Tributary (cfs)	Old Arcata Rd. Culvert[2] (cfs)	USGS Regional Eq. (cfs)	Lehre Method (cfs)
Q_2	3.7	92	15	20	107	137	108
Q_5	5.0	175	32	43	207	213	177
Q_{10}	5.5	210	40	53	250	284	225
Q_{25}	6.5	283	56	74	339	363	281
Q_{50}	7.3	345	69	92	141	439	323
Q_{100}	7.8	384	78	103	462	492	366

1) Precipitation depth for Rocky Creek watershed from NOAA Atlas 2,
2) Combined peak discharge from Rocky Creek and South Tributary hydrographs.

4 CONCEPTUAL DESIGN

Several meetings were held with landowners to discuss alternative design strategies and the implications of each strategy on channel dimensions and flooding. We considered three alternatives: (1) maintain a small OAR culvert to preserve existing conditions, (2) install a 100-yr flood culvert to pass all floods, and (3) upgrade to a medium-sized OAR culvert to reduce the frequency but allow some flooding along and over OAR. We judged each alternative based on improvements to fish passage, risk to property and infrastructure, and desirability to each of the landowners. Each design alternative is briefly described below.

4.1 Summary of Alternative Designs Considered

Design Alternative-1: This alternative would consist of replacing the OAR culvert with a similar-sized or slightly larger culvert that would maintain approximately the same flood conditions, in which the culvert causes a backwater and directs floodwater across the floodplain and down the drainage ditch along Old Arcata Road. The culvert would pass flood discharge up to approximately a 2-yr recurrence interval. During larger floods, floodwater would primarily flow along the OAR ditch and drain through the secondary culvert at the foot of Rocky Creek Road, but would continue to overtop OAR.

This design alternative is undesirable for several reasons. First, as was reported in the County's culvert assessment (Taylor and Associates 2000), the culvert is a partial barrier to salmonid migration because "excessive velocities occur in pipe at a moderate range of expected migration flows". Replacing the existing culverts with a similarly sized culvert would not necessarily resolve this problem. Second, the channel and culverts passing around the Hassrick property downstream of OAR are undersized and are a bottleneck to flow and sediment continuity between the upstream reaches (sediment sources) and the recently restored lower section of Rocky Creek. Third, the secondary flood channel along OAR may pose a stranding threat to young-of-year and juvenile salmonids; the more frequently that floods access this ditch, the higher the likelihood of stranding. Finally, this ditch acts as a sediment trap, becoming aggraded with fine sediment (sand and fine gravel), requiring frequent maintenance to maintain its capacity.

Design Alternative-2: This alternative was the design initially targeted by our analysis and landowner discussions, and was intended to enable a single-thread channel and adjacent floodplains to convey all flow up to the 100-yr flood through the OAR culvert and past Ginni Hassrick's residence. This alternative would eliminate the secondary flood channel and flooding over OAR, allow sediment to route downstream, and avoid risks of fish stranding and sedimentation in the inboard ditch along OAR.

There were several constraints that eliminated this alternative. First, upstream of OAR the creek is unconfined and slightly perched along this 600-800 ft section, which allows out-of-bank flow to drain away from the channel. In order to convey floodwaters to the OAR culvert, a new dike would be required to confine the floodplain for at least 500-700 ft or more upstream of the OAR culvert. This flood corridor would need to have the capacity to convey up to 445 cfs (our design 100-yr flood at the Old Arcata Road culvert). Second, downstream of OAR the constriction between Ginni Hassrick's garage and rental unit (45 ft wide) would require very large channel dimensions to convey the 100-yr flood (Figure 14). Engineered bank protection would also be required to prevent bank erosion and channel migration toward the rental house. The landowner was not supportive of these requirements in order to convey the 100-yr flood. Third, immediately downstream of the garage-rental constriction, floodwater would still flow out-of-bank along the left bank, and flow down onto the Rodoni pasture outside the newly reconstructed dikes, unless this left bank was confined by 200-300 ft of additional new dikes tied into dikes in the Rodoni pasture.

Design Alternative-3: This alternative would enlarge the OAR culvert and expand the channel capacity upstream and downstream of the culvert to convey approximately a 5-yr to 10-yr flood within the main channel, and minimal or no flow down the secondary flood channel. Material excavated to widen the channel upstream of the culvert would be spoiled on-site to construct a low-elevation berm that would help route floodwaters to the culvert. This configuration would restore sediment continuity of most sand and gravel, but would still maintain the secondary flood channel along OAR for larger floods. This would also reduce, but not eliminate, flooding over OAR. Enlargement of the secondary culvert at the foot of Rocky Creek Road may also help alleviate backwatering in the secondary flood channel and flooding over OAR. This design alternative would reduce flood risks for both landowners adjacent to OAR, greatly improve fish passage through the OAR culvert, and minimize flooding over OAR.

4.2 Description of Recommended Design Alternative

Based on our evaluation of these channel design configurations and discussions with landowners, we recommend Design Alternative-3 as the best approach to improve fish passage at the OAR culvert, restore channel capacity around the Hassrick property, and route floods through this residential area. Our hydraulic analysis of design conditions included only this alternative. We recommend the same general bankfull cross section dimensions used on the Rodoni project be extended up through the OAR culvert reach. By using the downstream cross section shape, the reach of channel through the culvert and around the Hassrick property will have the same channel-forming (bankfull) discharge design characteristics, which should improve flow and sediment continuity through the project reach. Figure 15 plots discharge versus channel slope for the typical design channel cross-section for different Manning's roughness conditions. We propose to extend the downstream design channel slope of approximately 0.0063 through the Hassrick property. At this slope, the proposed design channel (with inset floodplain) should convey approximately 170 to 210 cfs, which corresponds approximately to the 5-year peak flood discharge. The design cross section should have a bankfull channel width and depth of approximately 12.5 ft and 2.4 ft, with a floodplain bench occupying approximately 8 ft of width and set in approximately 1.5 ft below the pasture floodplain grade, for a total reconstructed channel width not to exceed approximately 20 ft. These are typical dimensions and the final as-built channel should incorporate topographic diversity (pools on outside of meander bend, shallow riffles, floodplain occupying the right bank upstream and left bank downstream of the downstream crossing etc.).

Humboldt County Public Works is currently proposing to replace the existing undersized culverts, both at Old Arcata Road and the downstream crossing on the Hassrick property, with a 16 ft x 5.25 ft corrugated arched box culvert at each crossing location. Due to anticipated infrastructure constraints, HCPW proposes to embed both culverts approximately 0.5 ft, and set both culverts at the design slope of 0.0063. We incorporated the HCPW culvert dimensions into our hydraulic models, and results are presented in Section 4.3 below.

In addition to the channel and culvert dimensions, we provide recommendations for several other design elements that were discussed and agreed upon with the landowners. These elements include (Figure 16):

- along the right bank upstream of OAR culvert: (1) remove berms confining the channel, (2) enlarge the channel to the recommended design dimensions for approximately 200 ft upstream of OAR, (3) rebuild small 2 ft high berm, set-back 50 ft from right bank, (4) remove old wooden retaining wall along the left bank just upstream of the culvert, and replace with Rock Slope Protection (RSP) to stabilize bank slope, (5) install rock overflow weir at head of OAR drainage ditch, and (6) revegetate new floodplain with native riparian vegetation.
- between the OAR culvert and the downstream crossing: (1) dispose of fill by building up the rental house driveway along the left bank, (2) excavate and relocate two cypress trees on the left bank downstream of the rental unit, (3) build a berm or floodwall along left bank from the driveway downstream past the rental unit, with top of berm elevation at or above 21.5 ft (NAVD88).
- below the downstream crossing: (1) widen the existing channel only along the left bank, and protect the right bank vertical undercut and the landowner’s fence and landscaping, (2) enhance the existing floodplain depression to convey overbank flow away from the channel along the left bank, (3) dispose of fill by building up the back yard grass area approximately 1-2 ft, and (4) remove or lengthen and raise wooden footbridge at station 57+75.
- downstream of the Hassrick property: (1) construct a smooth transition with the downstream reconstructed project reach so that the channel gradient, cross section dimensions, and floodplains merge naturally with the downstream reach.

Hydraulic analyses were conducted for existing conditions and for Alternative-3 channel designs, based on these design elements.

4.3 Hydraulic Analysis

The majority of the hydraulic analysis for this project used a one-dimensional (1D) hydraulic model, to develop existing flow conditions and evaluate the hydraulic effects of alternative design options within the project area. The existing conditions models represent land use, topography, and culvert conditions as they currently exist in the project area. Site topography was obtained from McBain & Trush and Humboldt County Public Works (HCPW). The recently restored lower portion of Rocky Creek is included in the existing conditions models. The design conditions model was developed to evaluate flooding upstream of OAR culvert, the proposed channel design around the Hassrick property, and the proposed HCPW culvert replacements for the OAR crossing and the downstream crossing on the Hassrick property. The design conditions model was used to analyze water surface elevations, water velocities, and flow distributions.

The 1D hydraulic model used for this analysis was the U.S. Army Corps of Engineers HEC-RAS modeling system (USACE, HEC 2002). The HEC-RAS model calculates (1D water surface profiles and average channel velocities for both steady, gradually varied flow, and unsteady flow through a network of channels. Both steady and unsteady modeling techniques were used for this analysis. Unsteady modeling was used to estimate effects from tidal conditions, flow splits, storage volumes, flood hydrographs, and culvert and weir flows on water surface elevations for both existing (pre-project) and design conditions. The unsteady model results were also used to provide boundary conditions and storage volume elevations for the steady model. The steady-state model was used to more rapidly assess project effects on peak floods and modified culvert hydraulics. During this analysis, problems with the HEC-RAS unsteady culvert routines were discovered that limited the ability and usefulness of the unsteady model to simulate different culvert options. These problems did not occur with the steady-state culvert routines. Reference can be made to the HEC-RAS manual for information specific to steady and unsteady modeling.

Both the steady-state and unsteady 1D models were used to estimate the effects of the proposed design elements on water surface elevations and water velocities through the project reach. The 1D steady-state and unsteady existing conditions models and design conditions models were run for the 1.5-year, 5-year, 10-year and 100-year flood events. The steady-state models were used to provide most of the results presented below. The unsteady model was used primarily to illustrate storage changes and provide boundary conditions for the steady-state models.

Study Area and Model Extent: The unsteady model reach extended from Humboldt Bay to approximately 300 ft upstream of Old Arcata Road. The unsteady model included channel flow, tidegate and tidal effects, storage areas, flow splits, and weir and culvert flow in a networked system. The steady-state model is a subset of the unsteady model with the model reach extending from approximately 2,000 ft downstream to 300 ft upstream of Old Arcata Road. The steady-state model includes the effects of channel flow, culvert and weir flow, and simple flow splits.

Topographic, Bathymetric and Flow Structure Data: Cross section and culvert data were obtained from channel cross section surveys, the 1-ft photogrammetry map provided by HCPW, and topographic surveys conducted by McBain & Trush. Model cross sections were typically extracted from digital surfaces using the SMS program, and directly incorporated into HEC-RAS. As necessary, channel survey data were inserted into specific cross sections in HEC-RAS. Storage area stage-volume relationships were developed from the site topography as required. Culverts and tidegates within the project reach were included in the HEC-RAS simulations as required. Culvert geometry and cross sections were obtained from field surveys and measurements.

Channel Parameters: Manning' roughness coefficients (*n*) were estimated based on prior modeling efforts and by field comparison of channel and overbank conditions with published color photos, descriptive data, and computed n values for stream channels found in Barnes (1967), French (1985) and Hicks and Mason (1991). The *n* values used in the 1D modeling are consistent with the values listed in Table 1. The default HEC-RAS contraction/expansion coefficients (contraction = 0.1, expansion = 0.3) were used for the 1-d steady-state model.

Discharge Values and Boundary Conditions: To analyze effects of the proposed project elements, the steady and unsteady models were run for different discharge conditions outlined in the hydrologic analysis (Section 3). For the steady model, the 1.5-yr, 5-yr, 10-yr, and 100-yr peak flood discharges for each tributary were analyzed (Table 4). For the unsteady model, the 5-yr, 10-yr, and 100-yr flood hydrographs were used in the analysis.

Downstream water surface elevations (boundary conditions) are required in order for HEC-RAS to generate water surface profiles. For the steady state model, the downstream boundary condition was determined from the unsteady model results (Table 4). For unsteady modeling, measured tidal elevations in Brainard Slough were used for the boundary condition.

Table 4. Discharge values and boundary conditions for steady-state model

Flood Event	Flood Discharge (cfs)		DS Boundary Condition WSE (ft – NGVD88)		Upstream Storage WSE (ft – NGVD88)	
	Rocky Creek	South Tributary	Existing Condition	Design Condition	Existing Condition	Design Condition
1.5-year	70	11	8.26	8.39	14.9	14.0
5-year	175	32	9.05	8.66	18.6	15.3
10-year	210	40	9.26	8.77	18.7	17.0
100-year	384	78	9.62	9.64	19.0	18.8

4.4 Hydraulic Model Results and Discussion

4.4.1 Discharge at Old Arcata Road

An important goal of the project is to improve flow conditions in Rocky Creek within the project reach. The recommended design alternative would enlarge the channel capacity upstream and downstream of the OAR culvert, and enlarge the culvert capacity at Old Arcata Road and the downstream crossing on the Hassrick property. Table 5 summarizes 1D steady-state model results for the expected change in discharge conditions from implementation of the proposed alternative. For all modeled cases, the proposed design elements would increase flows through the Old Arcata Road culvert and in the channel through the Hassrick property. As a result more flow would overtop the left bank downstream of Old Arcata Road and flood into the pasture. This flood condition is desirable because there is no infrastructure at risk, this flood bypass will help protect the newly constructed floodway from extreme flood events, and the duration of overbank flood events is quite brief. We recommend enhancing the topography along the left bank to form a flood overflow swale (Figure 16) that would convey floodwater down the pasture to the north. Several pasture drainage ditches convey floodwater back to Rocky Creek at the station 9+00 flapgate.

The 1D steady-state model could not accurately assess overbank flows and the flow divergence that occur upstream of Old Arcata Road. This is a limitation of 1D modeling compared to 2D modeling. Consequently, the 1D model results indicate more discharge through the Old Arcata Road culvert than would probably occur, simply because the entire flood flow does not reach the culvert. This analysis therefore provides high estimates of water surface elevations downstream of Old Arcata Road through the Hassrick property, which can be considered conservative when assessing flood effects of the project.

At the 1.5-yr flood stage, the primary change to existing conditions is that overbank flow from the left bank downstream of OAR and the houses is eliminated, and the entire flood flow is conveyed to the downstream restored reach on the Rodoni property. At the 5-yr flood stage, in addition to retaining most of the total discharge within our design channel cross section (with inset floodplain) downstream of OAR, the restored upstream channel would convey the entire 5-yr flood discharge to the OAR culvert. This is an important threshold, because floods in the range of 2-5 yr recurrence are critical to sediment transport processes. At the 10-yr flood stage, most flow is still routed to the OAR culvert, but the proportion of flow leaving the left bank downstream of OAR increases to approximately 34% of total discharge. The main reason overbank flooding is currently so low at this location is because the discharge does not reach this location with the existing undersized culverts. Modeling results show that between the 10-yr and 100-yr flood, the channel upstream of the OAR culvert loses discharge to the floodplain, and floodwater flows northwest across the pasture similar to existing conditions.

Table 5. Expected discharge changes from project design elements. Overbank discharge upstream of Old Arcata Road flows down the secondary flood channel to the secondary culvert. Overbank discharge downstream of Old Arcata Road flows north down the Rodoni pasture drainage ditches.

		Overbank Discharge Upstream of Old Arcata Road (cfs)		Discharge Through Old Arcata Road Crossing (cfs)		Overbank Discharge Downstream of Old Arcata Road (cfs)	
Flood Event	Flood Flow (cfs)	Existing Condition	Design Condition	Existing Condition	Design Condition	Existing Condition	Design Condition
1.5-year	80	0	0	80	80	10	0
5-year	207	110	0	97	207	25	70
10-year	250	147	1	103	249	29	105
100-year	462	200	67	262	395	165	229

4.4.2 Steady-State Water Surface Profiles

We analyzed water surface profiles through the project reach for the 1.5-yr, 5-yr, 10-yr and 100-yr flood flows, respectively (Figures 17-20), and cross-section plots and water surface elevations for selected sections within the project reach downstream of Old Arcata Road for the 5-yr and 100-yr flood event (Figures 21-26). The modeling cross section locations are indicated in Figure 10. For the 1.5-yr flood event the proposed project substantially lowers water surface elevations through the design reach due to the increased channel dimensions and the increased culvert capacities. However, for the 5-yr, 10-yr, and 100-yr flood flows the design condition water surface elevations are either slightly below or slightly above existing conditions within the design reach downstream of OAR. It appears that the transition in water surface elevations occurs at the downstream crossing within the Hassrick property. Our analysis indicates that water surface elevations are substantially reduced upstream of Old Arcata Road due to the increased channel and culvert dimensions.

In general, it appears that water surface elevations should remain approximately the same downstream of Old Arcata Road, despite the increase in flows from the project (Table 5). The primary benefit of the project will be improved conveyance with the more frequent flood events in the range of 1 to 5-yr recurrence. During these flood events, most of the flood flows will pass through the culvert and stay within the channel and inset floodplain through the Hassrick property. During larger flood events, water surface elevations downstream of OAR will be similar to existing conditions. However, upstream flood levels will be lower. For floods greater than a 5-year recurrence, overbank flooding will continue to occur along the left bank downstream of the Hassrick residential structures. Our design proposes to modify the left bank and enhance the existing shallow swale to convey floodwater away from the channel and down the pasture, as a way to control overbank flooding in this location.

4.4.3 Improved Channel and Flow Conditions at the Bankfull Discharge

A key component of the Rocky Creek channel design is not only to improve flow conditions, but also improve sediment routing through the project reach. Transport of coarse sediment through this reach is an important mechanism for maintaining the newly restored channel on the Rodoni property. To demonstrate the improved geomorphic condition, we estimated channel velocities and channel shear stress from the 1D steady-state model at the approximate bankfull discharge of 80 cfs (Figures 27 and 28). The restored channel and upgraded culverts generally increase and equalize channel velocities through the project reach. The channel and culvert improvements should slightly lower shear stress through the project reach, but more importantly, should provide uniform shear stress between the project reach and the recently restored lower reaches on the Rodoni property. An important item to note is the increased shear stresses upstream of the Old Arcata Road culvert for the design condition. The proposed project should improve sediment and flood routing conditions in Rocky Creek at the Old Arcata Road crossing and through the Hassrick property.

5 RECOMMENDATIONS

The following recommendations are provided for Humboldt County Public Works as they move forward with implementation of the proposed project.

- Discuss all final design features with adjacent landowners, including potential flood stages relative to their property structures, the final channel dimensions and layout, and the 16 x 5.25 ft culverts proposed by Humboldt County Public Works.
- Construct a smooth transition at the tie-in between the existing downstream restored channel and the proposed upstream channel, especially between channel and floodplain flow transitions.
- Construct a smooth transition upstream and downstream of the proposed culvert upgrades.
- Provide bank and channel erosion protection downstream of the proposed culvert upgrades.
- Provide bank and channel erosion protection in areas of high shear stresses and velocities, and/or provide bank protection along the entire restored channel.
- Improve flood overflow conditions along the left bank floodplain on the Hassrick property downstream of the residences.
- Provide micro topography within the restored channel to improve habitat conditions, such as pool features within the channel bend.
- Over-excavate the bottom of the channel 1 to 2 ft at selected locations, and backfill with appropriate river run gravels and/or spawning gravels to design grade.
- Develop and implement re-vegetation plans for both properties upstream and downstream of Old Arcata Road.
- Allow McBain & Trush, Inc. and Jeff Anderson & Associates to review final design and construction drawings prior to project implementation.

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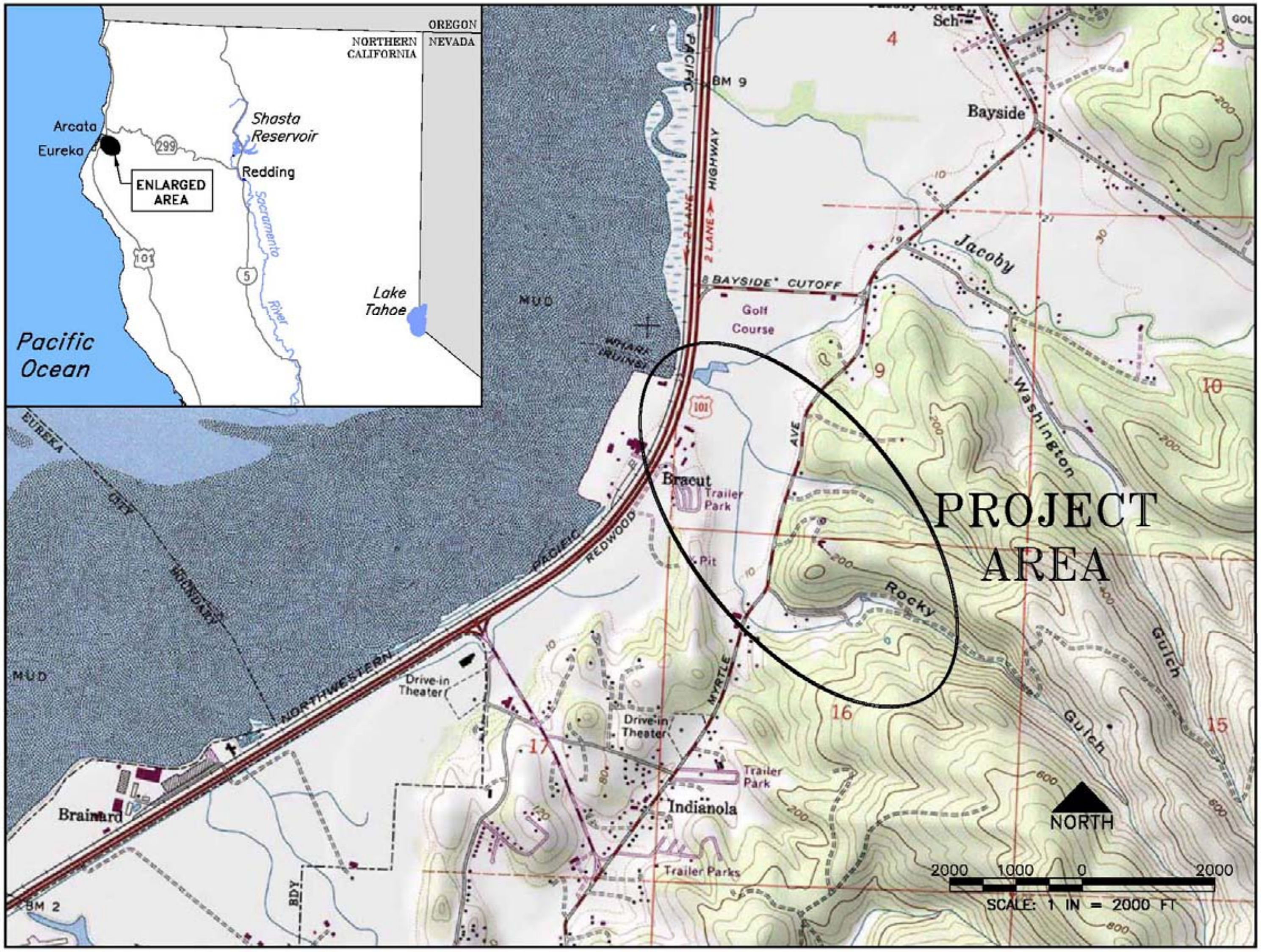

Figure 1. Location of Rocky Gulch project area. The intersection of Rocky Creek with Myrtle Avenue (Old Arcata Road) is the focus of this project.

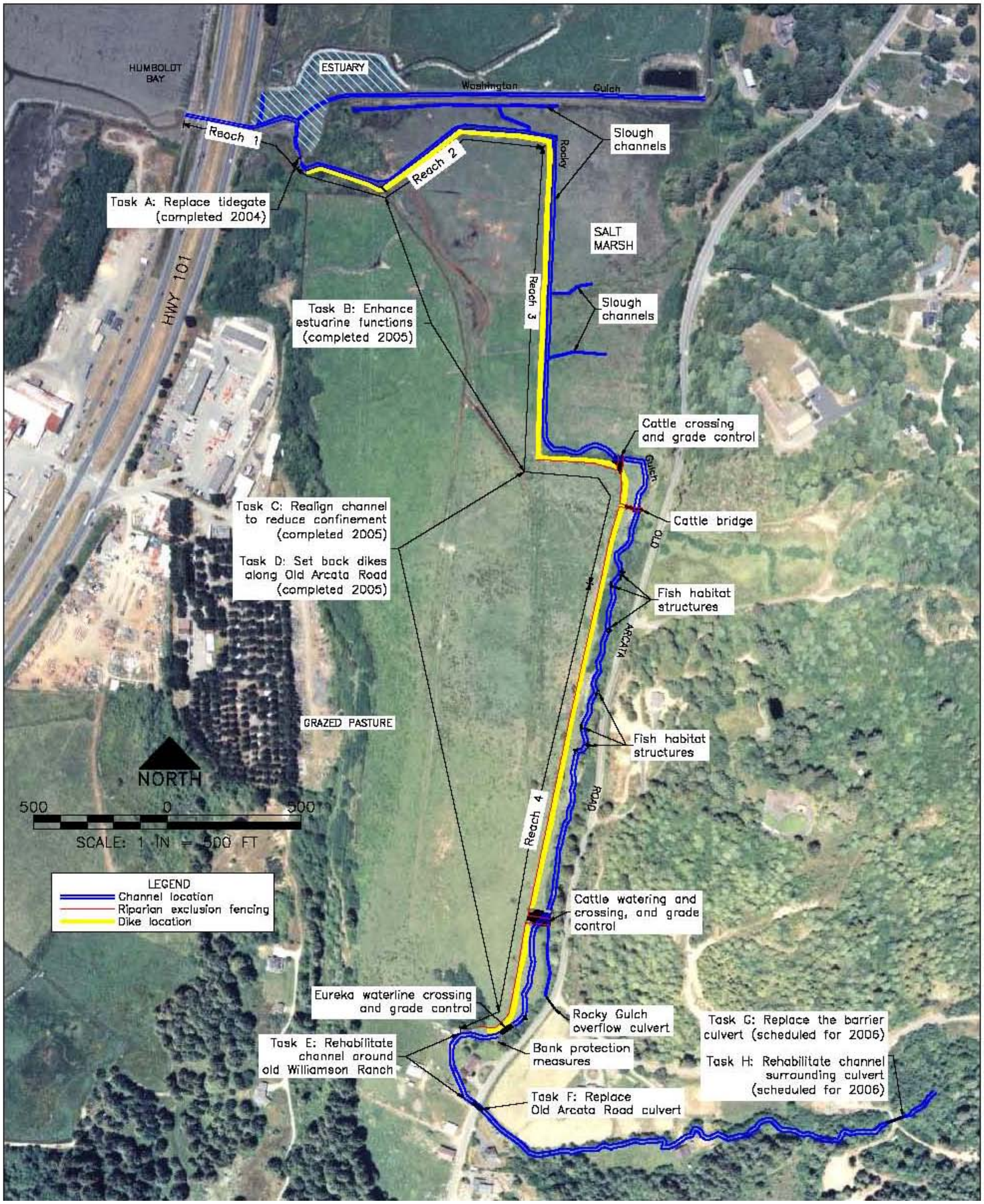

Figure 2. Proposed conceptual design for the anadromous section of Rocky Gulch, developed by McBain & Trush, Inc and CDFG during the initial Stream Assessment Project.

Figure 3. Residential parcels along Old Arcata Road surrounding the project area.

Figure 4. Downstream view of main channel and twin culverts passing under Old Arcata Road. The second culvert is underwater in this photo.

Figure 5. Floodwaters overtopping Old Arcata Road during the November 1998 flood. Photograph taken at the foot of Rocky Creek Road looking south. The main channel is in the distance; the secondary culvert entrance is in the foreground.

Figure 6. The downstream crossing culverts on Ginni Hassrick's property. The culverts were installed by a previous landowner, and are too small to convey large floods.

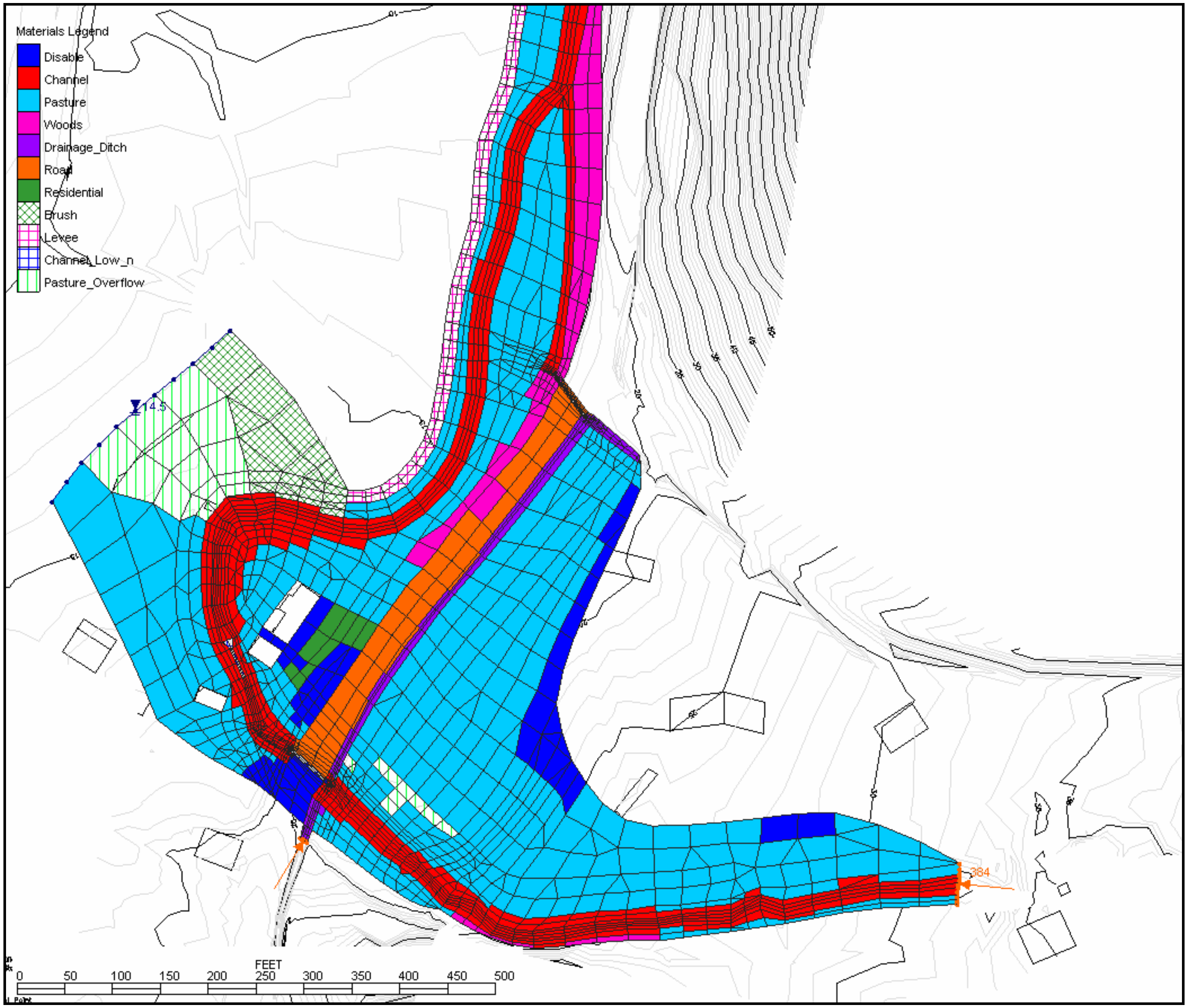

Figure 7. Plan view of material types and mesh for 2D modeled project area.

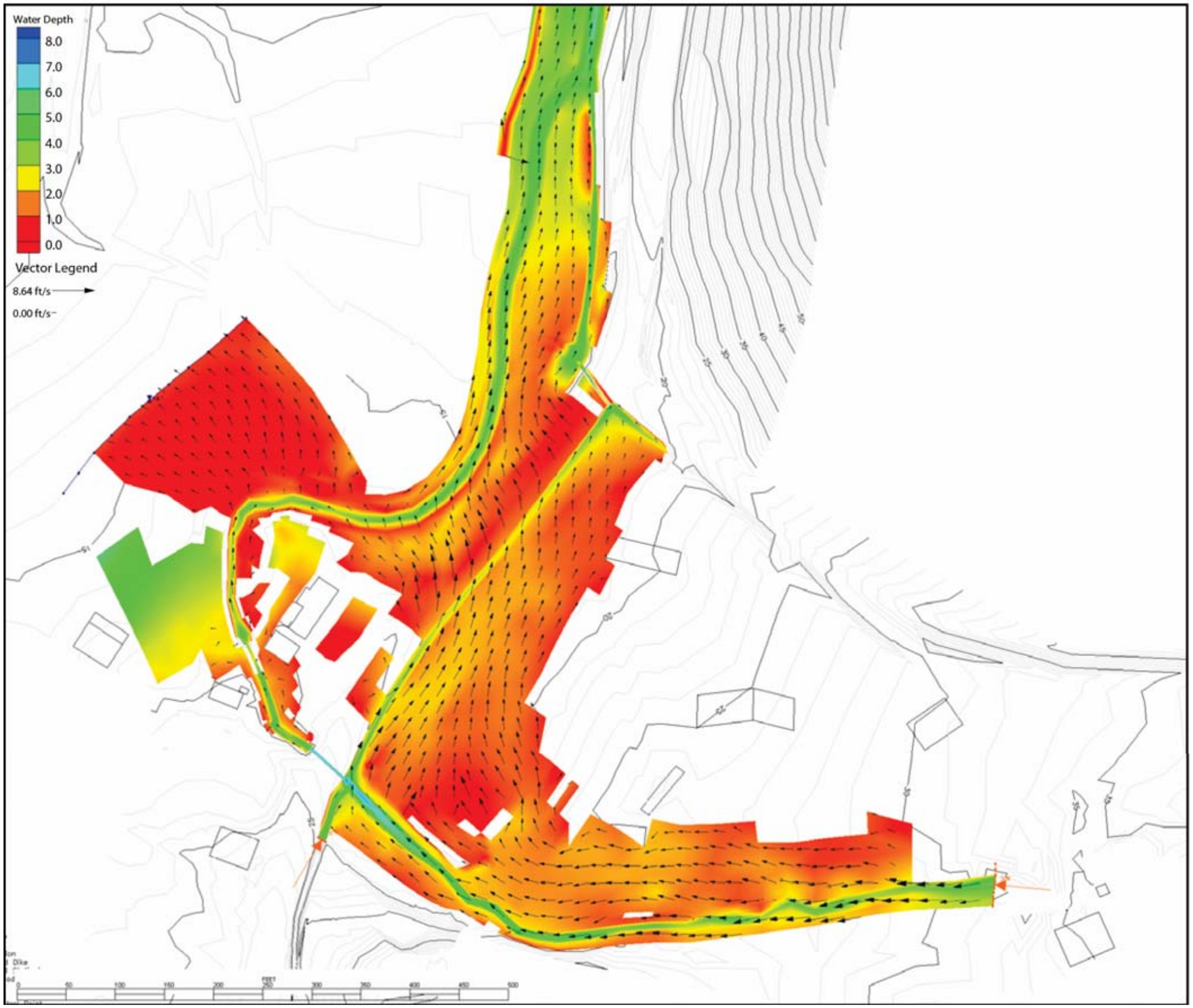

Figure 8. Preliminary 2D model results for depth and velocity vectors at 100-yr flood (Q100 = 445cfs).

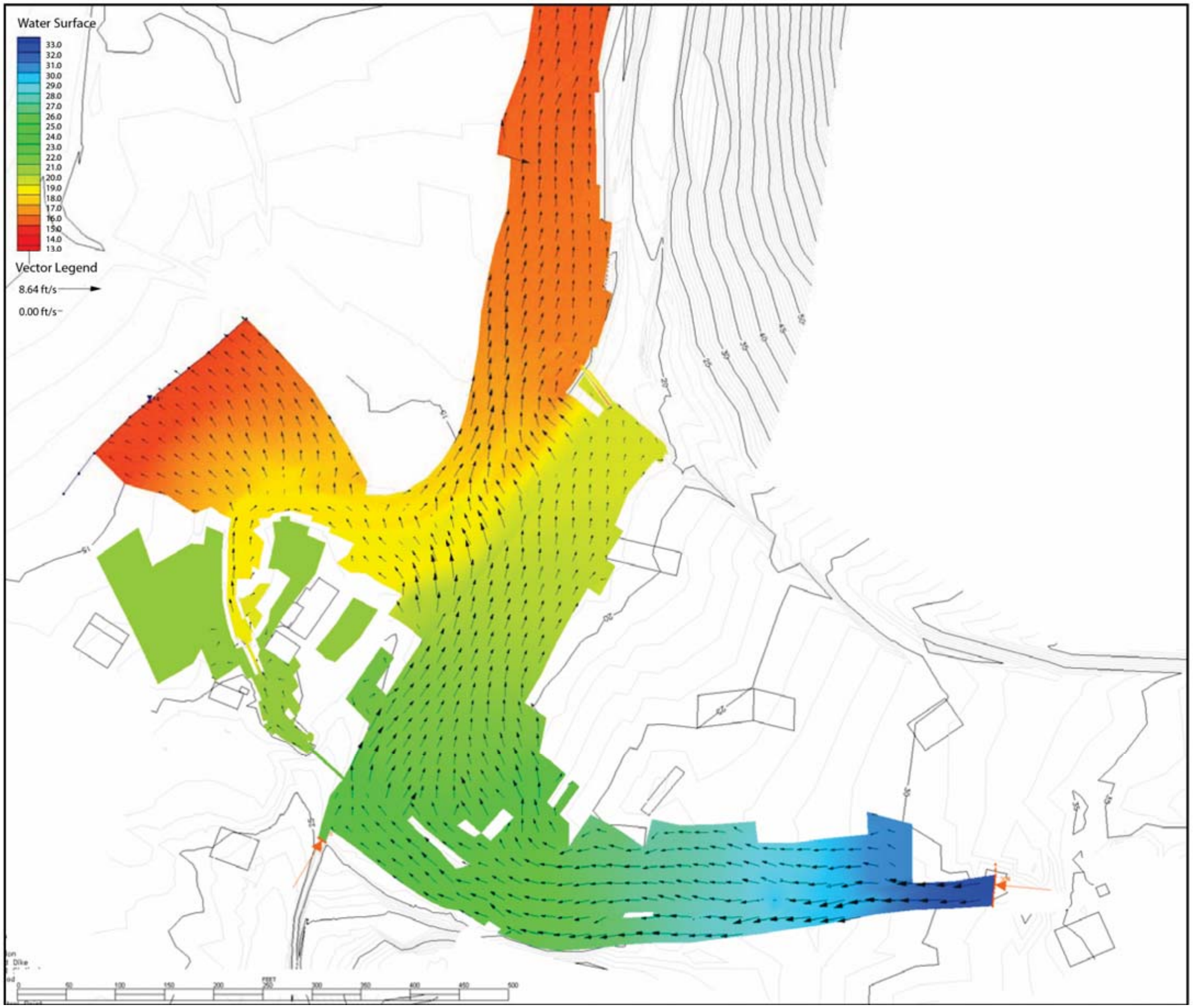

Figure 9. Preliminary 2D model results for water surface elevation and velocity vectors at 100-yr flood (Q100 = 445cfs).

Figure 10. Contour map showing the project boundaries and extent of topographic surveys conducted for the project conceptual design and hydraulic modeling.

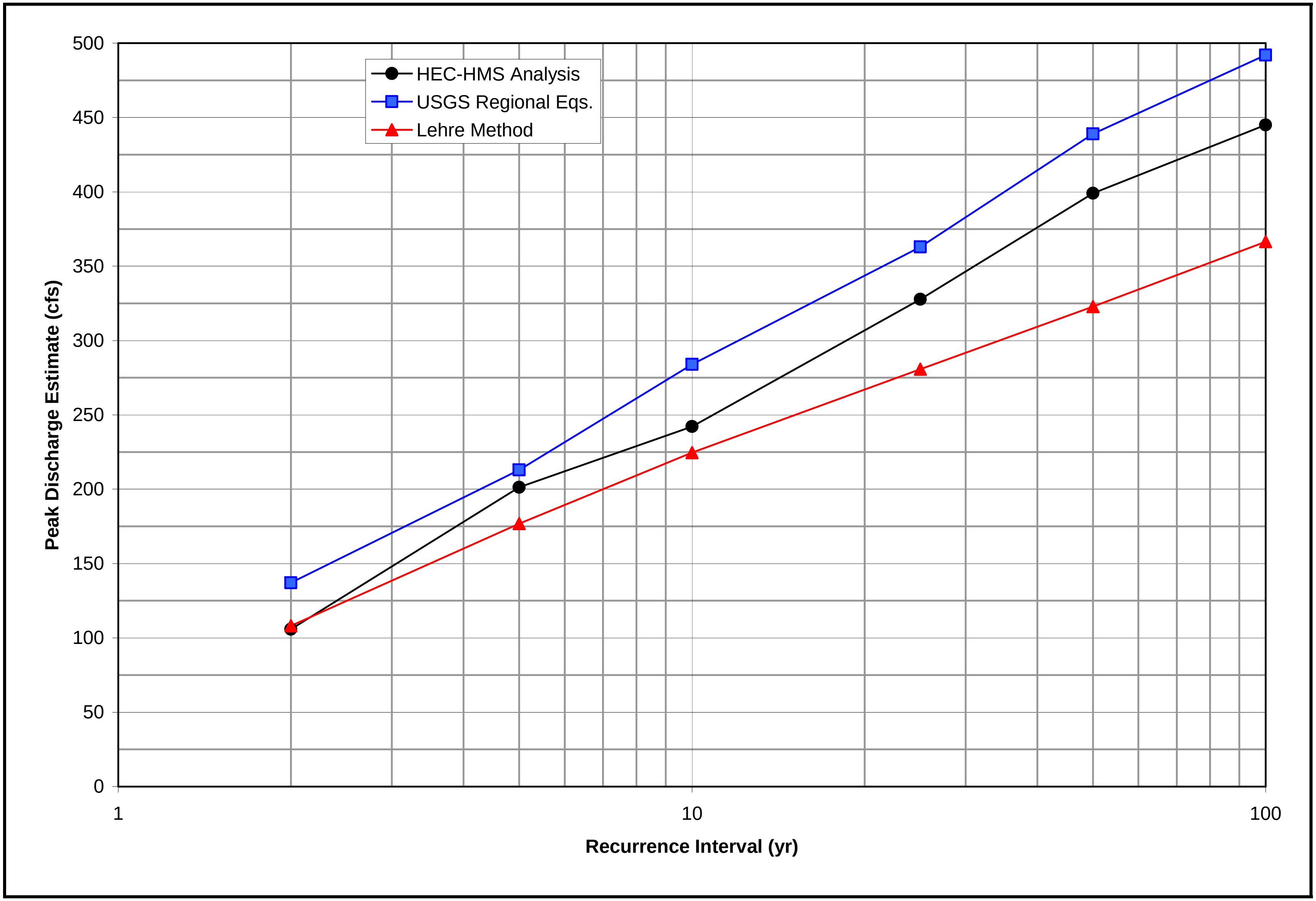

Figure 11. Peak flood discharge estimates for Rocky Gulch project area.

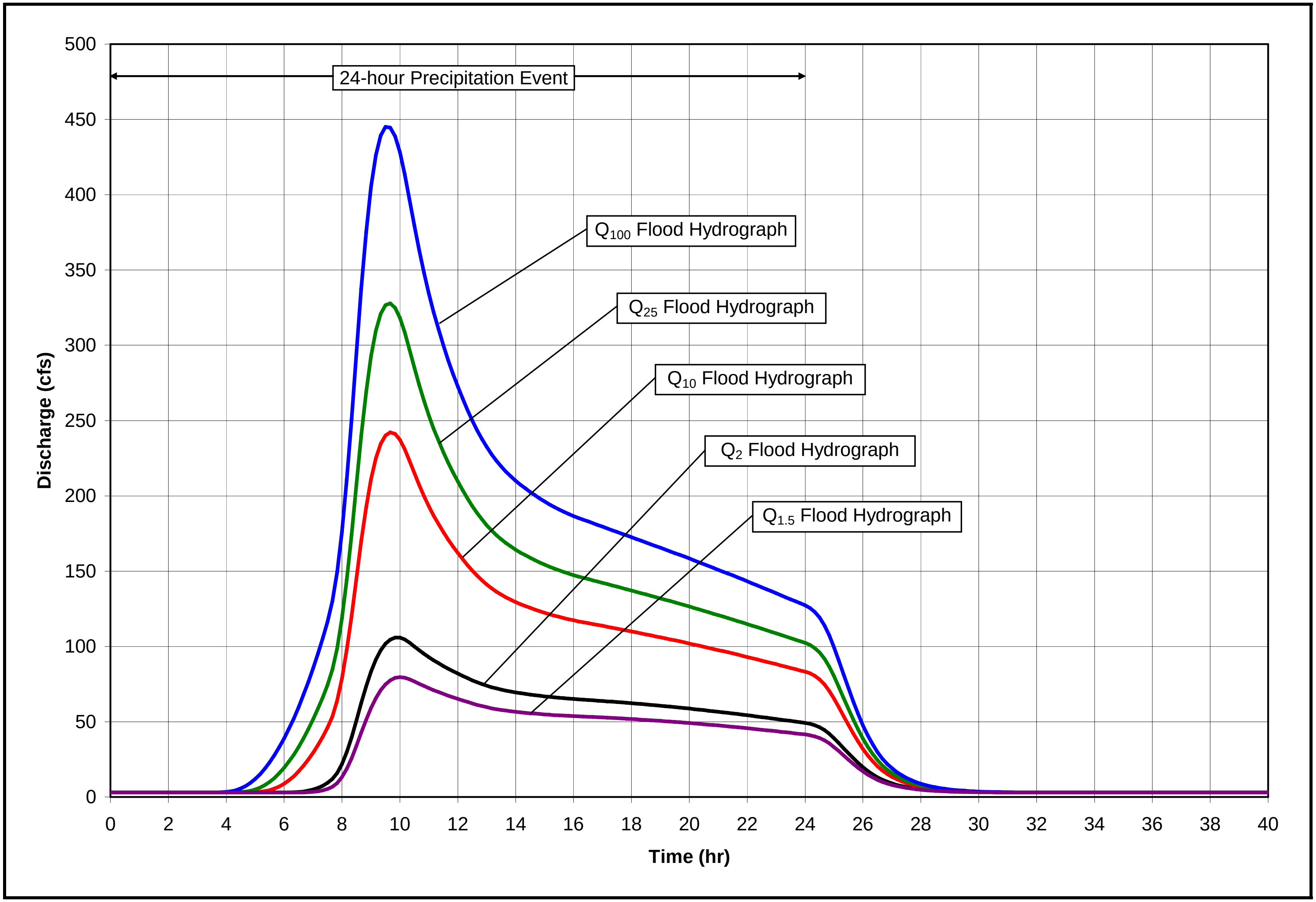

Figure 12. Flood hydrographs at Old Arcata Road Culvert.

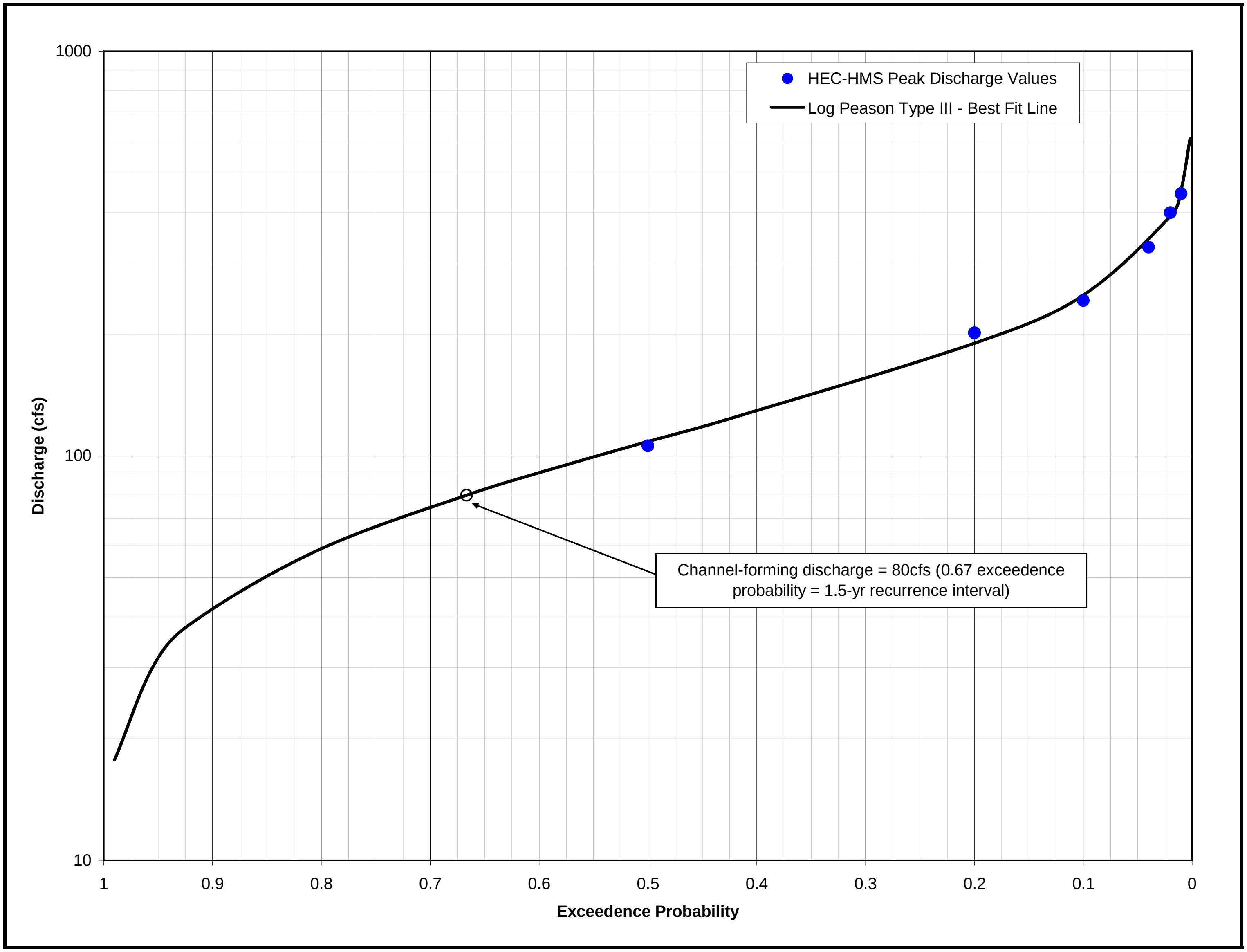

Figure 13. Best fit Log Pearson Type III distribution for the estimated HEC-HMS peak discharge events.

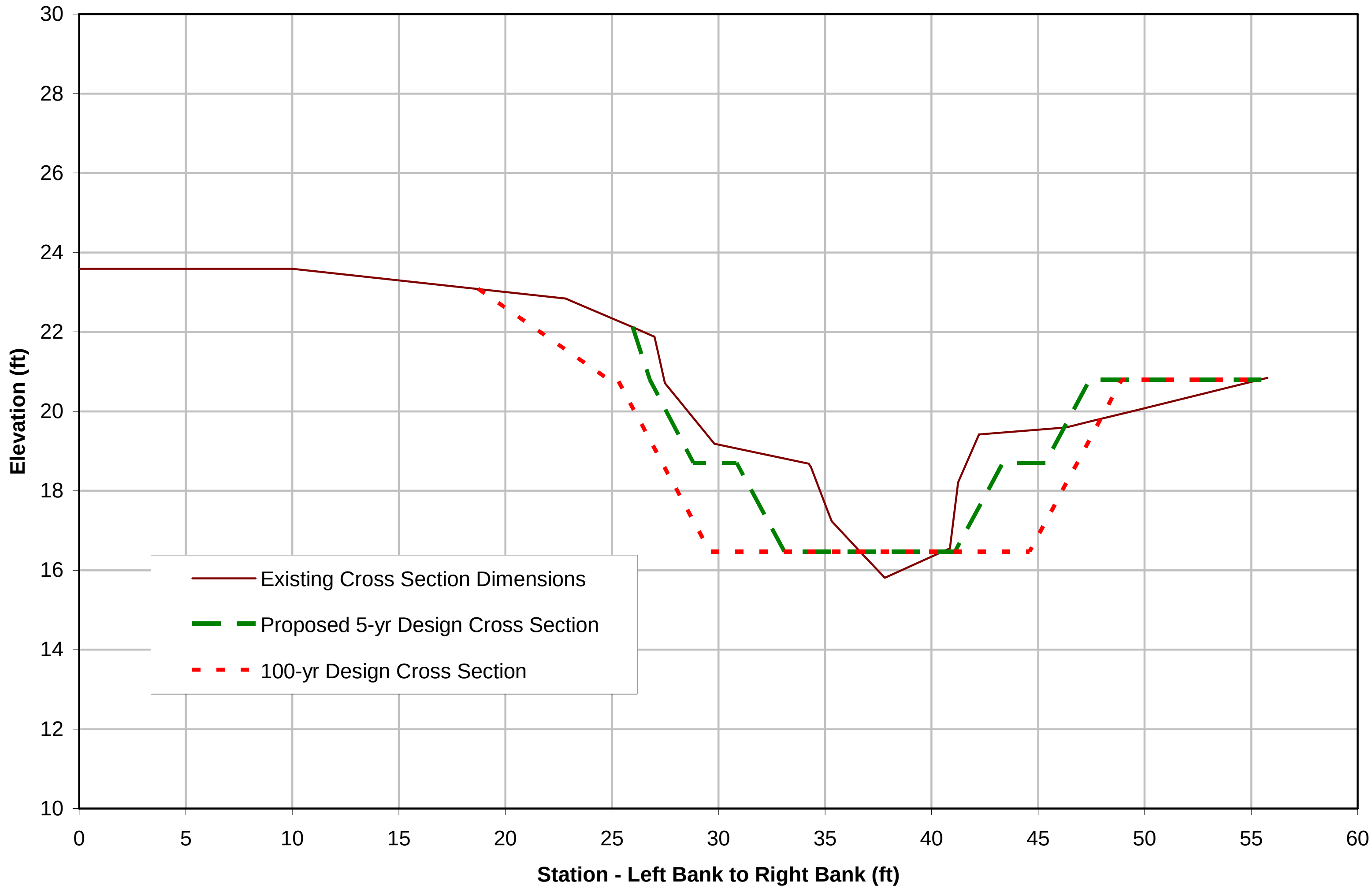

Figure 14. Cross section dimensions of the existing channel, the proposed 5-yr design channel, and an example cross section that would pass the 100-yr flood.

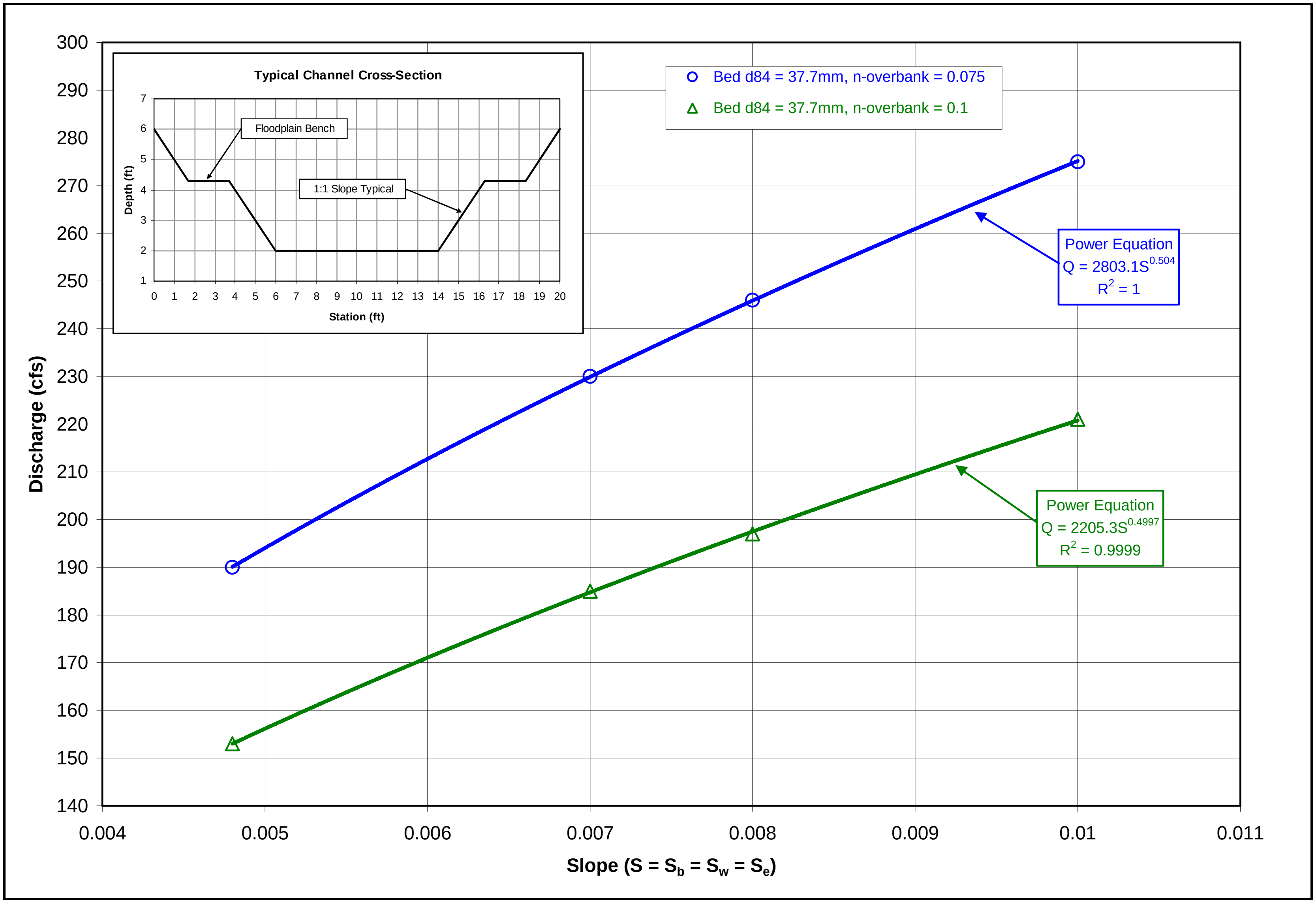

Figure 15. Proposed design channel discharge versus slope at uniform flow for different Manning's roughness conditions.

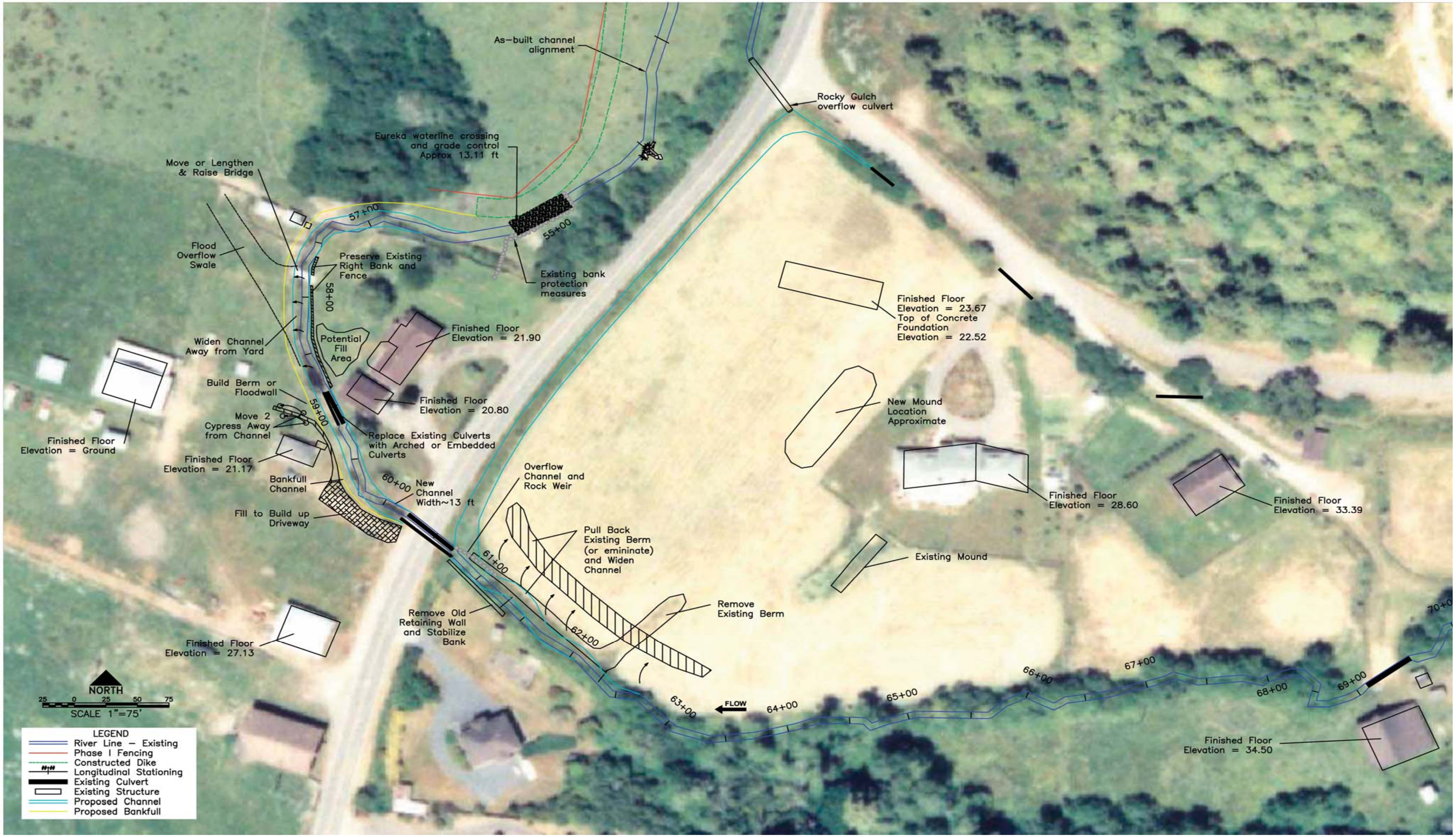

Figure 16. Conceptual design elements for the project area, including parcels upstream and downstream of the Old Arcata Road culvert.

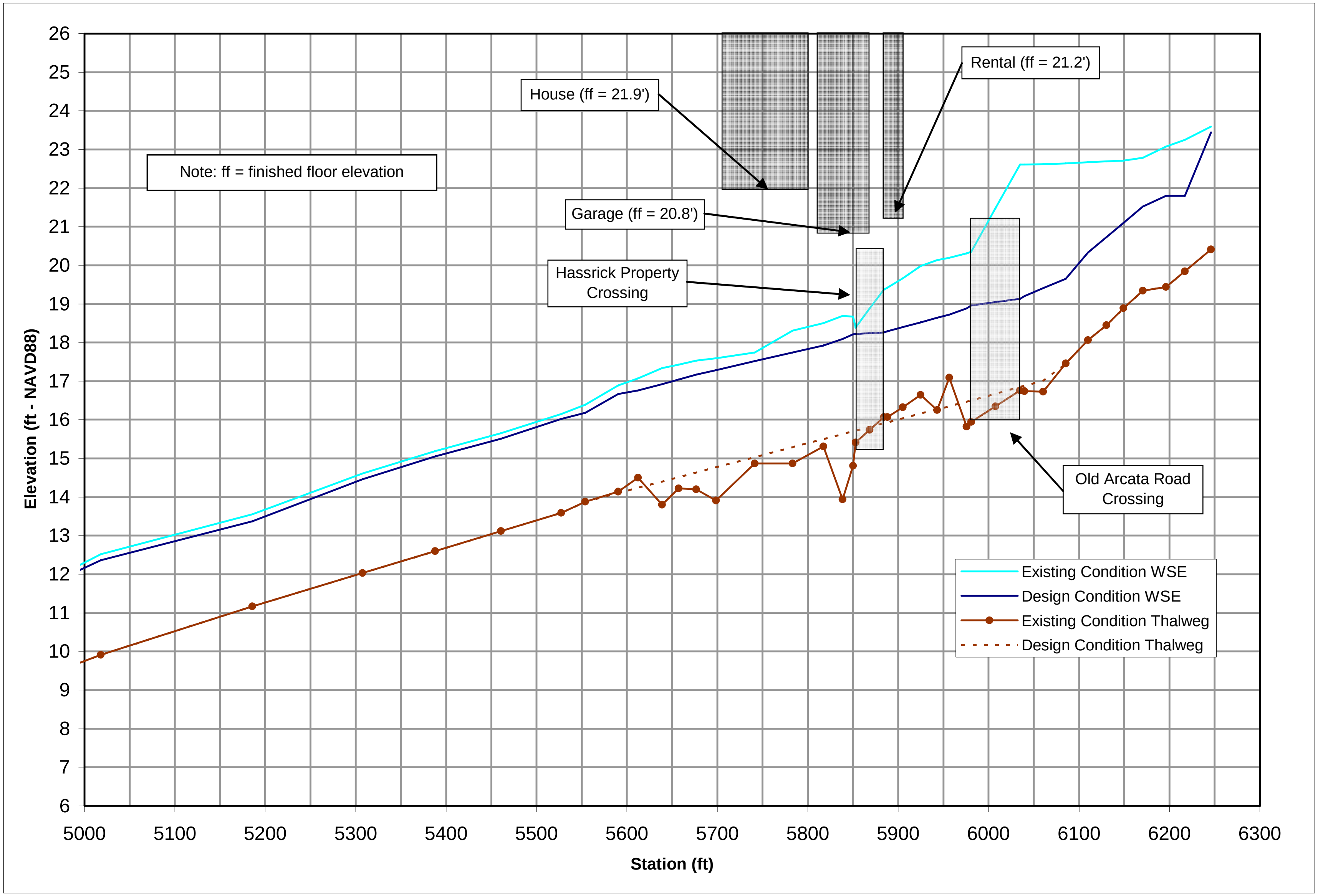

Figure 17. Profile showing existing and design condition water surface elevations (WSE) at 1.5-yr flood (80cfs).

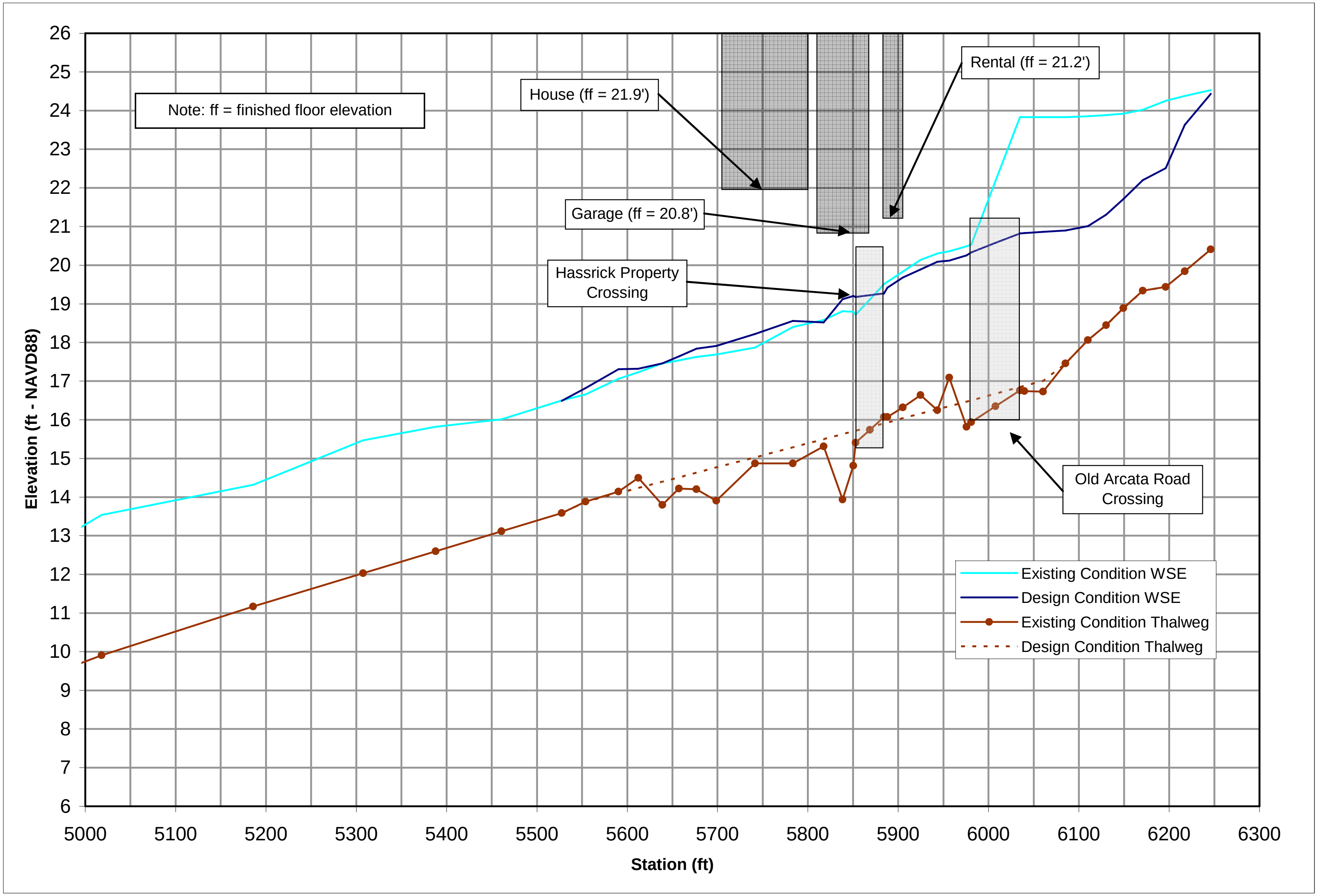

Figure 18. Profile showing existing and design condition water surface elevations (WSE) at 5-yr flood (201cfs).

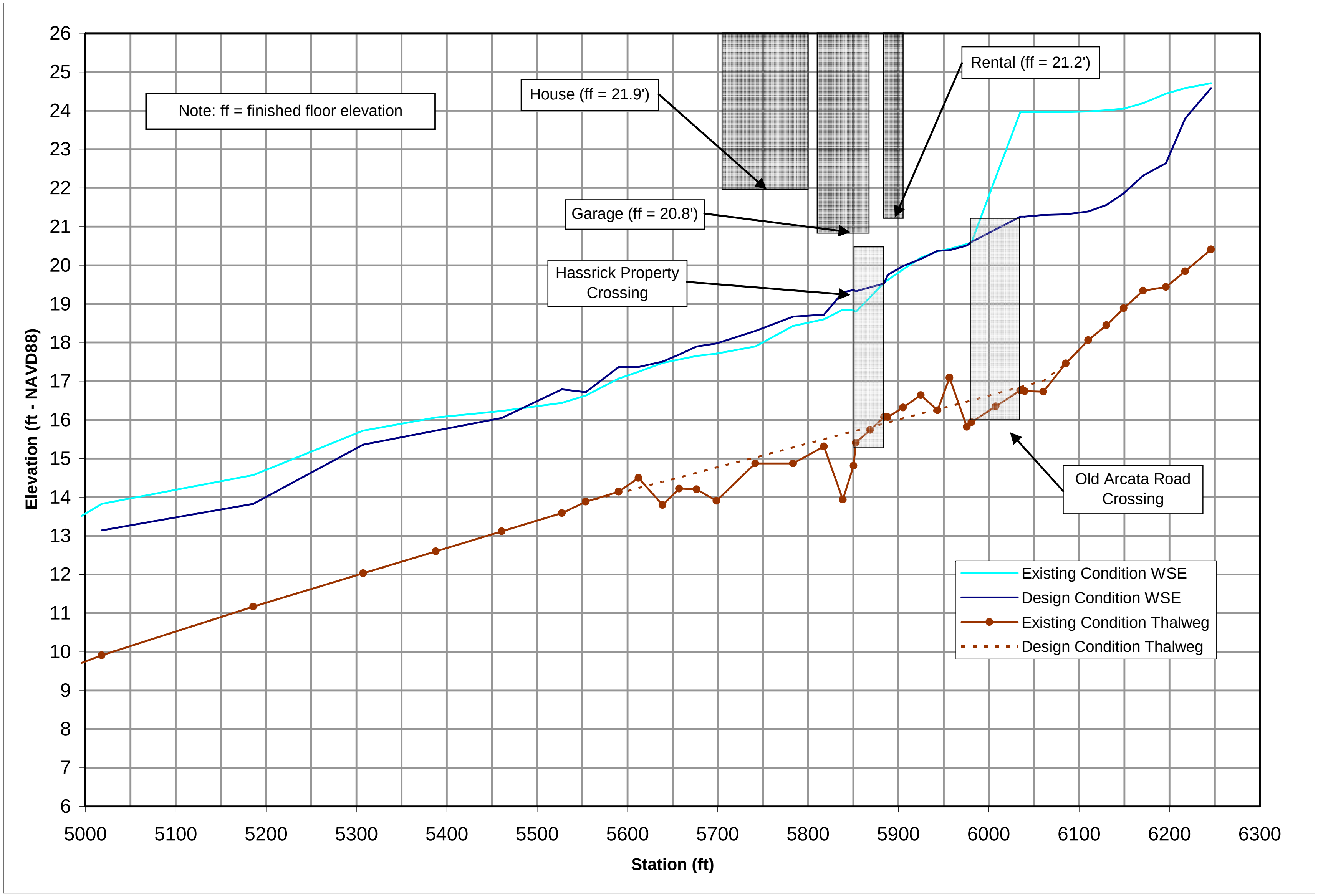

Figure 19. Profile showing existing and design condition water surface elevations (WSE) at 10-yr flood (242cfs).

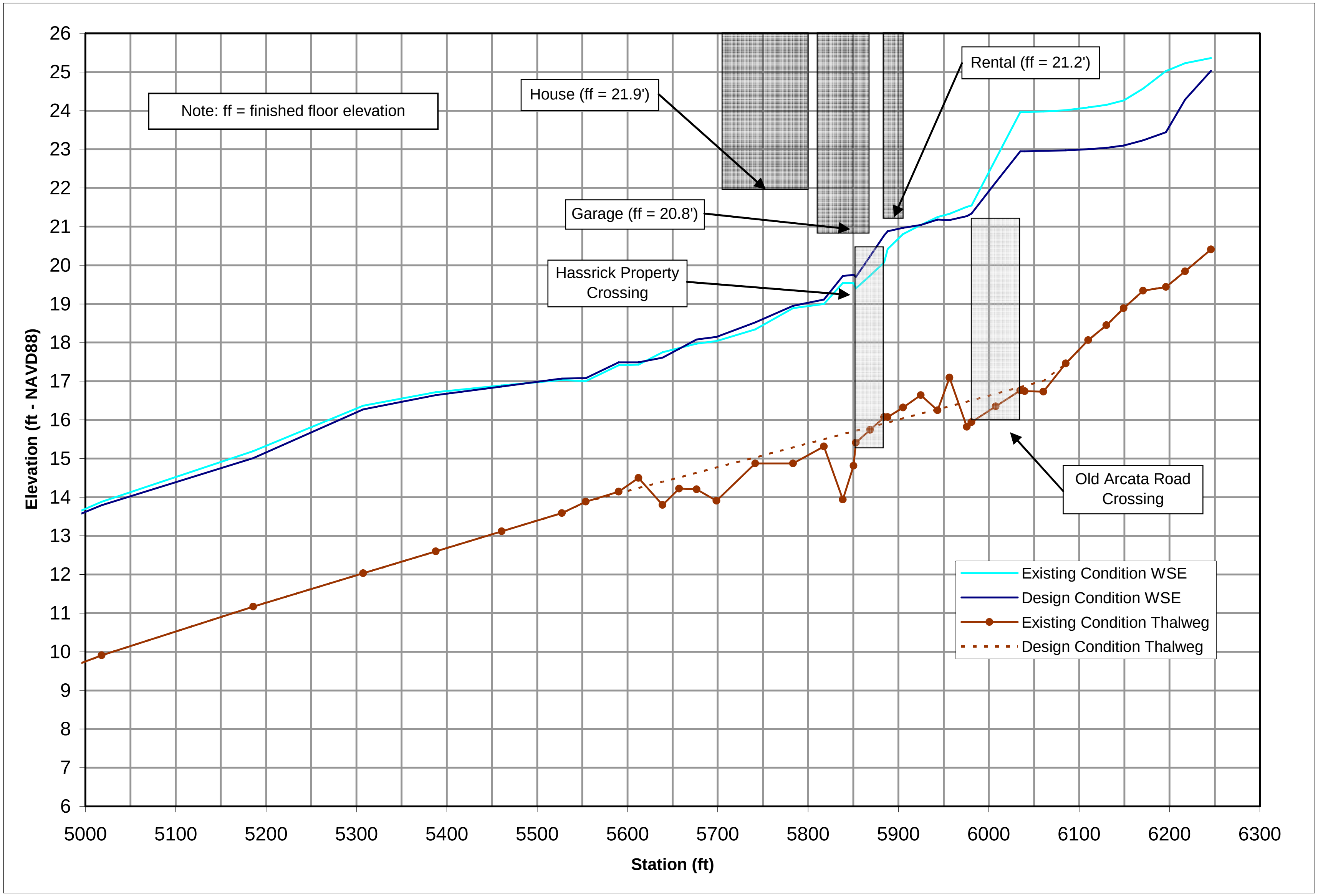

Figure 20. Profile showing existing and design condition water surface elevations (WSE) at 100-yr flood (445cfs).

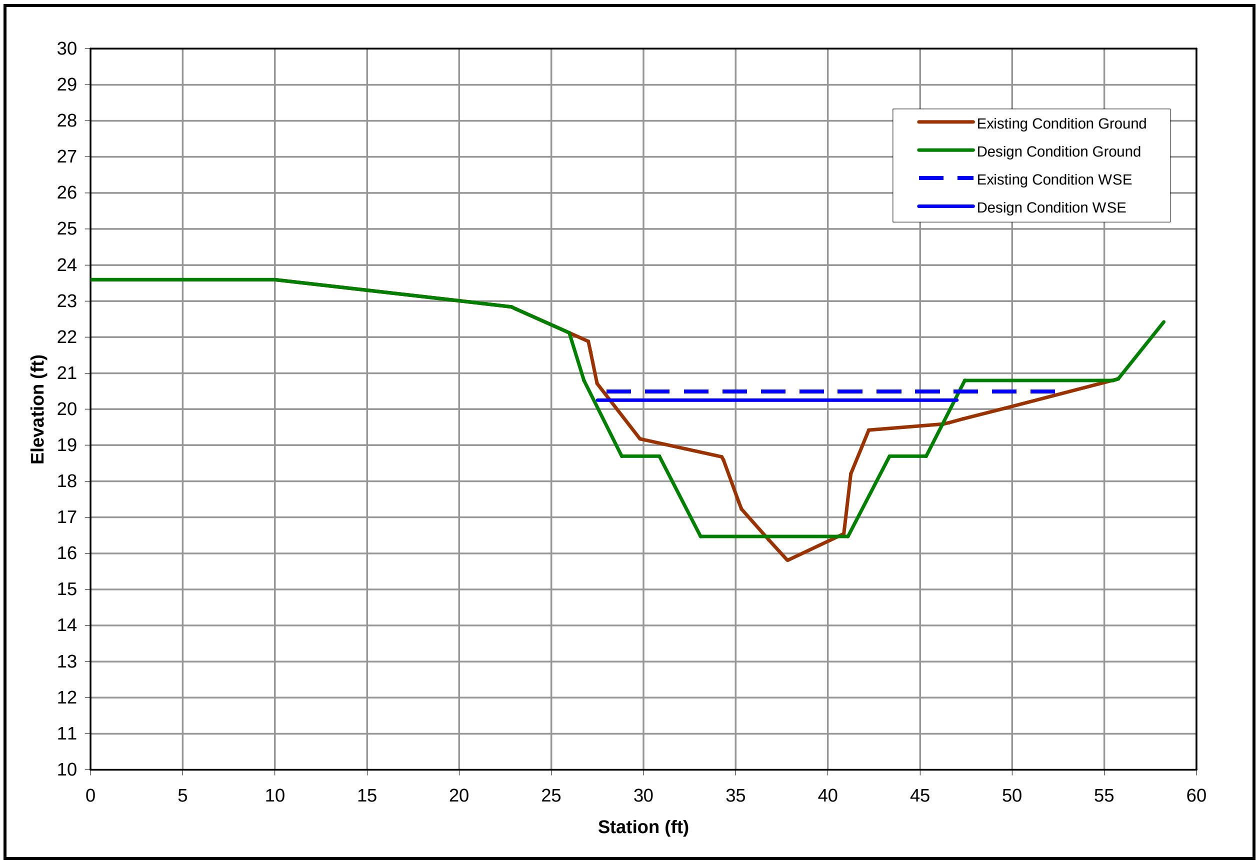

Figure 21. Cross-section 5975 showing existing and design condition water surface elevations (WSE) at 5-yr flood (Q5 = 201cfs). See Figure 10 for cross section locations.

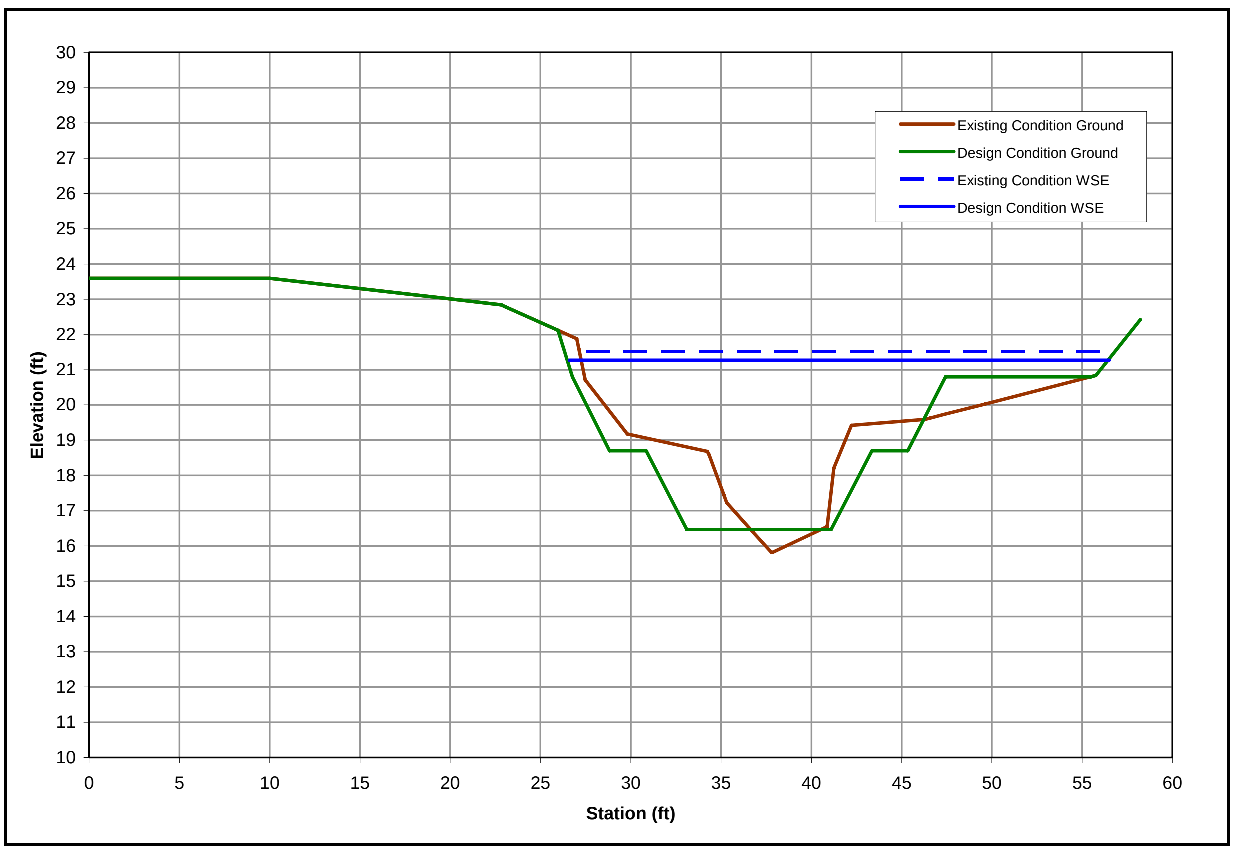

Figure 22. Cross-section 5975 showing existing and design condition water surface elevations (WSE) at 100-yr flood (Q100 = 445cfs). See Figure 10 for cross section locations.

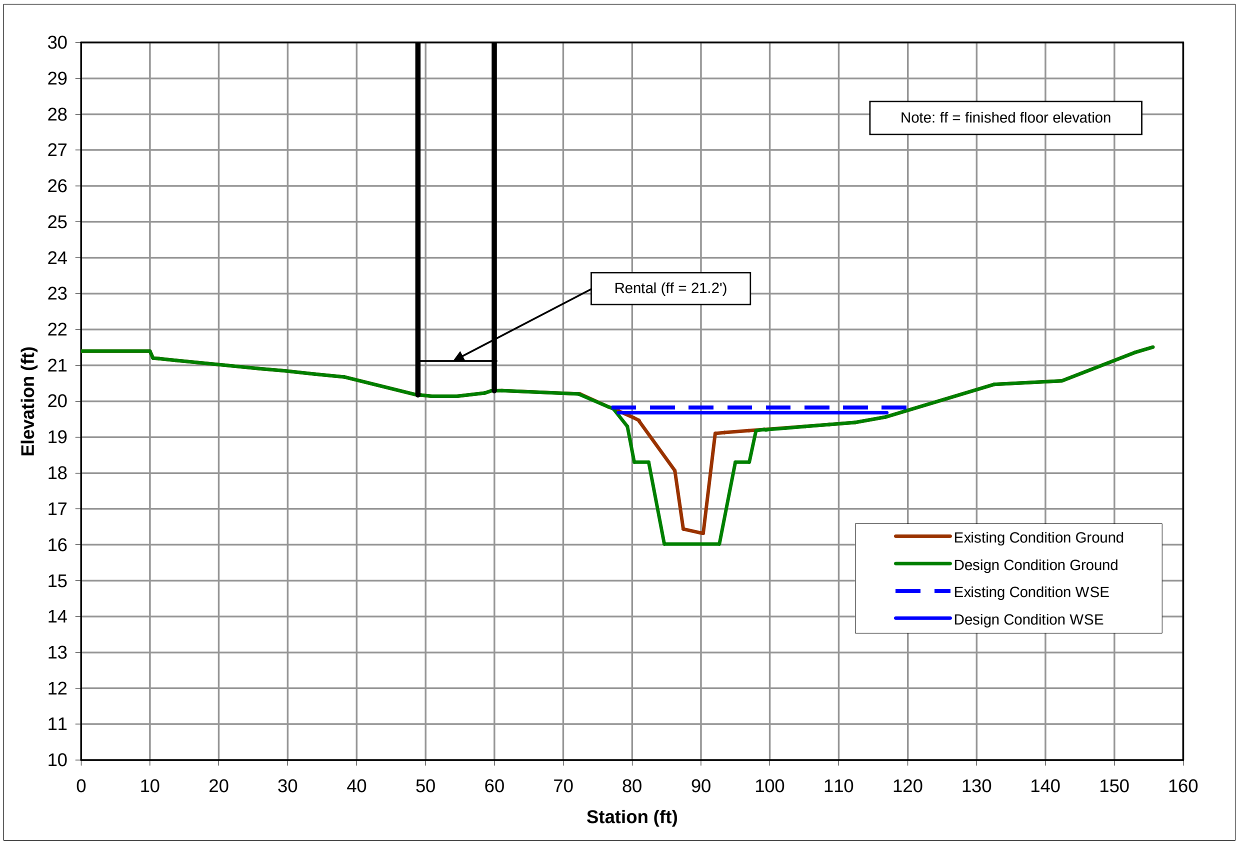

Figure 23. Cross-section 5905 showing existing and design condition water surface elevations (WSE) at 5-yr flood (Q5 = 201cfs). See Figure 10 for cross section locations.

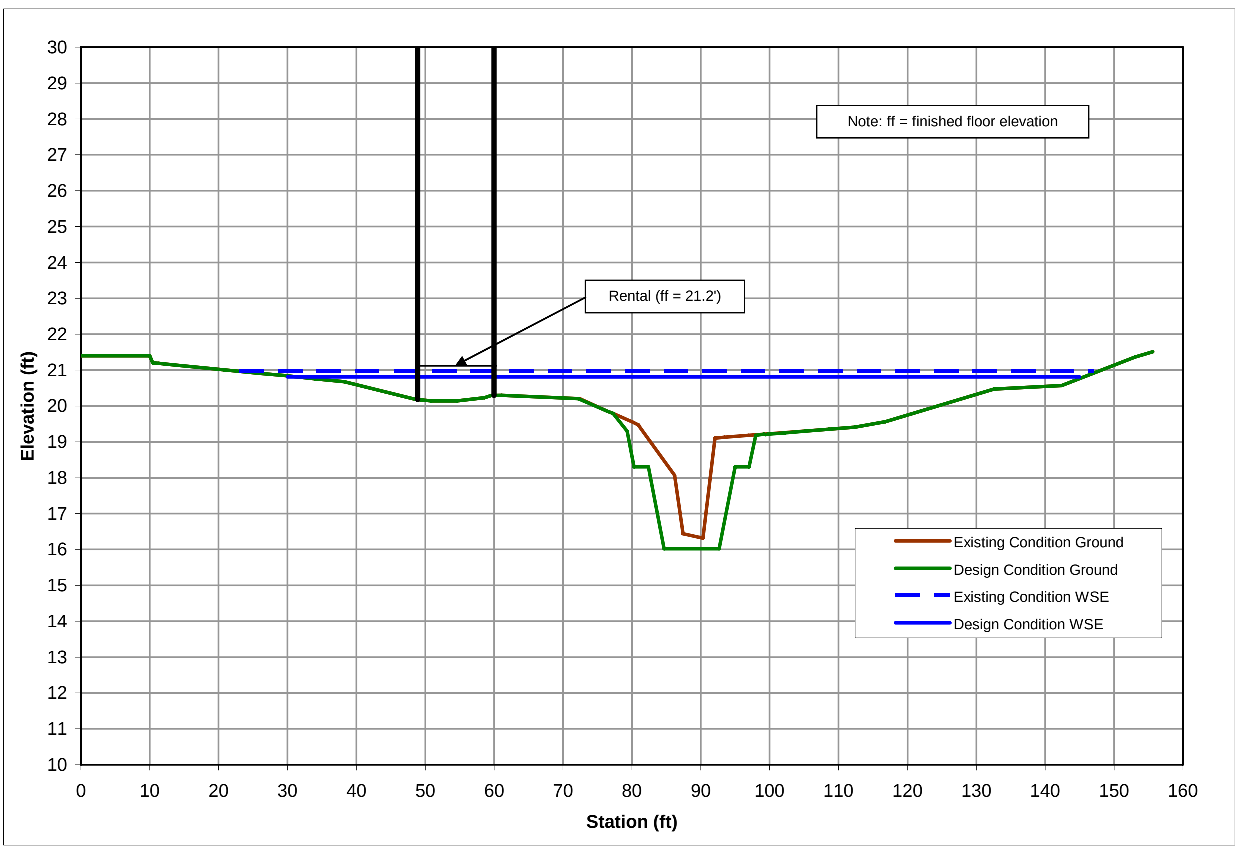

Figure 24. Cross-section 5905 showing existing and design condition water surface elevations (WSE) at 100-yr flood (Q100 = 445cfs). See Figure 10 for cross section locations.

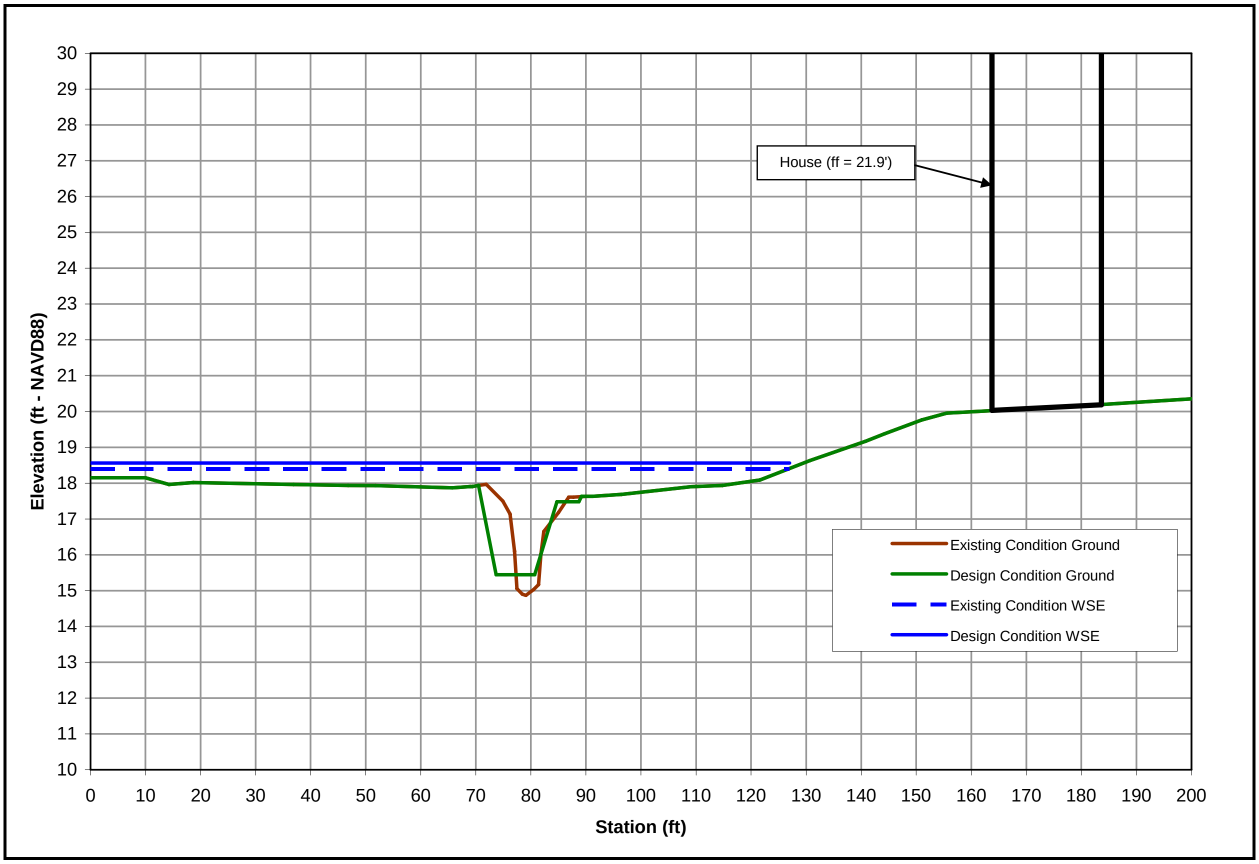

Figure 25. Cross-section 5783 showing existing and design condition water surface elevations (WSE) at 5-yr flood (Q5 = 201cfs). See Figure 10 for cross section locations.

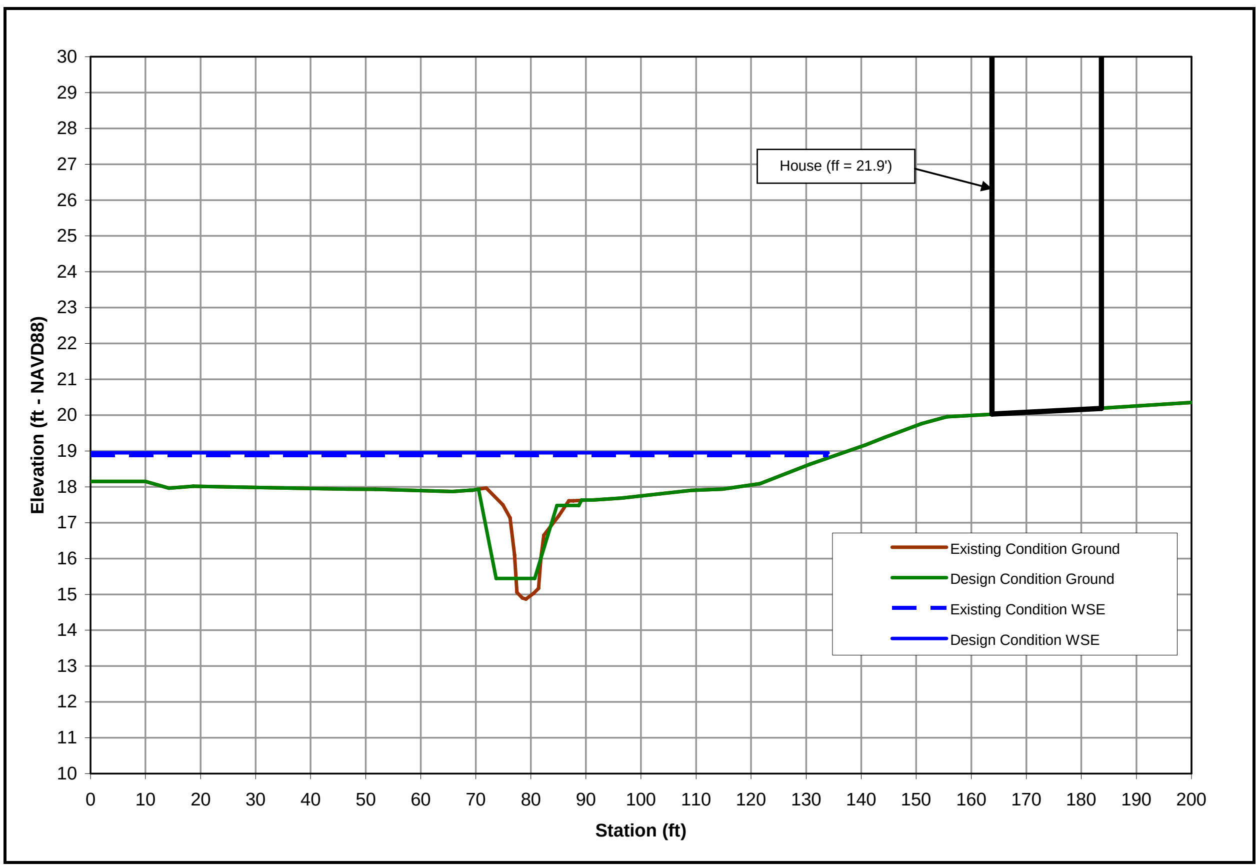

Figure 26. Cross-section 5783 showing existing and design condition water surface elevations (WSE) at 100-yr flood (Q100 = 445cfs). See Figure 10 for cross section locations.

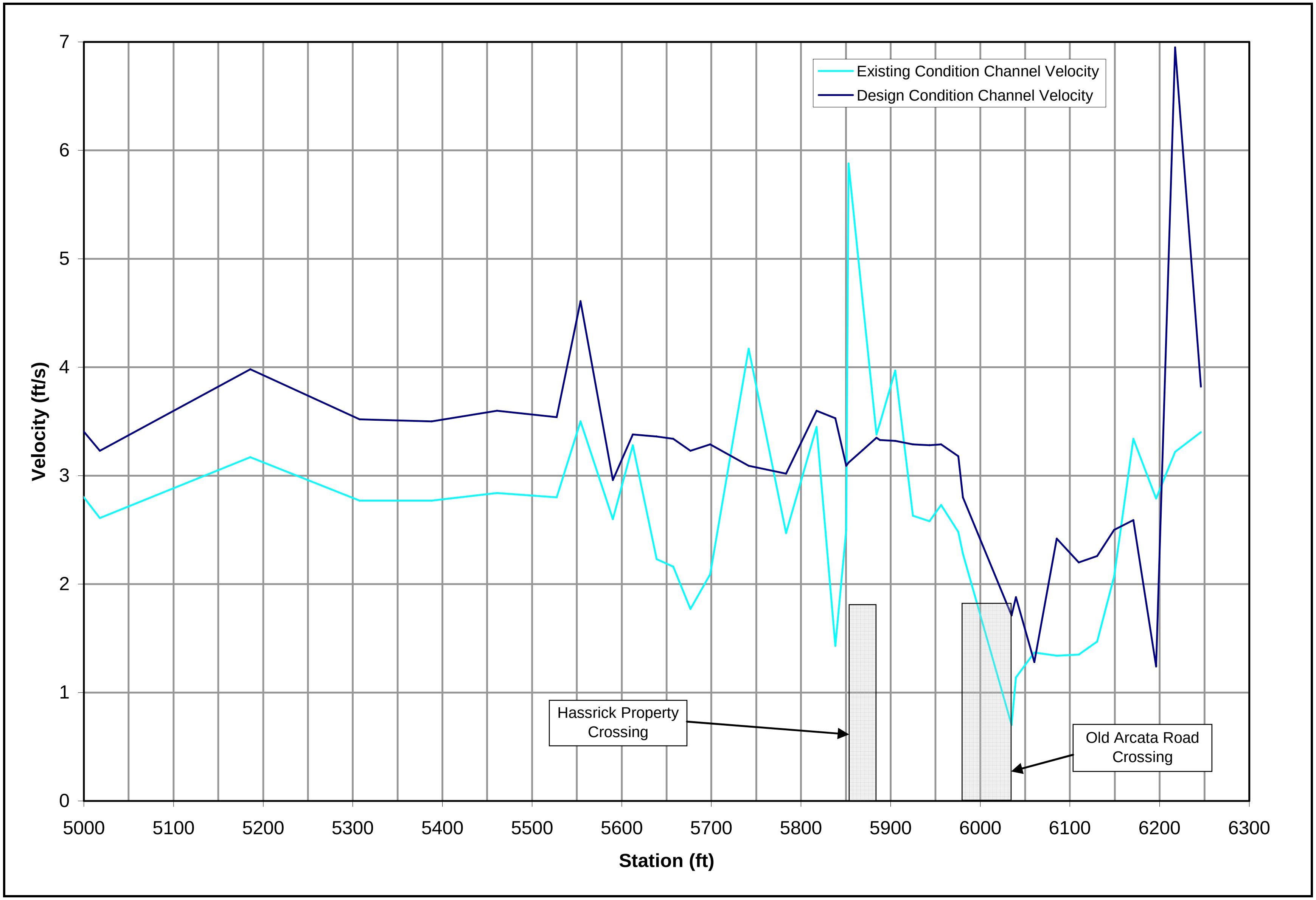

Figure 27. Channel velocities for existing and design conditions at bankfull (channel-forming) discharge (Q1.5 = 80cfs).

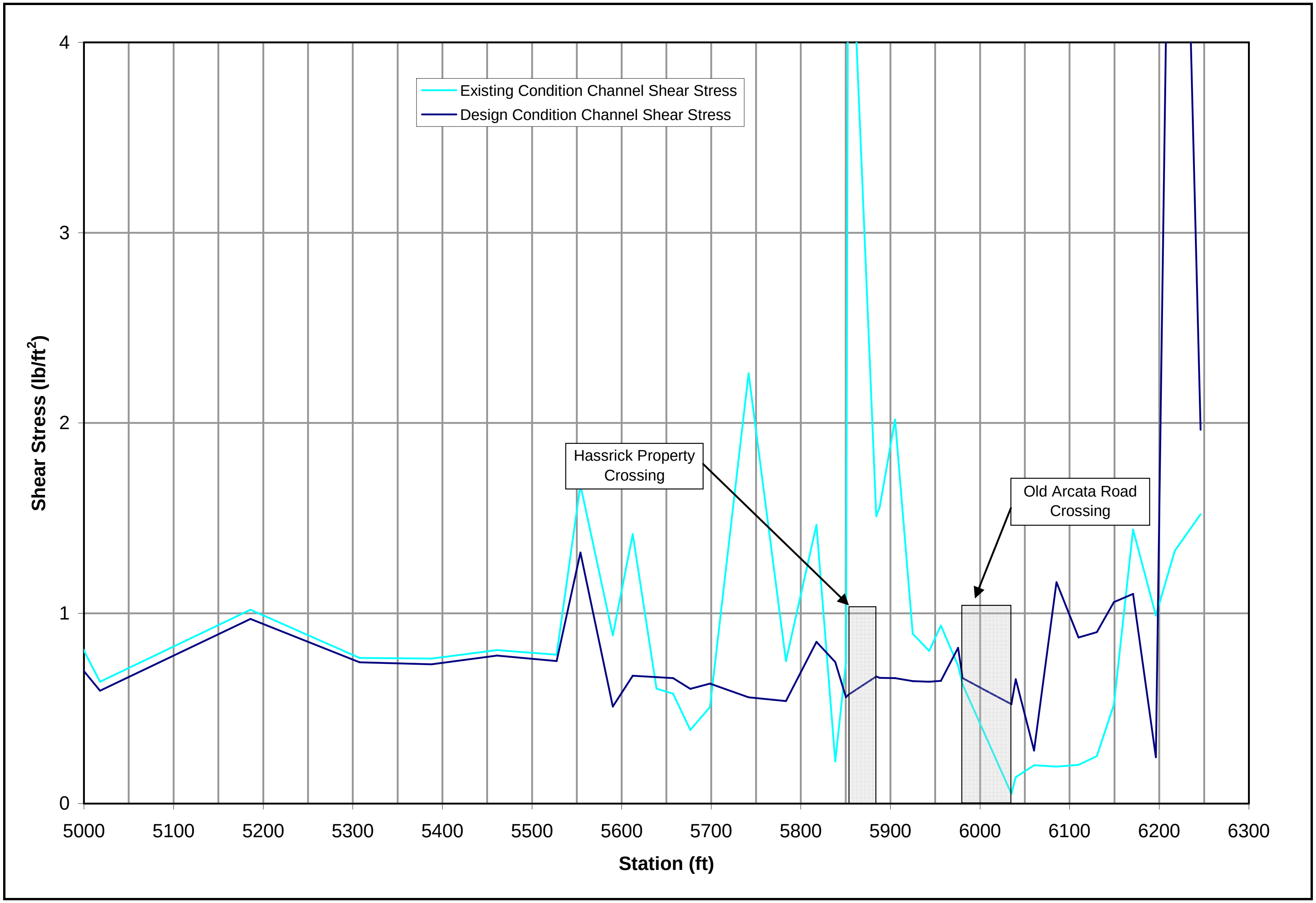

Figure 28. Channel shear stress for existing and design conditions at bankfull (channel-forming) discharge (Q1.5 = 80cfs).