# Corte Madera Creek
# Flood Control Channel

## Fish Passage Assessment and Alternatives Analysis

**Prepared for**

**Friends of Corte Madera Creek Watershed**
**Marin County Flood Control and Water Conservation District**
**U.S. Army Corps of Engineers**

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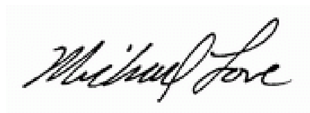
This project was completed for, and with invaluable assistance from, the Friends of Corte Madera Creek Watershed, a volunteer based non-profit organization. Assistance was also provided by the Marin County Flood Control and Water Conservation District. NOAA Fisheries and the California Department of Fish and Game provided input during the design process. The final report, including analysis and recommendations contained within, was prepared by:



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# 1 Background

## 1.1 Project Description

Corte Madera Creek and its tributaries support populations of steelhead trout (*Oncorhynchus mykiss*), which are part of the Central California Coast Distinct Population Segment (DPS) and listed as threatened under the Federal Endangered Species Act (Federal Register, 2006). The creek also historically supported runs of coho salmon, which were observed in the watershed until the early 1980s. However, they have been extirpated from the watershed, likely in part due to the construction of the flood control channel in lower Corte Madera Creek in the late 1960s and early 1970s.

This project is part of an effort by the *Friend's of Corte Madera,* the *County of Marin,* and other State and Federal Agencies to improve passage conditions within the Corte Madera Creek flood control channel for returning adult anadromous steelhead as they attempt to swim from the ocean to upstream freshwater spawning habitat. The specific objectives of this project are to (1) assess current upstream passage conditions and (2) develop feasible alternatives for providing suitable passage for returning adult steelhead within the existing concrete channel. Passage of coho salmon are also considered, in the event that they return to the system.

For this report, all elevations are referenced to the National Geodetic Vertical Datum of 1929 (NGVD29), unless otherwise noted.

## 1.2 Advisory Group

An advisory group was formed at the initiation of the project to review interim work products and provide guidance. The group included members of the Friends of Corte Madera Creek Watershed and staff from the California Department of Fish and Game (CDFG), National Marine Fisheries Service (NOAA Fisheries), Marin County Flood Control and Water Conservation District, and U.S. Army Corps of Engineers (ACOE) San Francisco District. The group met on three occasions and reviewed two interim technical memorandums and a draft of this Final Report.

## 1.3 Project Location

The Corte Madera Creek watershed drains the east side of the Coastal Range within Marin County, California. The 28 square mile watershed drains into San Francisco Bay at the Larkspur Ferry Terminal. The lower 3.9 miles of Corte Madera Creek is contained within a flood control channel that was designed and constructed by ACOE. From upstream to downstream, the constructed channel flows north to south through the cities of Ross, Kentfield, and Larkspur.

### 1.3.1 Flood Control Channel

The flood control channel was designed as four units (Figure 1.1). The first three units were completed by 1972. Unit 1 and the lower portion of Unit 2 consist of 2.9 miles of earthen channel with a bottom elevation below approximately -12.0 feet (NGVD29), followed by a stilling basin.

This reach of channel is periodically dredged and functions as a fully tidal slough channel. Beginning at the head of the stilling basin and extending upstream 4,900 feet to the Town of Ross is a 33 foot wide concrete flood control channel, which has a bottom elevation ranging between -12.0 and 6.5 feet (NGVD29). The lower 1,000 feet of channel has a mild slope of 0.0007 ft/ft, while the remaining upper channel has a slope of 0.0038 ft/ft. This upper section of channel, beginning at College Avenue, is Unit 3.

Unit 4 has never been completed due to public opposition to the original design, which consisted of a 3,000 foot long concrete channel. Currently, at least four alternative channel designs are being considered for Unit 4, each intended to preserve the streams aesthetic and environmental characteristics and provide for fish passage (Smeltzer and DeMaggio, 2006).

### 1.3.2 Unit 3 Channel Description

The Unit 3 section of the concrete flood control channel begins at the College Avenue bridge and ends 3,470 feet upstream at a Denil fish ladder near the Post Office in the Town of Ross. The 33 foot wide channel has vertical walls and a v-shaped bottom to concentrate lower flows towards the center of the channel (Figure 1.2). The channel consist of long straight sections, several subtle bends, and three tight curves. Within the straight sections the depth of the V-shaped bottom is approximately 3.2 feet. In the bends the cross-sectional shape of the channel bottom is asymmetrical, with the bottom superelevated towards the outside of the bend.

#### Tidal Elevations Relative to Unit 3

A large proportion of Unit 3 is tidally influenced, depending on the tides and streamflow conditions. The channel bottom elevation begins below sea level at elevation -6.5 feet (NGVD29) and ends at about 6.5 feet (NGVD29). To assess the extent of tidal influence, tidal datums referenced to Mean Lower Low Water (MLLW) were obtained from NOAA Station Gage No. 9414874 (Corte Madera Creek, CA) (Table 1.1). The conversion from the MLLW datum to NGVD29 at Corte Madera was obtained from NOAA staff. NOAA staff ran comparisons with Point Orient, CA and computed an inferred value relating MLLW to NGVD29 (Maria Little, pers. comm.).

The channel bottom throughout the lower 1,000 feet of Unit 3 is below MLLW (Figure 1.2) and all but the upper 840 feet of the channel bottom is below Mean Higher High Water (MHHW). Therefore, tidal stage directly influences fish passage in Unit 3.

#### Fish Resting Pools in Unit 3

The upper 1,900 feet of Unit 3 contains small concrete pools placed at regular spacing along the channel bottom, intended to create resting areas for returning coho salmon and steelhead trout. The downstream most pool is at Station 350+85. There are a total of 28 pools, each spaced roughly 64 feet apart. The concrete pools are rectangular in shape and centered along the channel invert. Each pool is 4 feet long (streamwise direction) and 13 feet wide (Figure 1.3). The bottom is flat and placed approximately 0.1 feet below the channel invert. Due to the v-shape of the channel bottom, the pool bottom along the sides is roughly 1.3 feet below the channel. Minor sediment deposition (< 2 inches in depth) was observed in nearly all pools during low flows in spring of 2005.

**Fish Ladder at Unit 3 – Unit 4 Transition**

A grade control structure marks the transition from Unit 3 (flood control channel) to Unit 4 (natural channel) (Figure 1.4). The grade control structure protects two sewer lines that cross under the creek immediately upstream of the concrete channel. A wooden Denil fish ladder was constructed as a temporary structure to provide fish passage over the grade control structure until the completion of Unit 4.

Steelhead have often been observed attempting to pass through the existing wooden Denil fish ladder. The ladder functions relatively well at low flows, but fails to provide suitable passage at higher flows that are more common during the period of migration. The ladder has an inadequate hydraulic capacity combined with adverse hydraulic conditions at the ladder entrance.

The County of Marin modified and repaired the ladder following severe damage during the flood of December 31, 2005. These repairs appear to have slightly improved overall passage through the ladder.

All recent alternatives developed for Unit 4, including the no action alternative, include removal of the existing fish ladder and replacement with either a gradual channel transition or a permanent fishway that would substantially improve fish passage (Smeltzer and DeMaggio, 2006).

## 1.4 Channel Capacity, Sedimentation and Flooding

Flooding from Corte Madera Creek is due to insufficient channel capacity at many locations upstream of Unit 3. At flows greater than approximately 3,200 cfs in Unit 4, water overtops the banks. The loss of overbank flows limit the discharge that can enter Unit 3 to 3,200 cfs.

Several modifications to the upstream reach (Unit 4) are under consideration that will increase the flow entering Unit 3 during high flow events. The Town of Ross is planning to replace the Lagunitas Road Bridge. If the new bridge is placed higher above the channel, the amount of flow able to enter Unit 3 will increase. Alternatives under consideration for completion of the Unit 4 channel will further increase channel capacity to between 5,200 and 5,600 cfs, depending on the selected alternative (Smeltzer and DeMaggio, 2006). Due to limited capacity in Unit 3, the walls of Unit 3 in selected locations would need to be raised to accommodate the increase in discharge.

Sedimentation in Unit 3 is largely limited to downstream of the College of Marin Pedestrian Bridge. This sedimentation combined with marine growth (tube worms) along the concrete walls reduces channel capacity (Copeland, 2000). Besides raising the walls, maintaining a channel capacity of 5,400 cfs may require frequent sediment maintenance.

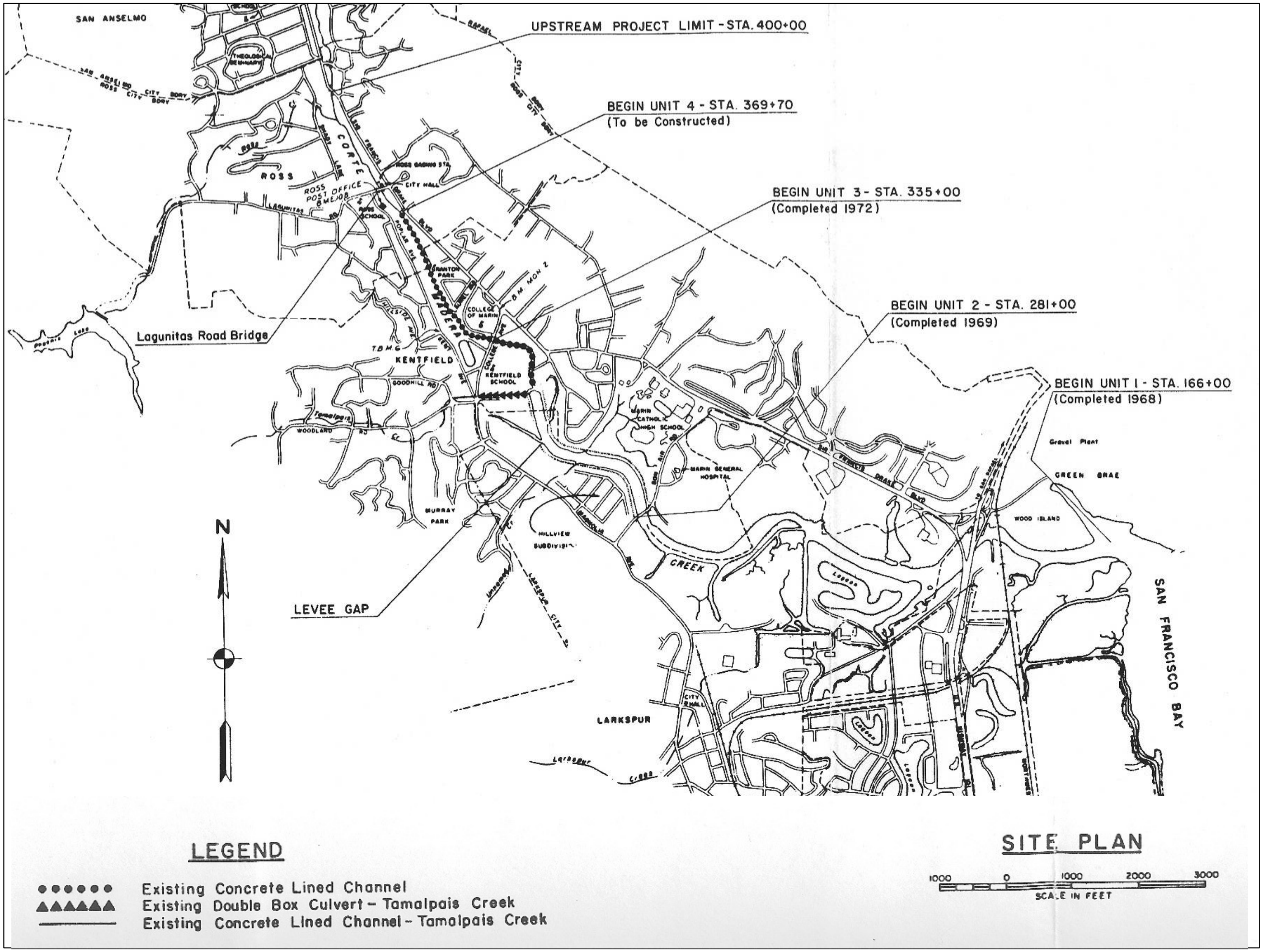


**Figure 1.1 –** Site map of the Corte Madera Creek Flood Control Channel, Units 1 thorough 4 (adapted from ACOE, 1989).

**Table 1.1 –** Tidal datum for lower Corte Madera Creek (NOAA station gage 9414874) related to MLLW and NVGD29.

| Tidal and Vertical Datums | REFERENCE DATUM MLLW (ft) | REFERENCE DATUM NGVD29 (ft) |
|---|---|---|
| Mean Higher High Water (MHHW) | 5.80 | 3.19 |
| Mean High Water (MHW) | 5.21 | 2.60 |
| Mean Tide Level (MTL) | 3.14 | 0.53 |
| National Geodetic Vertical Datum of 1929 (NGVD29) | 2.61 | **0.00** |
| Mean Low Water (MLW) | 1.07 | -1.54 |
| Mean Lower Low Water (MLLW) | **0.00** | -2.61 |

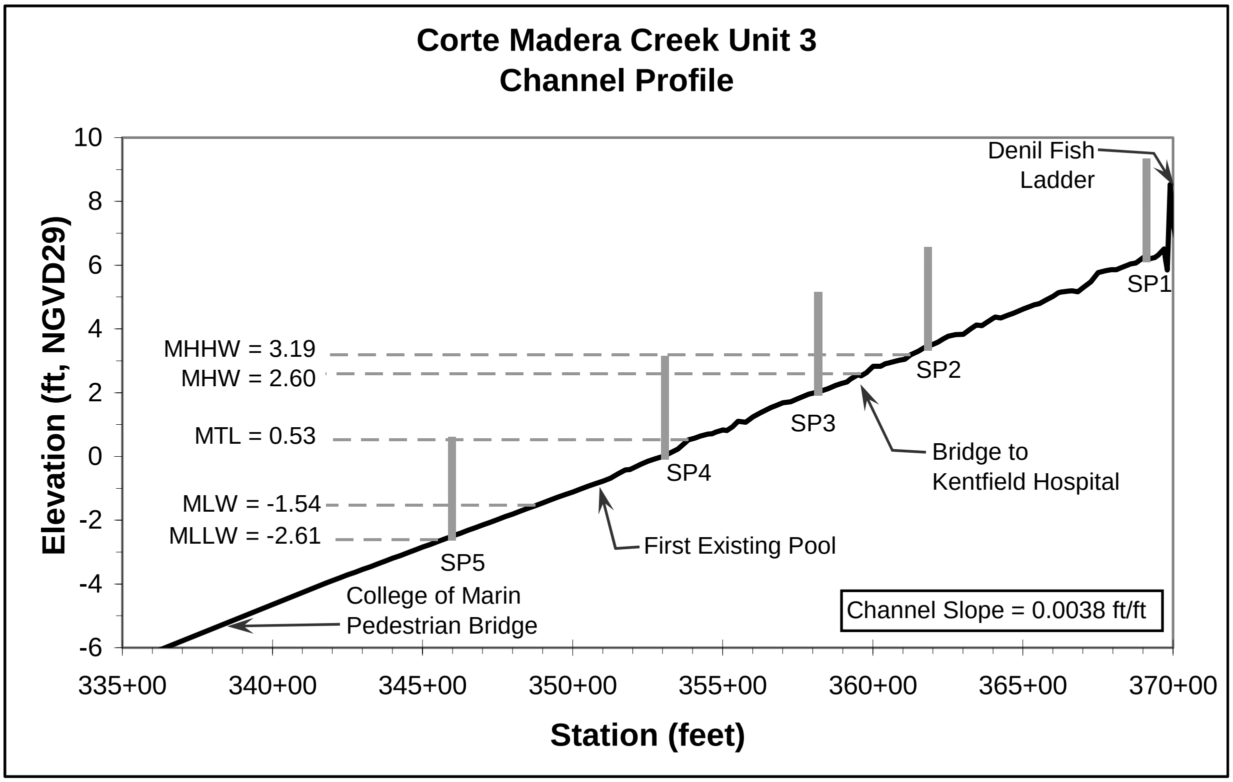


**Figure 1.2 –** Profile of the channel invert in Unit 3. Tidal elevations and locations of the two bridge crossings, fish ladder and downstream most resting pool are noted on the profile. The location and overall height of the five stage plates (SP) installed as part of this project are also shown.



**Figure 1.3 –** Dimensions of a typical straight channel reach (a) with v-shaped channel bottom and the channel bend downstream of the Kentfield Hospital Bridge (b) with the v-shaped bottom superelevated towards the outside of the bend.

**Figure 1.4** – Upper section of Unit 3 with existing fish resting pools. Each pool is 4 feet long, 13 feet wide, and spaced 64 feet apart. The flat concrete bottom in each pool is approximately 0.1 feet below the channel invert.


**Figure 1.5** - Existing Denil fish ladder and bypass weirs at the upstream end of Unit 3 (a) during low-flow in June 2005 and (b) at a typical steelhead migration flow in February 2007 following flood repairs.

## 1.5 Project Objectives and Constraints

This study is intended to identify the specific fish passage limitations within the existing channel and be a first step in developing and implementing a preferred fish passage improvement alternative. The specific objectives of this project are to (1) assess current upstream steelhead passage conditions within the flood control channel and (2) investigate potentially feasible alternatives for improving passage conditions. There are a number of site constraints and conflicting objectives associated with improving fish passage within the flood control that were considered in developing alternatives. Alternatives should strive to:

1. Minimize reduction in existing channel capacity.
2. Avoid modifications to the existing channel that are likely to be impractical or cost prohibitive.
3. Have minimal operational and maintenance requirements.

## 1.6 Project Approach

This project focuses on improving fish passage using concrete resting pools recessed into the channel bottom, similar to those in the existing channel. Pre-project observations of water velocities within the existing resting pools suggested they are too small to sufficiently reduce water velocities at most migration flows, but larger pools could potentially provide suitable resting areas. Alternatives that would substantially decrease the hydraulic capacity of the flood control channel such as the addition of roughness elements along the channel bottom to increase depths, decrease velocities, and provide suitable fish passage conditions were considered infeasible from the onset of the project.

The project has four components:

(1) Assess existing fish passage conditions.

(2) Develop and assess the effectiveness of specific resting pool shapes and configurations with respect to fish passage criteria.

(3) Determine the preferred spacing and location of resting pools needed to sufficiently improve passage conditions.

(4) Evaluate potential impacts the preferred alternative may have on water surface elevations at the 5,400 cfs design flow.

Existing fish passage conditions were assessed using a combination of field monitoring program and numerical model estimates. The field monitoring program consisted of volunteers video recorded observations of steelhead swimming in Unit 3 and at the fish ladder. Volunteers also recorded water surface elevations at locations throughout Unit 3 at various flows. These field observations were used to calibrate a two-dimensional (2-D) hydrodynamic model of the project reach. The 2-D model was used to estimate water velocities and depths encountered by steelhead at typical migration flows. These results were used in a fish routing and energetics model to estimate the proportion of the steelhead population able to ascend the concrete flood control channel over a range of stream flows and tidal conditions.

Resting pool alternatives were developed along with hydraulic performance criteria for fish passage. The 2-D model was used to predict the hydraulics within each resting pool alternative at steelhead migration flows. Based on these results, a preferred alternative was selected. The fish routing and energetics model was then used determine the preferred pool spacing and quantify the passage improvements resulting from the preferred resting pool alternative.

Lastly, the preferred alternative was modeled at the proposed Unit 3 design flow of 5,400 cfs to evaluate its impact on water surface elevations.

# 2 Data Collection and Monitoring

## 2.1 Topographic Survey

A topographic survey encompassing all of Unit 4 and Unit 3 upstream of the College of Marin Pedestrian Bridge was conducted by the County of Marin in the summer of 2005. The survey within Unit 3 captured the base and top of the flood control walls, the channel invert, and the four corners that define each existing fish resting pool. The wooden grade control and Denil fish ladder at the upstream end of Unit 3 was also surveyed. The County surveyor created a digital terrain model (DTM) from the survey data, which was used to generate channel geometry input files for the 1-D and 2-D hydraulic models.

## 2.2 Monitoring Activities

Several data needs were identified at the onset of the project::

- An updated stage-discharge rating curve for the Corte Madera Creek stream gage located immediately upstream of the Lagunitas Bridge in Ross.

- Water surface elevations at known discharge at multiple locations within the channel to assist in calibrating the numerical models.

- Observations of the channel at various flows to identify unanticipated hydraulic conditions and visually assess flow characteristics within the existing resting pools.

- Observations of steelhead swimming in the channel and attempting to pass through the fish ladder to assist in characterizing existing passage conditions and validate the fish routing model by identifying:
    - Channel locations and water depths steelhead swim through at various flows,
    - Speed and pattern of swimming used by the fish under different conditions,
    - Use of resting pools at various flows, and
    - Timing of migration relative to date and streamflow.

### 2.2.1 Monitoring Plan

A three part monitoring program was developed to address these data gaps:

1. Friend's of Corte Madera Creek Watershed and the Marin County Flood Control and Water Conservation District funded updating the rating curve for the Corte Madera Creek gaging station. This allowed for correlating observations in Unit 3 to a specific discharge.

2. Michael Love & Associates (MLA) installed stage plates at five locations within Unit 3 (Figure 2.1). Also, crest gages (measures peak stage of flow event) were installed at stations 2, 3, and 4. Subsequently, the stage plates and crest gages were surveyed relative to NGVD29 to relate stage readings to water surface elevations.

3. Video monitoring was conducted from November 2005 through February 2006 by several volunteers, and organized through Friend's of Corte Madera Creek Watershed. The video monitoring documented flow conditions in the channel and fish swimming in the channel and attempting to pass over the fish ladder. Volunteers followed a video monitoring protocol (Appendix A) and provide MLA with the video recordings for processing and analysis. Five monitoring stations were established, each adjacent to a stage plate. At the beginning and end of each video session volunteers recorded the stage at the plate and the exact time of day. The upstream Corte Madera Creek gaging station and updated rating curve allowed for correlating the video recording and observed stage to a specific streamflow.

Readings were also taken from the crest gages by staff from Stetson Engineers following several peak flows. However, the December 31, 2005 flood damaged all three crest gages, preventing any subsequent peak stage readings.

### 2.2.2 Monitoring Results

The monitoring data were used to calibrating the hydraulic models and support the fish passage analysis. A total of 75 video recordings were made by volunteers, totaling 57 hours and 50 minutes. Water surface elevations were recorded at each monitoring station at numerous flows ranging between 2.4 cfs and 1,328 cfs. The observations also documented the extent of tidal backwater within the channel. The complete rating tables for each monitoring station are provided in Appendix A.

During the video monitoring four adult salmonids were seen within Unit 3 (Table 2.1). The first observed fish, seen attempting to swim through the fish ladder on December 2nd, is believed to be an adult Chinook salmon. Although Chinook are not native to this stream, they periodically stray into Corte Madera Creek and other tributaries of San Francisco Bay on their migration to the Sacramento River and its tributaries. The other three are believed to be returning adult steelhead. Fish were observed in Unit 3 at flows between 16.8 cfs and 64.8 cfs.

In addition to the four salmonids observed in Unit 3, several steelhead kelts that had apparently spawned were observed holding in a pool immediately upstream of the fish ladder in February 2006. This observation confirmed that some steelhead are able to ascend the Denil fish ladder at certain flow conditions.

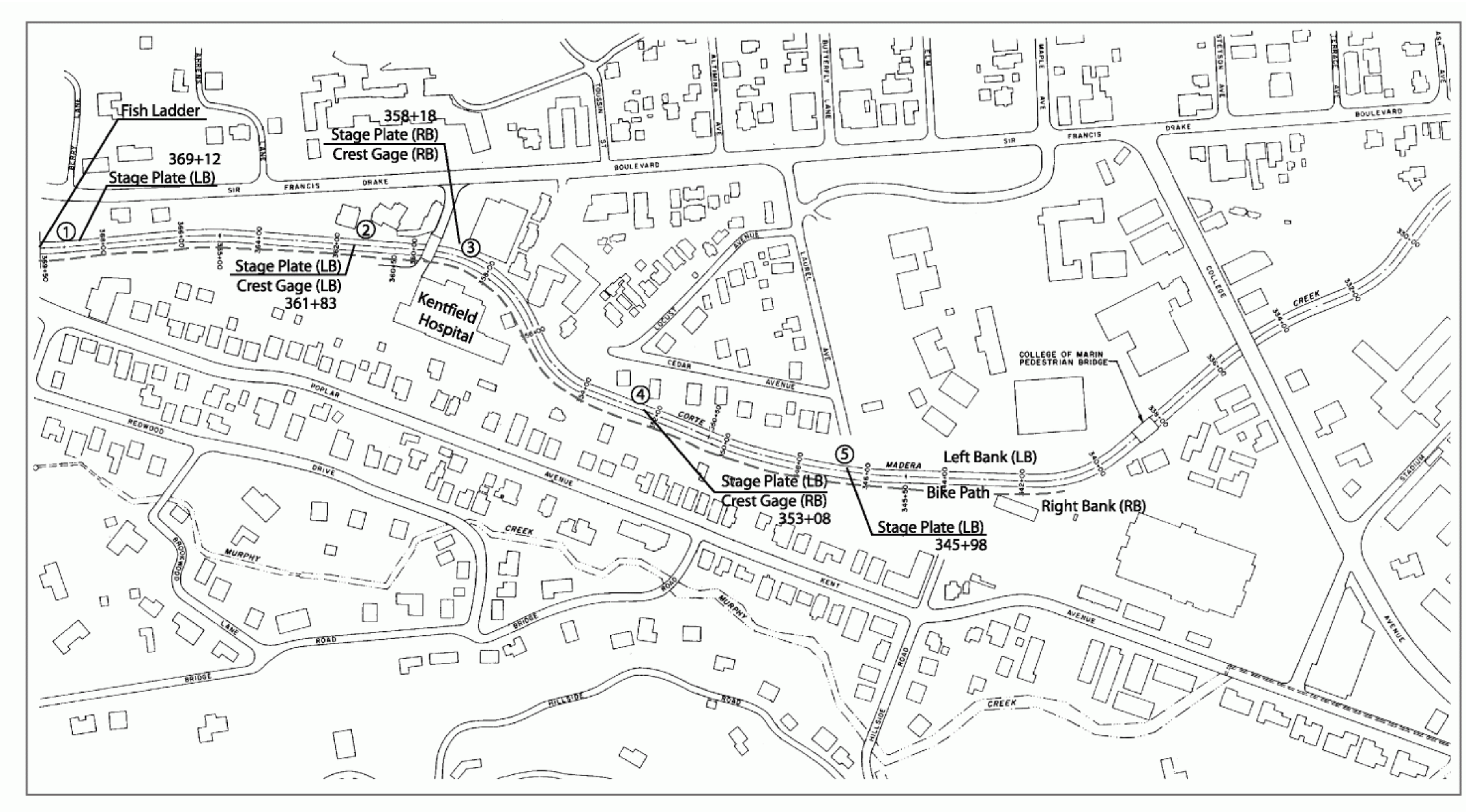


**Figure 2.1** – Location of monitoring stations 1 through 5 and associated stage plates and crest gages in Unit 3 (adapt from ACOE, 1989).

**Table 2.1** – Date, time and streamflow that adult anadromous salmonids were observed in Unit 3 during video monitoring between December 2005 and February 2006.

| Date and Time | Flow | Species | Location Observed |
|---|---|---|---|
| Dec. 2, 2005 1:00 pm | 16.8 cfs | Chinook | Fish Ladder |
| Dec. 20, 2005 12:30 pm | 31.7 cfs | Steelhead | Fish Ladder |
| Jan. 7, 2006 5:30 pm | 64.8 cfs | Steelhead | Fish Ladder |
| Jan. 10, 2006 5:00 pm | 30.9 cfs | Steelhead | Channel and Resting Pool |

# 3 Fish Passage Flows

Assessing fish passage conditions and developing alternatives for improving fish passage within Corte Madera Creek Unit 3 requires estimating the range of streamflows that adult steelhead attempt to migrate. Low and high fish passage design flows define the migration flow-range.

## 3.1 Defining the Migration Period

In Northern and Central California steelhead typically migrate from the ocean into coastal freshwater streams and rivers for spawning during high flow events occurring from December through March. Shapovalov and Taft's (1954) seminal study of steelhead and coho life histories on Waddell Creek in Santa Cruz County found the vast majority of returning steelhead (98%) entered lower Waddell Creek from the ocean between December 1st and March 31st. Eight years of recorded observations of steelhead attempting to pass over a barrier in lower Alameda Creek, a tributary to southern San Francisco Bay also indicate that the majority of steelhead within the San Francisco Bay region migrate into freshwater streams between early January and mid-March. This migration period is consistent with observations in Corte Madera Creek during the fall 2004 to winter 2006 monitoring period. Volunteers observed salmonids attempting to pass through the existing Denil ladder from early December through March.

**Based on these observations, a migration period from December 1st through March 31st was deemed appropriate for developing fish passage design flows.**

## 3.2 Fish Passage Design Flows

The range of fish passage flows is frequently defined by exceedance flows obtained from a flow duration curve for the site. The Corte Madera Creek at Ross stream gage, operated by the USGS from 1951 to 1993 (43 years of record), is located near the Lagunitas Road bridge, less than 800 feet upstream of the existing fish ladder. The historic daily average streamflow data from this gaging station was used to construct two flow duration curves for the project site; one representing year-round flow (annual) and the other representing flow conditions during the period of assumed adult steelhead migration (December through March) (Figure 3.1).

### 3.2.1 High Fish Passage Design Flow

In larger drainages, such as Corte Madera Creek (drainage area at College Avenue is 18.1 $mi^2$), a common high fish passage flow for salmon and steelhead is the 10% exceedance flow during the period of migration. The 10% exceedance flow is the discharge that is equaled or exceeded in the stream an average of 10% of the days for the indicated period; December through March in this case. This was the accepted criteria by CDFG and used for a recent evaluation of steelhead passage alternatives over the Bart Weir on Lower Alameda Creek, a tributary to San Francisco Bay (Wood Rogers, 2006), and is the high passage flow criteria applied to this project.

**For Corte Madera Creek at Ross the 10% exceedance flow for the migration period is 177 cfs, which was selected as the high fish passage design flow for upstream steelhead passage through Unit 3.**

### 3.2.2 Low Fish Passage Design Flow

In Northwest California, most salmon and steelhead appear to stop migrating at flows below the 50% (median) exceedance flow during the period of migration (Lang et al., 2004). This flow corresponds with the flows that returning steelhead were observed in Unit 3 of Corte Madera Creek and is designated as the low passage criteria for this project.

**For Corte Madera Creek at Ross the 50% exceedance flow for the migration period is 14 cfs, which was selected as the low fish passage design flow for upstream steelhead passage through Unit 3.**

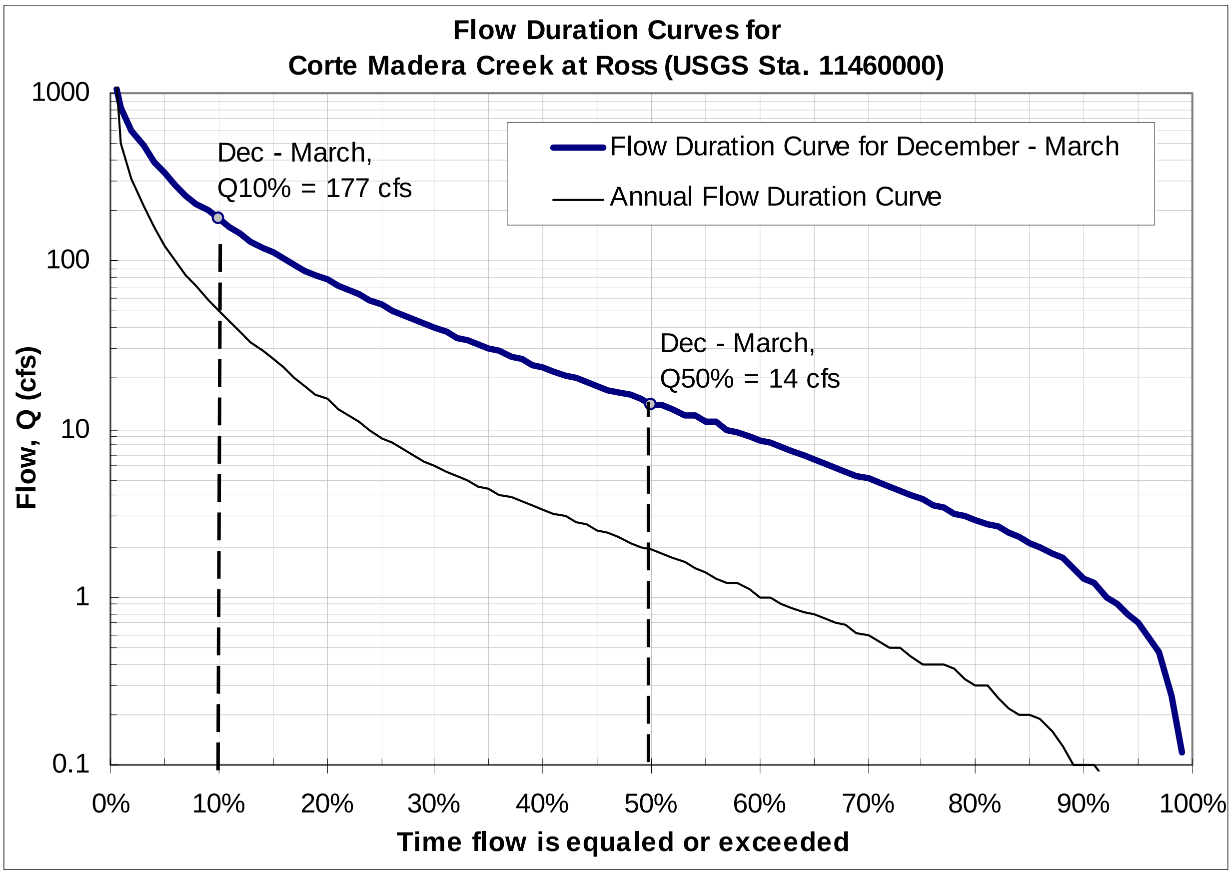


**Figure 3.1** – Annual and steelhead migration period (November through March) flow duration curves for Corte Madera Creek, constructed using daily average flows recorded from 1951 to 1993 at the USGS gage at Ross.

### 3.2.3 Fish Passage Flows Selected for Analysis

Existing fish passage conditions were evaluated at six flows within the designated migration design flows range Table 3.1. All flows are related to an exceedance value

**Table 3.1** – The six flows that passage conditions were assessed for returning adult steelhead, including the low and high fish passage design flows. Exceedance values are for the period of migration.

| Flow | Exceedance | Note |
|---|---|---|
| **14 cfs** | **50%** | **Low Passage Design Flow** |
| **23 cfs** | **40%** | |
| **40 cfs** | **30%** | |
| **77 cfs** | **20%** | |
| **113 cfs** | **15%** | |
| **177 cfs** | **10%** | **High Passage Design Flow** |

# 4 Numerical Modeling

## 4.1 Modeling Overview

The model reach extends from 300 ft upstream of the College of Marin Pedestrian Bridge to the fish ladder. The channel below the Pedestrian Bridge experiences sufficient tidal backwater effects as to maintain adequate depth and velocity for passage of returning adult steelhead (and coho salmon) at migration flows.

Existing hydraulic conditions within Unit 3 upstream of the Pedestrian Bridge were evaluated using both one-dimensional (1-D) and two-dimensional (2-D) models. A 1-D model calculates a single set of hydraulic conditions within a given cross section, thus providing insufficient information to evaluate fish passage and resting areas in Unit 3. A 2-D model enables prediction of hydraulic conditions at multiple locations within a given cross section, thus providing a more accurate description of the hydraulic conditions a fish may encounter. For instance, a simulated fish may migrate through the deepest portion of the cross section during low flow conditions and utilize lower velocity area on channel edges during high flows.

The 1-D model was used to assess the effect of design alternatives on water surface elevation. The 2-D model was used to predict the spatial distribution of depth and velocity for fish passage design flows (14 cfs to177 cfs) to determine the hydraulic conditions a fish encounters as it swims through the channel.

Roughness coefficient of the concrete channel has been estimated by others with a range of Manning's n of 0.014 to 0.018 (Copeland, 2000 and Copeland and Thomas, 1989). The roughness coefficient for the 1-D model was calibrated to water surface elevations measured during the monitoring period. The roughness coefficient estimated for the 1-D model was applied to the 2-D model and water surface elevation predictions from the two models were compared to verify that the transfer of the roughness coefficient between the two models was acceptable.

The Kentfield Hospital Bridge and the Pedestrian Bridge are located within Unit 3. The Kentfield hospital bridge spans the concrete channel and does not interact with flows contained within the concrete channel. Therefore this bridge is not included in either model. The project reach begins immediately upstream of the Pedestrian Bridge which backwaters the downstream boundary of the model at high flows. The backwater affect of this bridge is accounted for during high flows (5,400 cfs) in the 1-D model.

To assess fish passage for existing and proposed conditions, a fish routing, locomotion and energetics model was developed that accounts for the variability in steelhead swimming abilities and body size. The results from the 2-D model were used as input for modeling fish passage conditions. At each of the six flows, passage conditions were evaluated at three tidal conditions: MLLW, MTL, and MHHW. The fish passage results estimate the proportion of the steelhead population able to ascend the entire concrete channel at each flow and tidal condition.

## 4.2 One-Dimensional Hydraulic Model

A 1-D hydraulic model of Corte Madera Creek was developed by the ACOE Engineer Research and Development Center (ERDC) in HEC-RAS. This numerical model excludes the existing pools in Unit 3 from the channel geometry and therefore, does not provide the resolution required for fish passage analysis or evaluation of the impact of adding additional pools on water surface elevations.

As part of this project a 1-D steady-state HEC-RAS model was developed and calibrated. Channel topography for the model was provided by the County of Marin. Calibration data consists of water surface elevations and corresponding flow measured at the five monitoring stations (Figure 2.1) during water year 2006 (Appendix A).

Tidal influence within the lower portions of Unit 3 was accounted for during calibration. All of the monitoring stations are above MLLW but only stations 1 and 2 are above MHHW. Tidal elevations at the downstream end of Unit 3 were estimated using *XTides*, a software program developed by David Flater (1998) to provide tidal predictions.

Channel roughness was iteratively adjusted between Manning's n values of 0.012 and 0.015. Predicted water surface elevations were compared to observations (flow range from 3 cfs to 1,300 cfs) to determine the appropriate roughness coefficient. The Manning's n-value of 0.014 resulted in a slightly better fit (mean bias = -0.056 ft) of predicted water surface elevations to observed data than 0.013 (mean bias = -0.060 ft). As a conservative approach to evaluate fish passage, a Mannings n-value of 0.013 was selected to model the hydraulics in Unit 3.

The calibrated 1-D HEC-RAS model was used to generate predicted water surface elevations. These water surface elevations were compared to the 2-D model results. This approach does not provide model verification but offers an adequate level of certainty of the model predictions for this analysis. The downstream boundary condition for fish passage model runs was set to Mean Lower Low Water, which is a conservative condition for fish passage. High flow model runs used a downstream boundary condition equal to Mean Higher High Water, a conservative conditions for flooding.

## 4.3 Two-Dimensional Hydrodynamic Model

Stream hydraulics used to evaluate fish passage for existing and design conditions in Corte Madera Creek were estimated with a steady-state 2-D hydrodynamic model developed by the USGS and integrated into the Multi-Dimensional Surface-Water Modeling System (MD_SWMS).

### 4.3.1 Model Description

The developed model uses a curvilinear grid with 1 foot grid spacing and was used to predict the depth-averaged velocity, water surface elevation and boundary shear stress at each cell on the model grid. The model retains streamwise convective acceleration in the lowest order momentum equations and, therefore, can be used to investigate flow in channel bends with curvatures and topography that vary significantly in the stream wise direction. For a detailed description of model development, refer to Nelson and Smith (1989).

Model inputs include topographic elevations obtained from the County, water surface elevation at the downstream boundary, drag coefficient, and lateral eddy viscosity. The drag coefficient is computed using Manning's n (0.013) and hydraulic depth. Manning's n, depth and the downstream water surface elevation boundary condition were derived from the calibrated HEC-RAS model. Lateral eddy viscosity values ranged from 0.03 $m^2/s$ to 0.09 $m^2/s$ for flows between 14 and 1,383 cfs.

### 4.3.2 Model Comparison

Water surface elevation from the 2-D model correspond well with the 1-D model (Figure 4.1 and 4.2). Small differences in water surface elevations between the two models occurred at 14 cfs, the lowest modeled flow. This difference is partly is due to the increased drag coefficient in the 2-D model resulting from the shallow flow. The largest difference in water surface elevations at this flow was 0.15 ft. We are unable to determine which model is more accurate since water surface elevations were not recorded at 14 cfs.

The 2-D model water surface elevations are slightly higher than the 1-D model results from station 34+150 to 35+150 (section of concrete channel without pools). In the channel section containing pools both models predict bulges in the water surface elevation within and adjacent to the existing pools. Average increases in water surface elevations at the pools range from 0 to 0.4 ft for flows from 14 to 333 cfs. Rises in the water surface at the pools were not observed during video monitoring, but would be difficult to detect given the small elevation increases and turbulent fluctuations in the water levels observed in the video footage at similar flows.

Peak water level rise at each pool is slightly higher in the 1-D model for all flows greater than 14 cfs. As flows increase, the water surface profile predicted by the 1-D model begins to obtain a distinct step-like profile; with a flatter water surface profile between pools followed by abrupt drops at each pool. In contrast, the 2-D model shows a continuous gradient in water surface between pools interrupted by bulges in the water surface elevation at the pools. The 2-D model prediction of a continuous drop in water surface elevation between pools is consistent with recorded observations of the water surface during flood flows. The magnitude difference between the two predictions is relatively small. At the high fish passage design flow the difference is approximately 0.3 ft.

Results demonstrate good agreement in water surface elevation predictions between the two models. The slightly lower water surface elevations predicted by the 2-D model translate to slightly shallower depths and faster velocities, which are consistent with a conservative approach to fish passage analysis.

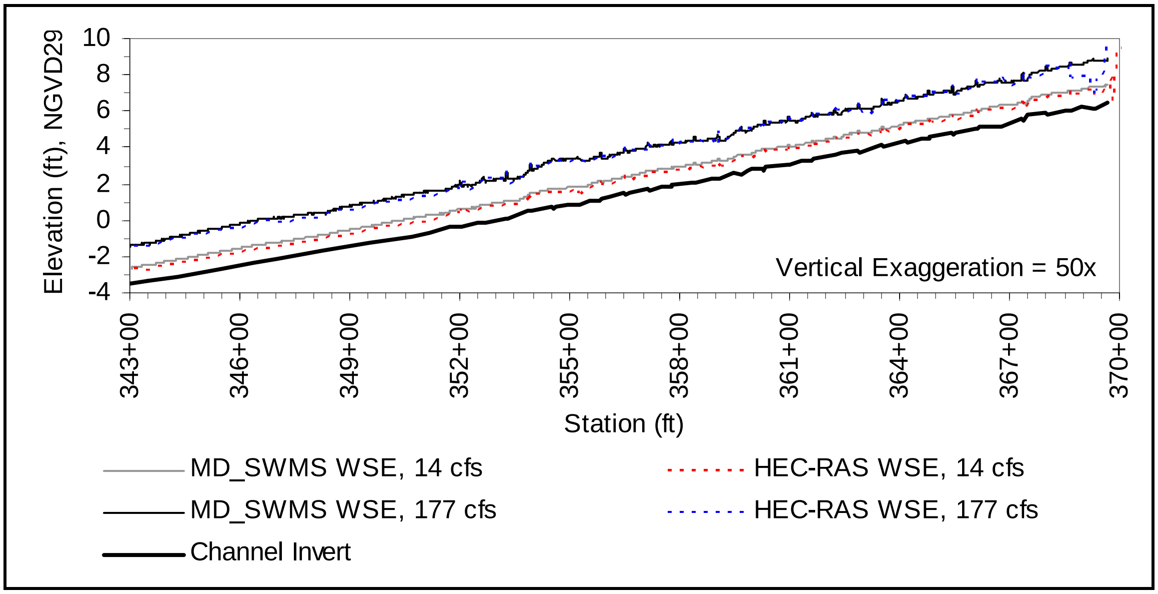


**Figure 4.1** - HEC-RAS and MD_SWMS predictions of water surface elevation at 14 cfs and 177 cfs in model reach, Unit 3.

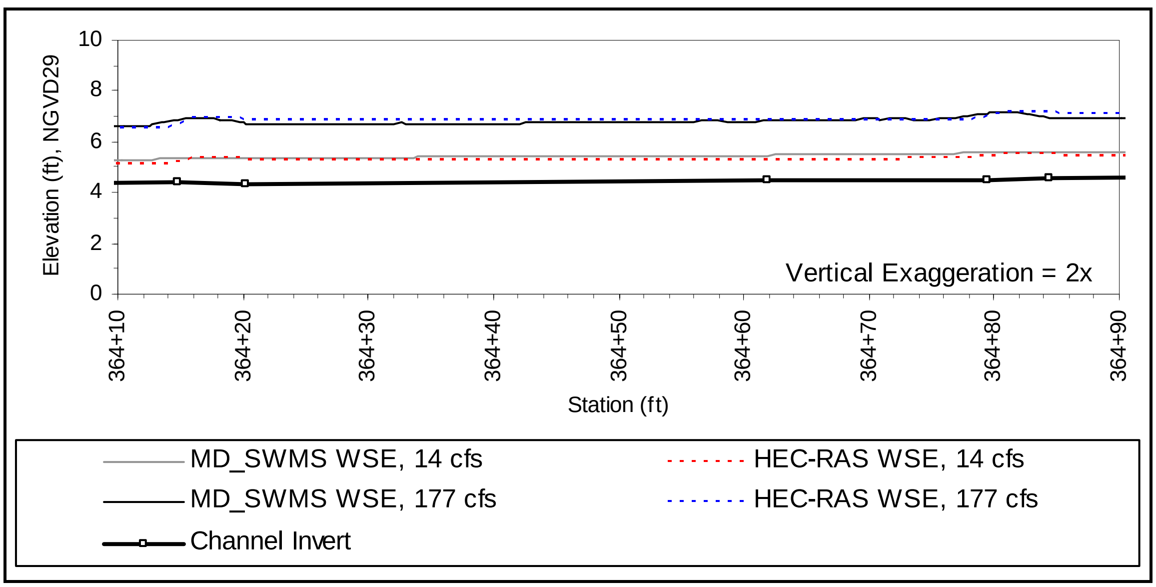


**Figure 4.2** - HEC-RAS and MD_SWMS predictions of water surface elevation at 14 cfs and 177 cfs at two pools in model reach, Unit 3.

## 4.4 Fish Routing, Locomotion and Energetics Model

### 4.4.1 Need for New Model

California Department of Fish and Game (CDFG) and National Marine Fisheries Service (NOAA Fisheries) have guidelines for providing suitable upstream passage conditions for adult salmon and steelhead through road-stream crossings (CDFG, 2002; NOAA Fisheries, 2001). However, these guidelines do not address fish passage through flood control channels, such as Unit 3.

The guidelines recommend a minimum water depth of 1.0 foot and a maximum average cross-sectional water velocity less than 2 ft/s for culverts exceeding 300 feet in length. Preliminary hydraulic analysis of Unit 3 with 1-D model indicated that these water depth and average cross-sectional water velocity criteria are never mutually satisfied throughout the entire channel reach. However, on numerous occasions individual steelhead have been observed swimming through the entire Unit 3 channel.

CDFG and NOAA Fisheries guidelines are widely recognized as being conservative, with the intent of providing passage for the weakest individual fish in the population, partly explaining why some steelhead are observed successfully swimming through Unit 3 even though velocity and depth criteria are not satisfied. Steelhead possess a wide distribution of swimming abilities (Bell, 1991). They also often swim in waters less than 1 foot deep and typically swim in areas of lower water velocities along the edges of a channel. To provide a more accurate assessment of fish passage conditions in Unit 3 a fish routing, locomotion, and energetics model was developed.

### 4.4.2 Model Overview

The Fish Routing, Energetics and Locomotion Modeling System (Fish-REALMS) was developed for this project and a similar project in the San Lorenzo Creek Flood Control Channel in Alameda County, California (MLA, 2006). Fish-REALMS is intended to account for the spatial variation in water velocities and depths throughout the channel and the variation in steelhead size and swimming abilities throughout the population. The model uses a combined deterministic based approach for routing the fish through the channel and probabilistic based approach for modeling the swim speeds and energetics of the population.

At each specific flow, an optimum swimming route is identified through the 2-D model predicted water depth and velocity field. Next, a stochastic approach is used that randomly selects individual steelhead from the population's distributions of (1) swimming abilities and (2) fish body lengths. For each simulation the randomly selected steelhead swims through the channel along the defined route. Each fish swims at its optimum speed (travels the furthest distance with the least amount of energy expended) and its energy consumption is tracked in terms of fatigue. If conditions are suitable for resting, the fish may rest and recover from fatigue before continuing upstream. If the fish becomes 100% fatigued it can not continue swimming, and the location in which it becomes exhausted is noted. Typically, at least 1,000 simulations are performed to adequately define the passage conditions for the entire population at a particular flow.

### 4.4.3 Hydraulic Input

The hydraulic environment within Unit 3 at fish passage flows was determined using the 2-D model, MD_SWMS. Model results were generated for the six fish passage flows. The hydraulic model output, which included water depths and depth-averaged water velocities in a 1 ft x 1 ft grid throughout the channel, was exported to ArcMap for use in routing the fish through the channel.

### 4.4.4 Fish Routing

The developed routing model assumes that the fish will swim upstream along the route that requires the least amount of energy. This route follows the path of slowest water velocities while maintaining adequate water depth. A minimum water depth needed for swimming was set at 0.6 feet to ensure that even the largest steelhead is fully submerged (see below for explanation).

The preferred swimming route for each flow was visually identified in ArcMap and manually digitized. The route was conservatively made 2 feet wide to account for the steelhead's tail swinging back and forth as it swims and because of the grid spacing. The water depths and velocities within the 2 foot wide swimming route were then exported from ArcMap and imported into a spreadsheet-based fish swimming model.

### 4.4.5 Size Distribution of Adult Steelhead Population

The swimming capabilities of most fish species, including steelhead, are directly related to the fish's overall length. Therefore, to describe the range of swimming capabilities requires describing the range of body lengths that make-up the population of sexually mature steelhead as they return to freshwater streams to spawn.

Based on determinations made by NOAA Fisheries, steelhead returning to Corte Madera Creek are from the Central California Coast Distinct Population Segment (DPS) (Federal Register, 2006). Since only a few steelhead have been observed in Corte Madera Creek within recent years and lengths were not recorded, it was necessary to use other data sets from the Central California Coast DPS to describe the distribution of steelhead body lengths. Body length data was obtained from four streams within the Central California Coast DPS: Pudding Creek near Fort Bragg (Neillands, Per. Com.2006), Scotts Creek near Santa Cruz, (Hayes, Per. Com. 2006) and Waddell Creek near Santa Cruz (Shapovalov and Taft, 1954).

From this data it is apparent that the size of steelhead ranges widely, from 12 inches to 35 inches (Figure 4.3). To avoid skewing the distribution towards the streams that had larger sample sizes, the data was normalized by stream. The resulting distribution of steelhead body lengths was use in Fish-REALMS to describe the body size of steelhead returning to Corte Madera Creek. This normalized distribution has an average steelhead body length of 24.5 inches. The lower and upper 10 percentile is 17 inches and 28 inches, respectively.

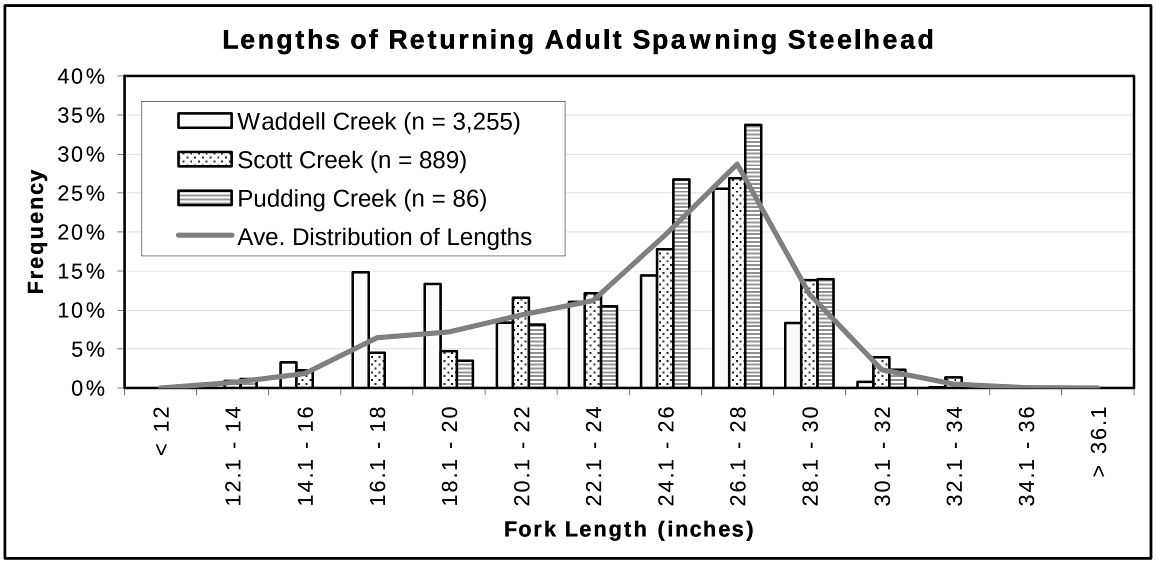


**Figure 4.3**– Distribution of fish lengths for sexually mature steelhead trout in three streams within the Central California Coast Distinct Population Segment (DPS**)**. Average distribution of fish lengths normalized by stream was used to describe the size distribution of steelhead returning to Corte Madera Creek.

### 4.4.6 Steelhead Swimming Capabilities

An extensive literature search was conducted to identify studies that quantify (1) the relationships between steelhead swimming speeds and time to fatigue, (2) the swim speeds defining sustained, prolonged, and burst swimming, (3) the time required for an exhausted adult steelhead to rest before regaining its full stamina, and (4) the distribution of fish body lengths that generally describes the Central California Coast adult steelhead population as they enter freshwater to spawn.

**Swim Speed – Fatigue Time Relationship**

Most fish, including salmonids, are known to have three distinct modes of swimming: sustained, prolonged, and burst (Beamish, 1978). Sustained swimming is a completely aerobic activity and can be maintained indefinitely. Prolonged swimming is a combination of aerobic and anaerobic metabolic activity that can be maintained between 20 seconds and 60 minutes before the fish becomes fatigued. Burst is the fastest mode of swimming and uses anaerobic muscles almost exclusively. It can only be maintained for between 1 and 20 seconds before the fish becomes fatigued.

When relating swim speed to the amount of time a fish can be sustained before fatigue, the swim speed is often directly proportional to the body length of the fish for a given species and life stage (Bainbridge, 1960). Therefore, swim speed – fatigue time relationships commonly use swim speeds in terms of body lengths per second (BL/s).

Swim speed – fatigue time relationships are frequently described by a log-linear relationship of the following form (Beamish, 1978; Castro-Santos, 2002):

$$\ln T = aU_s + b \qquad \text{(Eq. 1)}$$

where,

$T$ = time to fatigue (s)
$U_s$ = Swim speed of the fish relative to the water (BL/s)
a and b = constants for the slope and intercept of the line

## Prolonged Swim Speeds for Steelhead

An examination of the literature regarding swimming capabilities of *Oncorhynchus mykiss* (steelhead/ rainbow trout) found only two primary studies concerning adult anadromous steelhead (Weaver 1963; Paulik and DeLacy, 1957). Of the two studies, only Paulik and Delacy swam the fish to fatigue. These fatigue tests were conducted using 21 wild steelhead captured in Soos Creek near Seattle, Washington. Fish ranged in length from 17.75 inches to 30.75 inches. Tests were conducted in a rotary fish tank and water temperature, which influences swimming performance, ranged between 50.0° and 53.5° F. Each fish was subjected to four constant water velocity tests, with a 24 hour resting period between tests. Velocities in the tests ranged between 4 ft/s and 10 ft/s. Most, if not all, of the speeds reported by Paulik and Delacy appear to be associated with swimming in prolonged mode.

We used the raw data published by Paulik and DeLacy to develop swim speed – fatigue time relationships for use in modeling steelhead swimming performance within the Unit 3 of the Corte Madera Creek Flood Control Channel. The swim speed test results seem applicable to steelhead in Corte Madera Creek since the range of fish lengths tested were within the same range of those that define the population of steelhead in the Central California Coast DPS. Additionally, water temperatures measured in the flood control channel by District staff during runoff events between December and March commonly ranged between 49° and 56° F, which is close to temperatures in the swim speed tests.

A log-linear relationship was used to fit a regression line to the steelhead swim speed data (Figure 4.4). Confidence intervals around the regression line and prediction intervals for the log-transformed data were computed assuming the residual error is normally distributed, which was visually checked and verified. This was used to describe the distribution of slopes and intercepts for swim speed – fatigue time relationships among the population.

## Transition Between Modes of Swimming

For modeling fish locomotion and energetics it is necessary to define the transitions between each of the swimming modes (sustained, prolonged, and burst). Based on the swim speed data in Figure 4.4 and results from Weaver (1963), we assumed steelhead swim in prolonged mode at speeds between 1 BL/s and 7 BL/s. At lower speeds the steelhead is assumed to be in sustained swimming mode, and in burst swimming mode at higher speeds.

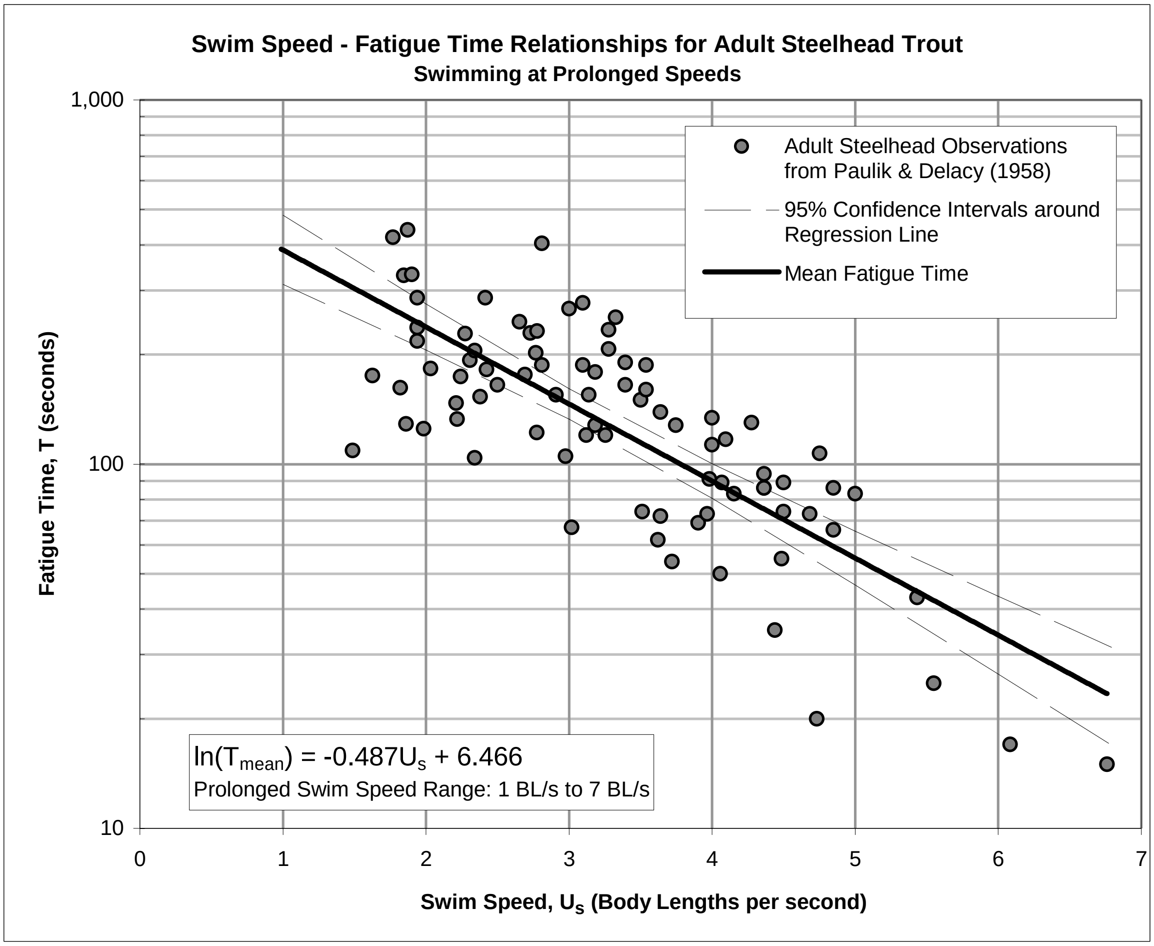


**Figure 4.4–**Relationship of swim speed verses time to fatigue for steelhead trout swimming at prolonged speeds, developed from data presented in Paulik and Delacy (1958).

## Burst Swim Speeds for Steelhead

Steelhead swimming at burst speed through Unit 3 is impractical given the channel distance and short time to exhaustion associated with burst swimming. However, at higher flows there is likely short sections of channel that burst swimming is required. Weaver (1963) appears to be the only study that examined swim speeds of adult steelhead at burst speeds, but these fish were not swam to exhaustion, making it difficult to develop burst swim-speed fatigue time relationships. Hunter and Mayor (1986) developed swim speed – fatigue time relationships based on both published and unpublished data that relied on some of Weaver's original data for steelhead as well as burst swimming abilities of resident rainbow trout. They developed a power function to describe the burst swim speed – fatigue time relationship. For this study, a log linear equation was fitted to the fatigue times predicted by the power function for various swim speeds. The resulting log-linear equation has the following form:

$$\ln T = 3.79U_s + (-0.337)$$

Since steelhead only rarely need to swim at burst speeds in Unit 3, the potential error associated with this relationship has minimal influence on the fish passage modeling results.

## Optimum Swim Speed

The swim speed of a fish ($U_S$) is relative to the water, and can be described as the sum of the water velocity ($U_W$) and the speed of the fish relative to the ground ($U_G$):

$$U_S = U_W + U_G \qquad \text{(Eq. 2)}$$

For example, a fish swimming up the channel at 2 ft/s against water flowing at 6 ft/s has a swim speed of 8 ft/s.

Castro-Santos (2005) showed that for prolonged and burst modes of swimming there is a distance optimizing swim speed ($U_{S\text{-}opt}$), which results in the fish being able to swim the furthest distance before fatigue. This optimum swim speed is the speed of the water the fish is swimming against minus the inverse of the slope ($a$) of the swim speed-fatigue time regression line, where $a$ is constant:

$$U_{S\text{-}opt} = U_W - 1/a \qquad \text{(Eq. 3)}$$

In other words, a fish may maximize the distance it can swim before fatigue by maintaining a constant ground speed ($U_{G\text{-}opt}$) regardless of the water velocity. It is important to note that $U_{G\text{-}opt}$ changes depending on the mode the fish is swimming in (prolonged or burst).

For an example, using the swim speed equation shown in Figure 4.4 for prolonged swimming, the optimum ground speed is:

$$U_{G\text{-}opt} = -1/(-0.487)$$
$$= 2.05 \text{ BL/s}$$

For the average sized steelhead (BL = 24.5 inch), this equates to a constant ground speed of 4.2 ft/s. Therefore, if the water velocity encountered by the fish is 6.0 ft/s (2.9 BL/s), the optimum swim speed ($U_{S\text{-}opt}$) is 10.2 ft/s (5.0 BL/s)

Castro-Santos (2005) demonstrated through swim speed tests, that certain species do tend to swim in prolonged and burst at the optimum ground speed. However, of the six species studied, none of them were salmonids. Examination of results from earlier published work (Weaver, 1963) strongly suggest steelhead swim near the optimum ground speed. Weaver reported ground speeds for over 1,000 adult steelhead from the Columbia River swimming through a 30 ft long timed section within a flume 85 ft in length. For water velocities ranging between 2 ft/s and 6 ft/s the average recorded ground speed ranged between 4.0 ft/s and 4.8 ft/s, which falls within the range of optimum ground speeds for the size of steelhead tested. At higher speeds results were less conclusive, possibly because some of the fish were swimming in burst mode while others were swimming in prolonged mode.

Based on this work, the swim speed model used to assess passage through the flood control channel assumed that steelhead swim at there optimum ground speed when in prolonged mode.

## Variable Speed Swimming verses Fatigue

A fish swimming at optimum speed must adjust its speed as water velocities change. Therefore, a method was devised to keep track of the fish's fatigue as it swims through changing water velocities and as it changes swim modes (Castro-Santos, 2006). Determining the percent fatigue of the fish ($F\%$) while it swims at variable speeds requires summing the amount of time swam at each swim speed ($t_{U_S}$) divided by the fatigue time associated with that swim speed ($T_{U_S}$):

$$F\% = 100 \times \sum \frac{t_{U_S}}{T_{U_S}} \qquad \text{(Eq. 4)}$$

When fatigue reaches 100% the fish is assumed to be exhausted and must rest and recover before resuming swimming at prolonged or burst speeds.

## Recovery from Fatigue

The ability of fish to exert themselves, recover, and swim again without hindrance has important ecological ramifications, especially for species such as salmon and steelhead that undertake extensive migrations to complete their life cycles. A study by Milligan et al. (2000) showed that after swimming to exhaustion, rainbow trout recover quicker when slowly swimming against a current than in still water. Study results showed trout that swam at a prolonged speed of 0.9 BL/s after exhaustive swimming fully recovered (muscle glycogen completely re-synthesized and lactate cleared) within two hours, whereas trout subjected to the same exhaustive swim required more than six hours to recover when held in still water. This finding agrees with the idea that steelhead can recover from fatigue when swimming at sustained speeds. The swim speed data presented in Figure 4.4 suggests that the transition between sustained and prolonged speeds for adult steelhead is near 1 BL/s.

**Based on this, and other similar studies, a water velocity of 1 BL/s was selected as the maximum suitable velocity for allowing an adult steelhead to rest and recover from fatigue.**

## Resting Period

Brett (1964) measured sockeye salmon recovery from fatigue in terms of a fish's metabolic rate and showed that recovery is exponential relative to the time spent resting. Although most of the tested fish required as long as 6.5 hours to fully recover, within the first 10 minutes their metabolic rate had decreased by half. This helps to explain observations of steelhead resting for only brief periods in Unit 3 and in natural channels. They likely only rest long enough to partially recover from fatigue.

Although the fish passage model used in this study does not attempt to account for the amount of time the fish must rest at each pool, it does assume that the fish will fully recovered from fatigue when encountering suitable resting areas. This assumption may lead to predicting higher passage success than truly occurs, since the returning steelhead likely only partially recover from fatigue when resting.

### 4.4.7 Tidal Conditions and Fish Passage

The tidal conditions combined with flow determines the location in the channel that the fish can no longer swim at sustained speeds and must begin swimming at prolonged speeds. Once the fish transitions to prolonged swimming they begin to fatigue. Since the 2-D model results were for MLLW conditions, 1-D model was run with different downstream tidal boundary conditions and used to estimate the extend of tidal backwater and the location that prolonged swimming would begin for each fish at each fish passage flow. Prolonged swimming was assumed to begin at the location in which the average cross-sectional water velocity predicted in 1-D model was greater than the 1.0 BL/s threshold.

### 4.4.8 Required Water Depth

Routing the fish required selecting a minimum water depth sufficient to allow the fish to swim freely. Steelhead are frequently observed swimming through extremely shallow water with their body only partially submerged. However, this is typically only done over short distances, such as over a shallow riffle. When swimming partially submerged the fish's tail is not providing as much thrust as when fully submerged, which would result in less than optimal swimming performance. Additionally, swim speed– fatigue time relationships are developed from tests that involved the fish swimming fully submerged. Application of these relationships to partially submerged fish would likely lead to substantial inaccuracy. Therefore, when modeling steelhead locomotion it is logical to set the minimum water depth to be equal to or greater than the body depth of the fish.

Unlike body length, body depth is not often measured. However, a body depth to length ratio of 0.222 for steelhead has been established (FishBase, 2006). The largest steelhead in the population is approximately 32 inches in length, which gives a corresponding body depth of 0.60 feet.

**Therefore, for fish routing purposes a minimum required water depth of 0.60 feet is used.**

#### Water Depth for Resting

Although not ideal, steelhead are often observed resting in waters just deep enough to submerge their body. For modeling fish passage conditions we allowed the fish to rest as long as the depth was 0.6 feet deep and the water velocity was less 1 BL/s. However, for developing alternatives for providing resting pools, a water depth of 2 feet was set as the design criteria. This is intended to provide sufficient cover to reduce risk of predation and address behavioral factors.

### 4.4.9 Consideration of Model Assumptions and Limitations

Although the developed fish passage population model, Fish_REALMS, provides a more realistic representation of passage conditions than commonly used deterministic approaches, such as FishXing (USFS, 2007), it does have some important assumptions and limitations that should be considered when evaluating its results. Some of the key assumptions include:

**Fish swims along a route that minimizes its energy expenditure**

Given the velocity distribution within Unit 3, the preferred fish route is nearly always along either side of the channel, where the water is just deep enough to meet the 0.6 foot depth requirement. Therefore, assumption 1 seems reasonable.

**Fish swims at a distance-optimizing speed**
The results from steelhead swimming tests presented in Weaver (1963) strongly suggest that steelhead swim close to their distance-optimizing speed when swimming in prolonged mode. However, undoubtedly the speed of each steelhead will vary from the distance-optimizing speed to some extent. Therefore, any deviation from the distance-optimizing speed reduces the proportion of steelhead able to ascend Unit 3.

**Fish fully recovers from fatigue when encountering resting habitat**
The assumption that steelhead fully recovers from fatigue when resting in a pool could likely skew the results to predict substantially higher passage success than may actually occur. Research has found full recovery can take 3.5 hours or longer, while observations of steelhead swimming in Unit 3 and swimming in natural streams suggest they typically only rest for short periods (minutes rather than hours) before continuing swimming upstream. This is likely sufficient to allow for at least 50% recover from fatigue (Brett, 1964). However, the fish would not be able to swim as far before becoming exhausted if beginning partially fatigued. Unfortunately, the resting pattern of a fish is highly behavioral and not widely study, making it very difficult to incorporate into the model.

Fish_REALMS is developed using the limited available information on the swimming capabilities and behaviors of steelhead, and fish in general. The quantitative results presented in this report should not be interpolated as definitive. The results from the model are intended to allow for direct comparison of fish passage alternatives, provide guidance and inform the decision-making process.

# 5 Existing Fish Passage Conditions

The fish routing, locomotion and energetics model (Fish-REALMS) was used to evaluate existing upstream passage conditions through Unit 3 for returning adult steelhead. Using a stochastic approach, the model accounts for the variation in swimming abilities and fish size to estimate the percent of the population that can successfully ascend the flood control channel at a specific flow and tidal condition.

The model begins at station 341+78, 300 feet upstream of the College of Marin Pedestrian Bridge, and stops at the end of the concrete channel. Passage conditions over the Denil fish ladder are not accounted for in the results. Fish passage conditions were evaluated at the low passage design flow (14 cfs), the high passage design flow (177 cfs), and at four flows in-between (23 cfs, 40 cfs, 77 cfs, and 113 cfs). At each of these flows passage conditions were assessed at three different tidal conditions: mean higher high water (MHHW), mean tide level (MTL), and at mean lower low water (MLLW).

## 5.1 Occupied Water Velocities and Depths

The optimum swimming route through Unit 3 at each of the 6 flows was determined from the 2-D model results. The one constraint placed on the fish's route is that the water must be at least 0.6 feet deep to ensure that the steelhead is fully submerged. To calculate the average water velocity and depth along the route at each cross section, the fish's body is assumed to occupy a two-foot wide area. The water depths and velocities encountered by the fish as it swims along the route are referred to as the occupied water velocities and depths. These are plotted for 14 cfs and 177 cfs at the MLLW tidal condition (Figure 5.1 and Figure 5.2). Occupied water velocities and depths for all six evaluated flows are provided in Appendix B.

At 14 cfs, the low fish passage design flow, there remains sufficient depth throughout the channel, but the fish must often swim along the center of the channel where the highest water velocities occur. Within the first 200 feet of channel water velocities slowly rise as the tidal backwater effect decreases. Between Station 344+00 and 350+85 there are no tidal influences and no existing resting pools, resulting in a relatively constant occupied water velocity averaging 3.1 ft/s. In the channel reach with pools velocities become much more variable. The pools reduce velocities much below 2 ft/s. However, depths within the pools are never more than 1.2 feet.

At 177 cfs, the high fish passage design flow, the occupied water depth remains above 1 foot throughout most of the channel and exceeds 2 feet deep in seven of the existing pools. The pools located in the channel bend near Station 355+00 appear to function best. However, most of the other pools fail to reduce water velocities to less than 2 ft/s. Occupied water velocities throughout the channel are highly variable. In the 900 foot long reach with no pools the occupied water velocities averages 5.6 ft/s and peaks at 7.4 ft/s. Further upstream in a section between pools the occupied water velocity peaks at 8.0 ft/s. Given the distances involved, these water velocities are extremely challenging to a migrating adult steelhead and result in fatigue relatively quickly.

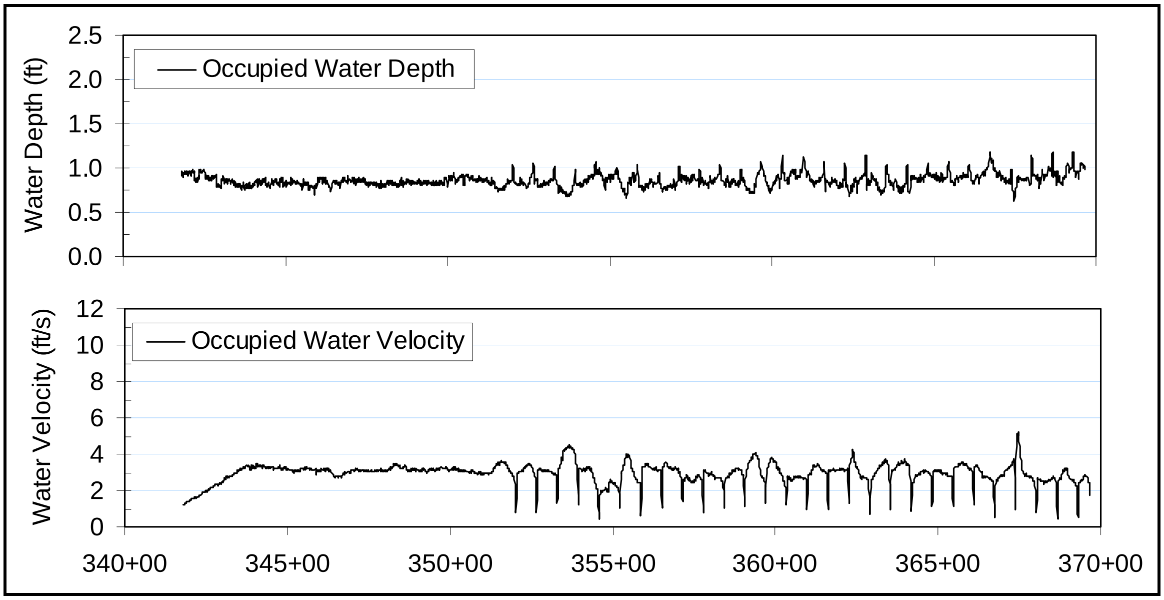


**Figure 5.1** – At 14 cfs and tidal conditions equal to MLLW, the "occupied" water velocities and depths encountered by the fish along its swimming route through Unit 3.

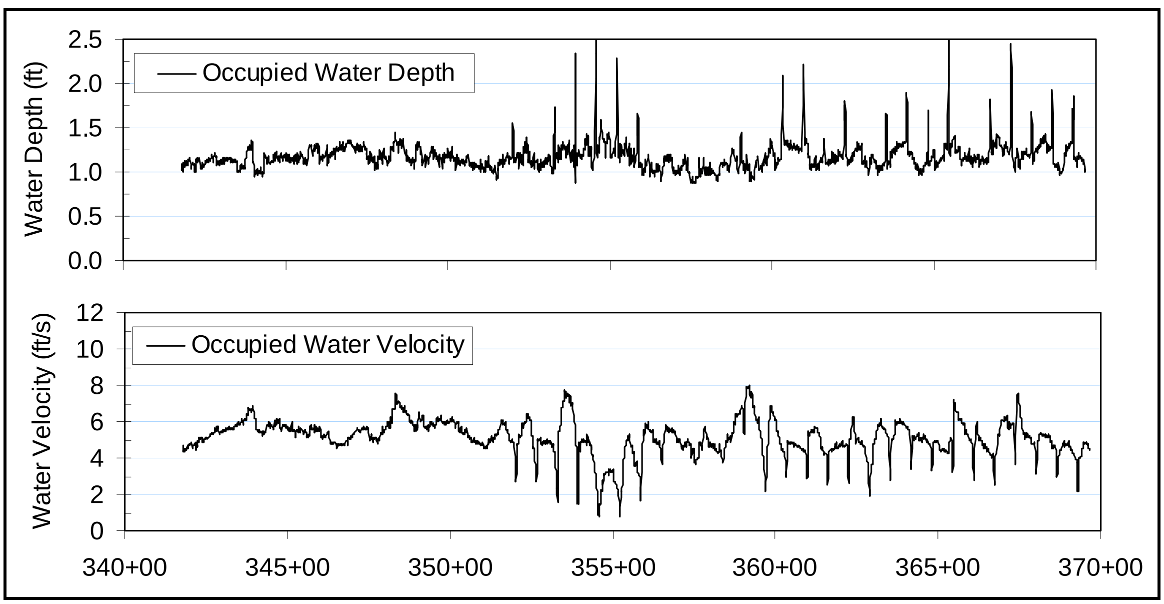


**Figure 5.2** – At 177 cfs and tidal conditions equal to MLLW, the "occupied" water velocities and depths encountered by the fish along its swimming route through Unit 3.

## 5.2 Fish Passage Performance

### 5.2.1 Resting Habitat Provided by Existing Pools

As part of the fish passage assessment, the hydraulic performance of the existing pools was evaluated to determine if they provide resting habitat at fish passage flows. Resting habitat must be an area at least 2 feet long by 2 feet wide containing water velocities less than 2 BL/s and water depth of at least 0.6 feet, the lowest possible resting depth. Evaluation of the existing pools found they provide resting habitat at the analyzed flows of 14 cfs, 23 cfs and 40 cfs, and to a lesser extent at 77 cfs. At 113 cfs and 177 cfs only a select few of the existing pools provided suitable resting habitat, resulting in excessively long sections of channel with no areas for fish to rest.

Therefore, the existing pools only provide resting habitat for roughly half of the fish passage design flow range. And, this resting habitat is less than ideal due to the associated shallow water depths provided in the pools.

### 5.2.2 Passage Efficiency Relative to Flow and Tidal Conditions

Results from Fish_REALMS for existing conditions found tidal conditions in Unit 3 are as important a factor influencing fish passage as flow magnitude. The lower 900 feet of the modeled reach does not contain existing resting pools and at MLLW tidal condition this section of channel is not tidally backwatered. The result is an excessively long reach with relatively swift water velocities and no resting opportunities. As a result, nearly the entire population of steelhead are unable to ascended Unit 3 at any of the assessed fish passage flows during low tide (Table 5.1).

As the tide increases the distance steelhead can swim up the channel at sustained speeds (results in no fatigue) extends further upstream (Figure 5.3). At MHHW the tidal backwater extends well upstream of the first existing resting pool (Station 350+85) at all of the assessed migration flows. This enables nearly the entire steelhead population to be capable of ascending Unit 3 at 40 cfs and below. However, at 77 cfs and 113 cfs many of the existing resting pools fail to provide resting habitat for the smaller and weaker swimming fish, resulting in a substantial decline in the proportion of fish able to ascend Unit 3. At the high fish passage design flow of 177 cfs nearly all of the existing pools fail to provide resting habitat, resulting in only 4% of the population able to ascend Unit 3 at MHHW.

**Table 5.1** – Estimated proportion of steelhead population capable of ascending Unit 3 at various fish passage flows and tidal conditions.

| | Percent Successful | | | | | |
|---|---|---|---|---|---|---|
| **Tide** | **14 cfs** | **23 cfs** | **40 cfs** | **77 cfs** | **113 cfs** | **177 cfs** |
| **MLLW** | 7 | 2 | 2 | 2 | 2 | 1 |
| **MTL** | 98 | 85 | 51 | 13 | 7 | 1 |
| **MHHW** | 99 | 92 | 97 | 73 | 54 | 4 |

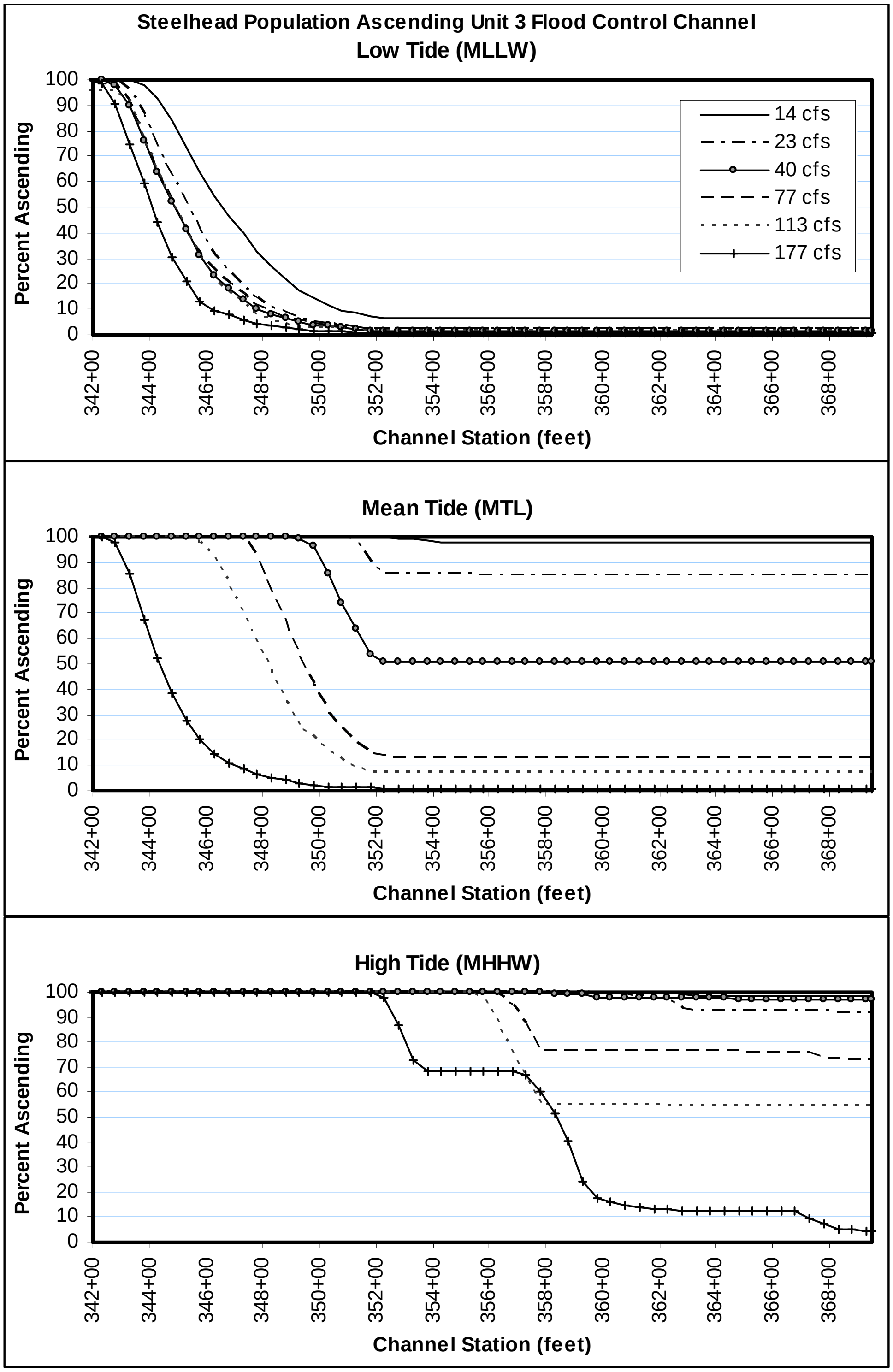


**Figure 5.3** – Existing steelhead passage conditions. Percent of individual adult steelhead from the population capable of reach the corresponding Unit 3 channel station at a given flow and tidal condition. The existing resting pools begin at Station 350+85.

# 6 Resting Pool Alternatives

## 6.1 Resting Pool Objectives and Criteria

The objective of the resting pools is to provide locations that steelhead and coho salmon are able to rest and recover from fatigue at flows between 14 cfs and 177 cfs, thus avoiding exhaustion. The pool designs should also strive to avoid excessive sedimentation and require minimal maintenance.

The physical criteria developed for evaluating suitability of resting pool alternatives at fish passage design flows within the existing concrete channel are:

1. Minimum water depth in the pool of 2 feet to provide suitable "cover" and reduce risk of predation.
2. Water velocities occupied by the fish must be less than 1 BL/s to allow for rest and recovery from fatigue (see section 4.4.6 for explanation). For evaluating effectiveness of pool alternatives, 2 ft/s was used.
3. Velocity and depth criteria in the pool must be satisfied within a minimum horizontal area of 2 ft wide x 2 ft long to provide fish sufficient space to hold and rest.
4. Minimize potential for sedimentation within the pool.

### 6.1.1 Justification of Minimum Pool Depth Criteria

In addition to the requirement of slow water velocities within resting pools, it is also necessary to ensure that the pools have sufficient depth. Depth within the pool provides cover from overhead predation. If a fish feels vulnerable to predation, it may not utilize the resting pool. Bates (2001) recommends providing at least 2.5 feet of cover for Pacific salmon and steelhead. Others recommend a minimum water depth of 2 feet for pools within a pool and weir fish ladder (CDFG 1998; FAO/DVWK, 2002).

Based on recommendations from these references, a minimum water depth for design of resting pools was set at 2.0 feet at the low fish passage design flow (14 cfs), with the expectation that water depth will quickly increase at higher migration flows.

### 6.1.2 Sedimentation

Pools within the concrete channel have the potential to accumulate sediment. The volume of sediment that will accumulate in pools depends on the upstream sediment supply (volume and gradation of material available to the channel) and flows capable of mobilizing and transporting the bed material downstream. The volume and location of sedimentation in the pools has important implications for resting habitat. Deposition has the potential to change the flow field, affecting velocity in the resting habitat and potentially decreasing flow depth below that required for resting habitat. Excessive deposition would require regular cleaning of the pools. Thus, a preferred resting pool alternative should minimize the potential for sediment deposition.

## 6.2 Resting Pool Evaluation Process

Alternative pool shapes were evaluated in two pilot reaches typical of Unit 3; a straight section and a reach that contains a bends (meanders). Within each pilot reach a single new pool was inserted and the resulting pool hydraulics were evaluated to determine if the pool was suitable for resting at flows 14 and 177 cfs (low and high fish passage design flows). Based on results from analysis of the first two resting pool alternatives, a third alternative was developed and analyzed. From the results of this analysis and from agency and stakeholder input, a preferred pool shape was selected for straight and curved sections of channel.

### 6.2.1 Sediment Mobility Analysis

The magnitude and distribution of pool sedimentation can alter pool hydraulics and potentially reduce the resting area in design pools. A preliminary analysis of the effect of the design pools on sediment mobility within the channel was conducted to determine whether there are significant differences in mobility between pool alternatives and whether a comprehensive sedimentation study is warranted.

Sediment mobility is a descriptor of the potential for sediment to move. An array of identically sized particles placed in immobile (stable), partially mobile and fully mobile zones on a stream bed are expected to behave in predictable ways. All particles in the stable areas are expected to remain in place. In the partially mobile areas, some particles are expected to move, while others will remain stationary. In fully mobile areas, all particles are expected to move at least once.

Shields parameter is a non-dimensional shear stress and is commonly used as an estimate of sediment mobility (Wilcox and McArdell 1993, Buffington and Montogomery, 1997). Shields parameter can be directly computed with a hydraulic model and known grain size of the bed material according to the equation :

$$\theta = \frac{\tau_0}{(\rho_s - \rho)gD}$$

where

$\tau_o$ = bed shear stress
$\rho_s$ = sediment density
$\rho$ = water density
$g$ = gravitational constant
$D$ = grain size

Changes in the patterns of sediment mobility affect patterns of scour and fill. Areas that are mobile have the potential to both scour and fill, while immobile areas can only fill. While sediment mobility can indicate potential changes to the sediment transport field, it is not a prediction of scour or fill. Depth of scour and fill is dependent on imbalances in local sediment supply and transport. For instance, if sediment is transported from a fully mobile area, scour would occur if sediment was not delivered from upstream to replace it, and fill would occur if more sediment was delivered from upstream than transported out. If sediment is supplied to a location on the stream bed exactly equal to the rate that sediment is removed from that location no scour or fill would occur. Generally, patterns of transport are variable such that sedimentation is likely to occur when sediment crosses zones of decreasing mobility and scour is likely to occur where sediment mobility is increasing. Changes in sediment mobility are, therefore, indicators of possible changes in sedimentation patterns.

Sediment in areas of Shields parameter less than 0.03 are considered immobile and is generally well accepted in the literature. The value of the Shields parameter that delineates full and partial mobility has varies in field and flume studies. The two most common values in use are 0.045 and 0.06. For the purposes of this study, the magnitude of the Shields parameter is less important than the shift in the degree of mobility. Categories for discussion purposes are designated as stable (0-0.03), partially mobile (0.03-0.045), partial-fully mobile (0.045-0.06) and fully mobile (>0.06). The characteristic grain size ($D_{50}$) of the bed material in Corte Madera Creek at Ross is 8 mm (Copeland, 2000).

Changes in sediment mobility within the concrete channel are irrelevant if no sediment is available to transport. Therefore, sediment mobility is evaluated at a flow that significant sediment transport occurs relatively frequently (1.5 yr recurrence flow, 1383 cfs). The 1.5 year recurrence flow was estimated from the annual peak flow record for USGS Corte Madera Creek gaging station at the Lagunitas Road Bridge in Ross (31 years of record). The actual recurrence interval of the flow is not critical for this analysis because this exercise is to simply demonstrate whether there is a significant difference in the sediment mobility field between the pool alternatives and whether those differences are occurring in fish resting areas.

## 6.3 Resting Pool Alternatives

As an initial test of the resting pool concept, a simple 10 ft wide by 10 ft long resting pool with a level pool bottom placed 1.5 ft below the channel invert was modeled at 177 cfs. Two scenarios were examined; pool placed in center of the channel and pool placed along one side of the channel. From these initial trials it became apparent that placing the pool to one side produced more desired water velocities since there is less flow entering along the side of pool at fish passage flows. Therefore, all three proposed alternatives have the pools placed to one side of the channel. To minimize heating from solar radiation, the pools in the straight reaches are placed on the right side of the channel (looking downstream) where practical.

### 6.3.1 Existing Pools

The hydraulic conditions created by the existing resting pools within the straight and curved pilot reaches were evaluated for comparison to the performance of the three alternatives. The existing pools are 4 feet long, 13 feet wide, and the bottom is flat and placed approximately 0.1 feet below the channel invert (Figure 6.1).

Based on the model results, the existing pools fail to satisfy the project's resting pool criteria at 14 cfs in both the straight and curved reaches due to lack of depth (Table 6.1, Figures 6.2 through 6.4). At 177 cfs there is sufficient depth but velocities are excessive within the pools. The existing pool in the curved reach has a small area (4.3 $ft^2$) containing water velocity less than 2 ft/s. However, this area is less than 2 feet wide, which fails to meet one of the resting habitat criteria. The pools also fail to provide 2 feet of depth at nearly all migration flows.

The mobility analysis for the $D_{50}$ (median) particle size indicates that the entire pool is fully mobile at the 1.5 year return flow (Figure 6.5). Little sediment has been observed in existing pools suggesting that sediment supply is currently less than the sediment transport capacity of the channel.

### 6.3.2 Alternative 1

Alternative 1 was designed to provide more than 2 feet of water depth at 14 cfs and sufficient pool volume to avoid excessive turbulence within the outer four feet of the pool at 177 cfs (Figures 6.6 and 6.7). The horizontal pool bottom is set 1.5 feet below the channel invert and the outer edge of the pool is within a few feet of the predicted waters edge at 177 cfs, to reduce velocities in the pool. The downstream end of the pool has a gradual transition to steadily accelerate flow out of the pool and promote sediment flushing. The upstream face of the pool is vertical to help promote scouring and minimize sedimentation within the head of the pool.

Based on the model results, this alternative provides suitable water depth and velocities to allow fish to rest at the low and high fish passage design flows of 14 cfs and 177 cfs, respectively (Table 6.1, Figures 6.8 through 6.10). The mobility analysis for the $D_{50}$ (median) particle size indicates that less than half of the resting area provided at 177 cfs is fully mobile at the 1.5 year return flow (Figure 6.11). If sediment supply is greater than the transport capacity in the partially mobile zone, sediment could accumulate in the pool, change flow patterns and reduce the suitable resting pool area.

### 6.3.3 Alternative 2

Alternative 2 is a less complex shape and likely less costly to construct. It has vertical walls on all four sides and the horizontal pool bottom is 1 foot below the channel invert (Figure 6.12 and 6.13). This alternative is intended to provide exactly 2 feet of water depth at 14 cfs. Like Alternative 1, the outlet edge of the pool is near the waters edge at 177 cfs. Keeping the depth to the minimal allowed is expected to increase sediment mobility relative to Alternative 1. To further reduce velocities within the outer portion of the pool, the leading edge is slightly skewed to direct flow back towards the center of the channel. This is also intended to help keep the pool scoured and avoid sedimentation.

Based on the model results, this alternative provides suitable water depth and velocities to allow fish to rest at the low and high fish passage design flows of 14 cfs and 177 cfs, respectively (Table 6.1, Figures 6.14 through 6.16). Alternative 2 provides approximately half the resting area compared to Alternative 1. The mobility analysis for the $D_{50}$ particle size indicates slightly higher Shields stress then Alternative 1 (Figure 6.17). If sediment supply is greater than the transport capacity in the partially mobile zone, sediment could accumulate in the pool, change flow patterns and reduce the suitable resting pool area.

### 6.3.4 Alternative 3

Alternative 3 was developed based on results from the previous two alternatives. Relative to Alternative 2, Alternative 1 provides a larger resting area at 177 cfs but lower mobility of bed material at the 1.5 year flow. The design objective of Alternative 3 was to modify Alternative 1 to increase mobility while maintaining similar resting area at 177 cfs. The Alternative 3 pool shape matches that of Alternative 1, but also includes a 16 ft long by 8 ft wide triangular wedge at the upstream end of the pool that is set equal to the existing elevation of the channel invert (Figure 6.18 and 6.19). The upstream transition was expected to increase the amount and velocity of flow entering the lateral edge of the pool, thus increasing mobility of bed material.

Based on the model results, this alternative provides suitable water depth and velocities to allow fish to rest at the low and high fish passage design flows of 14 cfs and 177 cfs, respectively (Table 6.1, Figures 20 through 22). This alternative provides equivalent resting habitat to Alternative 1 at low flows. Resting habitat is reduced in the straight reach by 21% and increased in the curved reach by 19%. The mobility analysis for the $D_{50}$ particle size indicates that more all of the resting area provided at 177 cfs is either fully mobile or partial-fully mobile and at the 1.5 year return flow (Figure23). If sediment supply is greater than the transport capacity in the partially mobile zone, sediment could accumulate in the pool, change flow patterns and reduce the suitable resting pool area. Alternative 3 provides a balance between Alternatives 1 and 2 for maximizing area of resting habitat and sediment mobility.

### 6.3.5 Use of Pools by Multiple Resting Fish

During a spawning run, multiple steelhead can be expected to migrate upstream at the same time. Therefore, resting pools should be able to accommodate more then one fish at a time. Bates (1992) recommends providing 0.4 cubic feet of pool volume per pound of fish. Assuming conservatively that the average sized steelhead weights 5 pounds, it would require at least a 2.0 cubic foot area of suitable resting pool habitat. Using the resting habitat area and depth provided in Table 6.1, the available resting volume can be determined. Alternative 2 at 177 cfs provides the least resting volume at 59.4 cubic feet, which is sufficient for 29 adult steelhead. It is unlikely that this many steelhead would be in one pool at one time in Corte Madera Creek. However, sedimentation could substantially reduce the volume of available resting habitat.

**Table 6.1** - Summary of results for the resting pool alternatives in the straight and curved pilot reaches. Resting Area Habitat is defined as the portion of the pool having water depth greater than 2 ft and water velocities less than 2 ft/s.

| Metric | Existing Pools | | Alternative 1 | | Alternative 2 | | Alternative 3 | |
|---|---|---|---|---|---|---|---|---|
| | Straight Reach | Curved Reach | Straight Reach | Curved Reach | Straight Reach | Curved Reach | Straight Reach | Curved Reach |
| Resting area habitat ($ft^2$): | | | | | | | | |
| At 14 cfs | 0[1] | 0 | 107 | 99 | 48 | 43 | 108 | 95 |
| At 177 cfs | 0[2] | 4.3[3] | 37 | 58 | 18 | 18 | 29 | 72 |
| Depth in resting habitat (ft): | | | | | | | | |
| At 14 cfs | NA | NA | 2.5 | 2.4 | 2.0 | 2.0 | 2.5 | 2.3 |
| At 177 cfs | NA | 2.3 | 3.4 | 3.3 | 3.3 | 3.3 | 3.6 | 3.3 |
| Velocity in resting habitat (ft/s): | | | | | | | | |
| At 14 cfs | NA | NA | 0.6 | 0.5 | 0.6 | 0.8 | 0.7 | 0.6 |
| At 177 cfs | NA | 1.4 | 1.0 | 0.9 | 1.2 | 0.8 | 1.0 | 1.0 |
| Average Shields stress at 1,383 cfs within resting habitat[4] | NA | 0.080 | 0.052 | 0.052 | 0.053 | 0.059 | 0.057 | 0.068 |

[1] Depth less than 2 ft

[2] Water Velocity greater than 3.5 ft/s

[3] The resting area is less than 2 feet wide, technically failing to meet satisfy resting pool criteria

[4] Resting habitat at 177 cfs.

**Figure 6.1** – Schematic drawing of existing resting pool configuration in plan, profile and section.

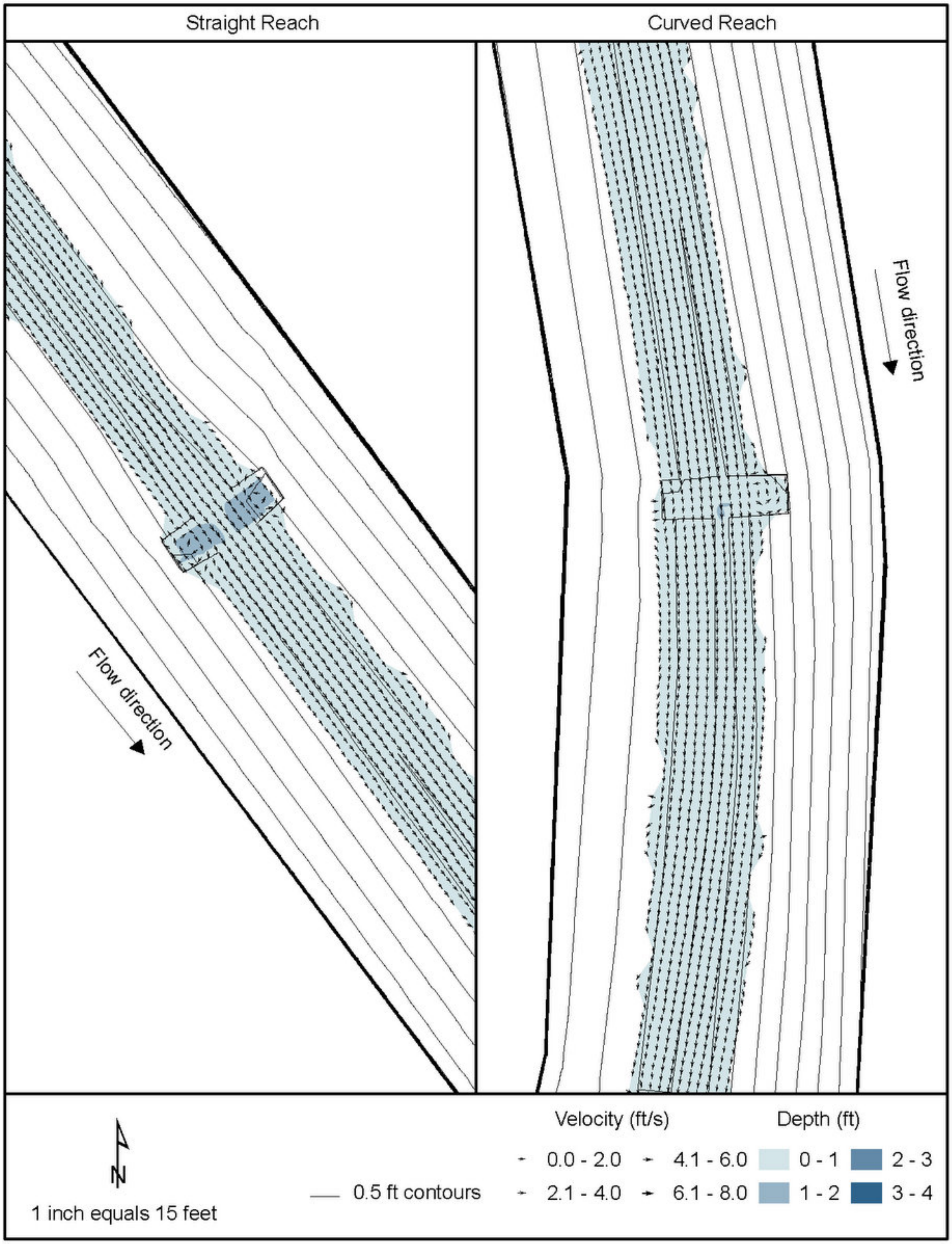


**Figure 6.2** – Existing water depth and velocity field at the low passage design flow of 14 cfs. No resting habitat exists due to low flow depths.

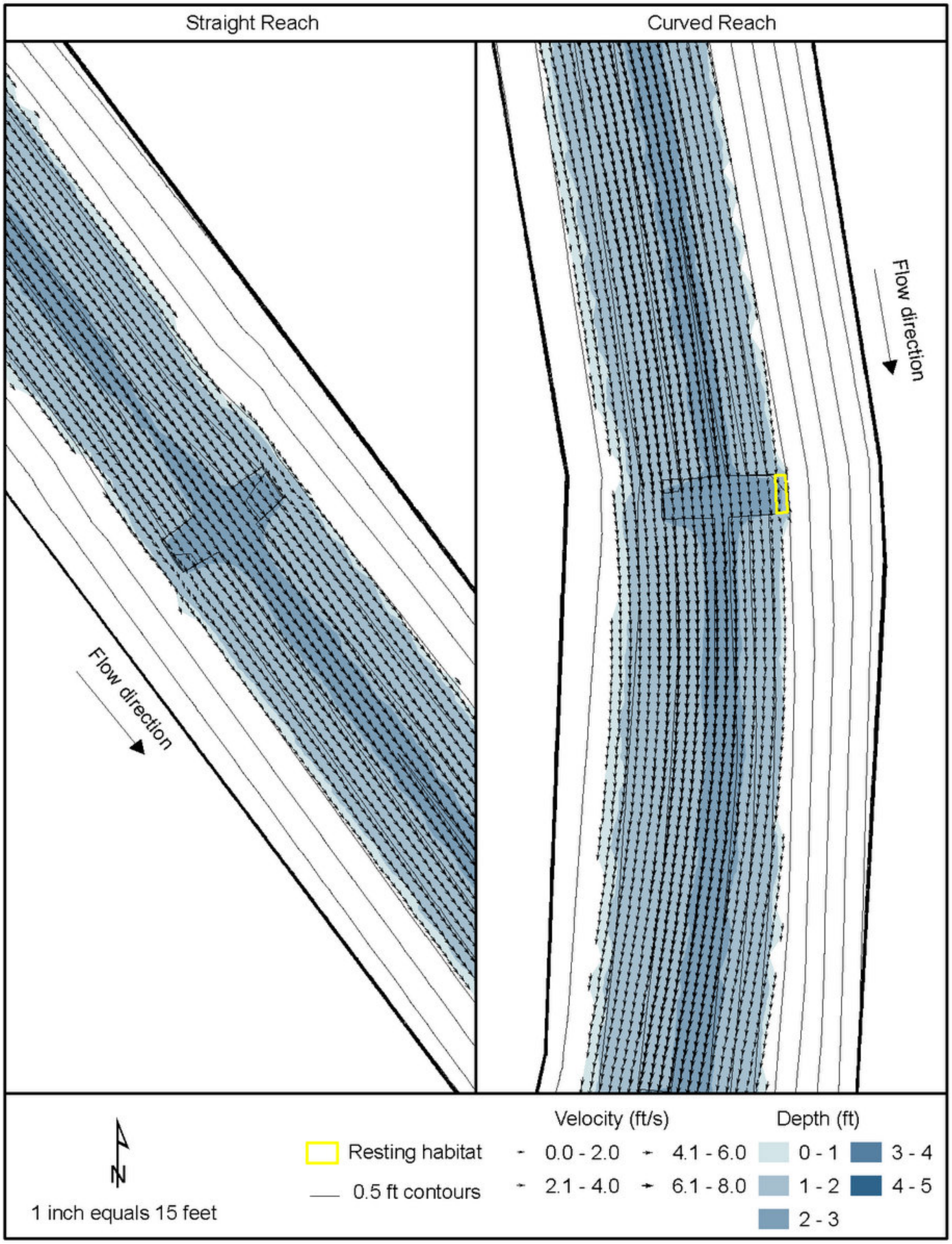


**Figure 6.3** – Existing water depth and velocity field at the high passage design flow of 177 cfs. Resting habitat is not large enough for a fish to hold.

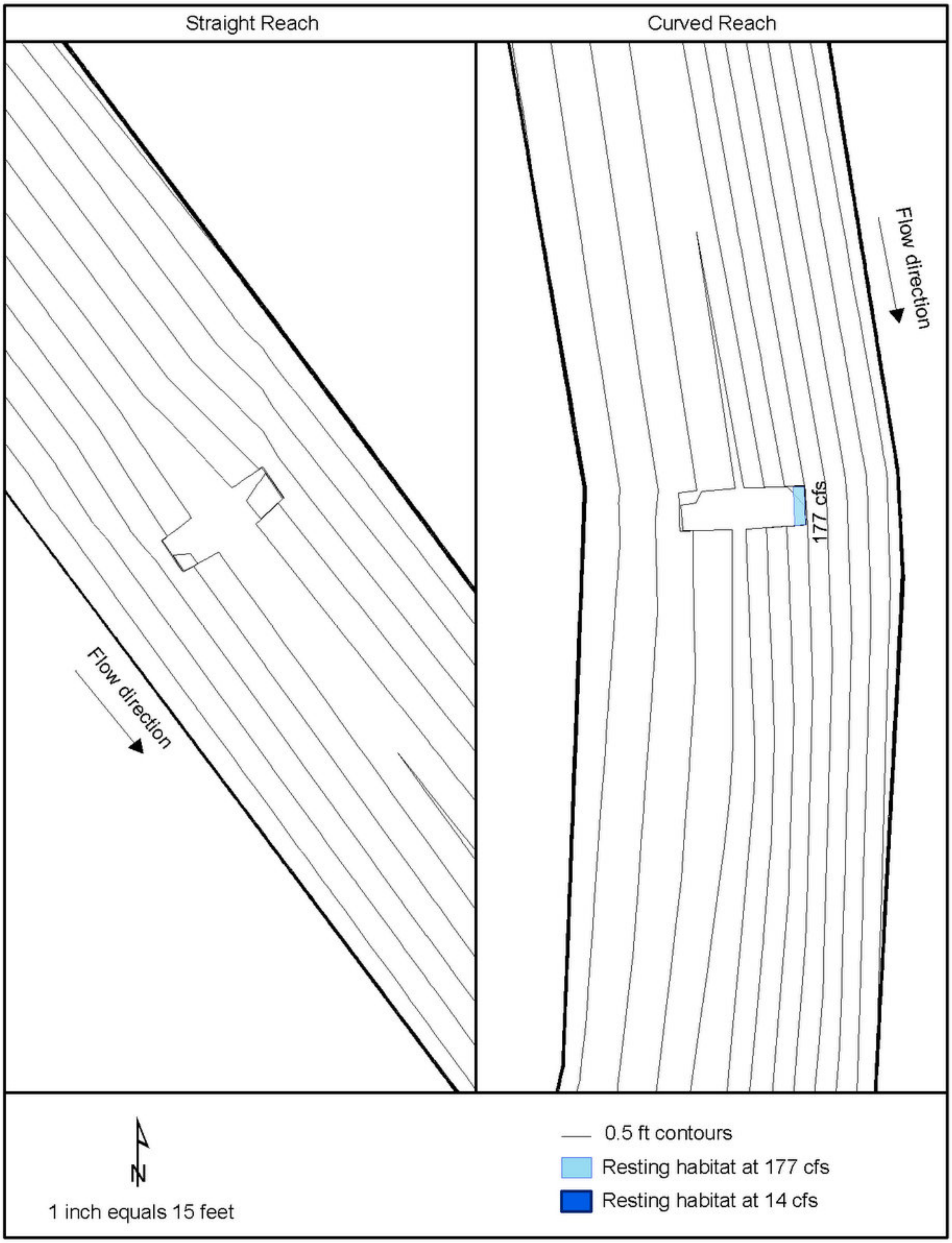


**Figure 6.4** – Existing available resting pool habitat at 14 cfs and 177 cfs

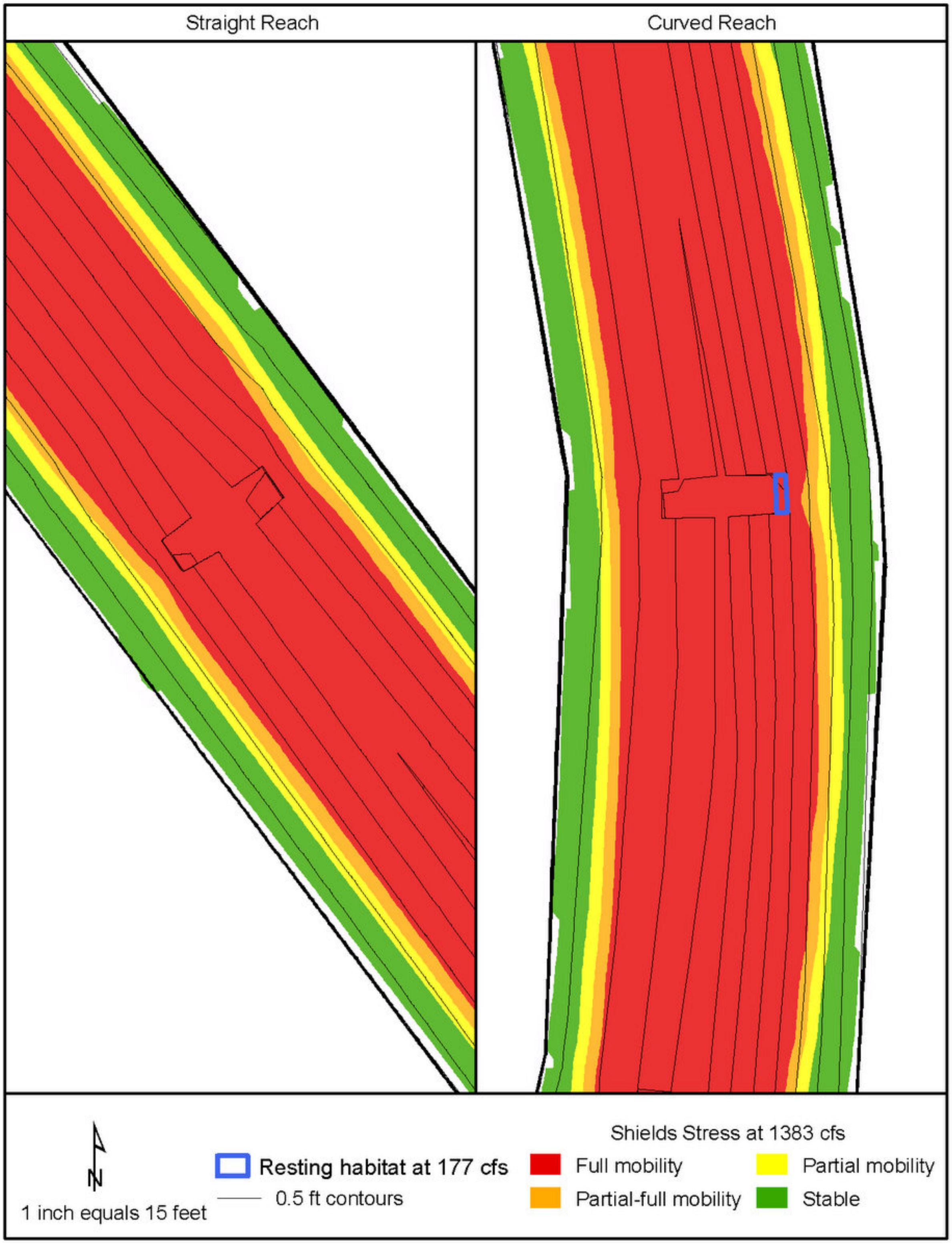


**Figure 6.5** – Existing predicted mobility of streambed material at the 1.5 year return flow of 1,383 cfs

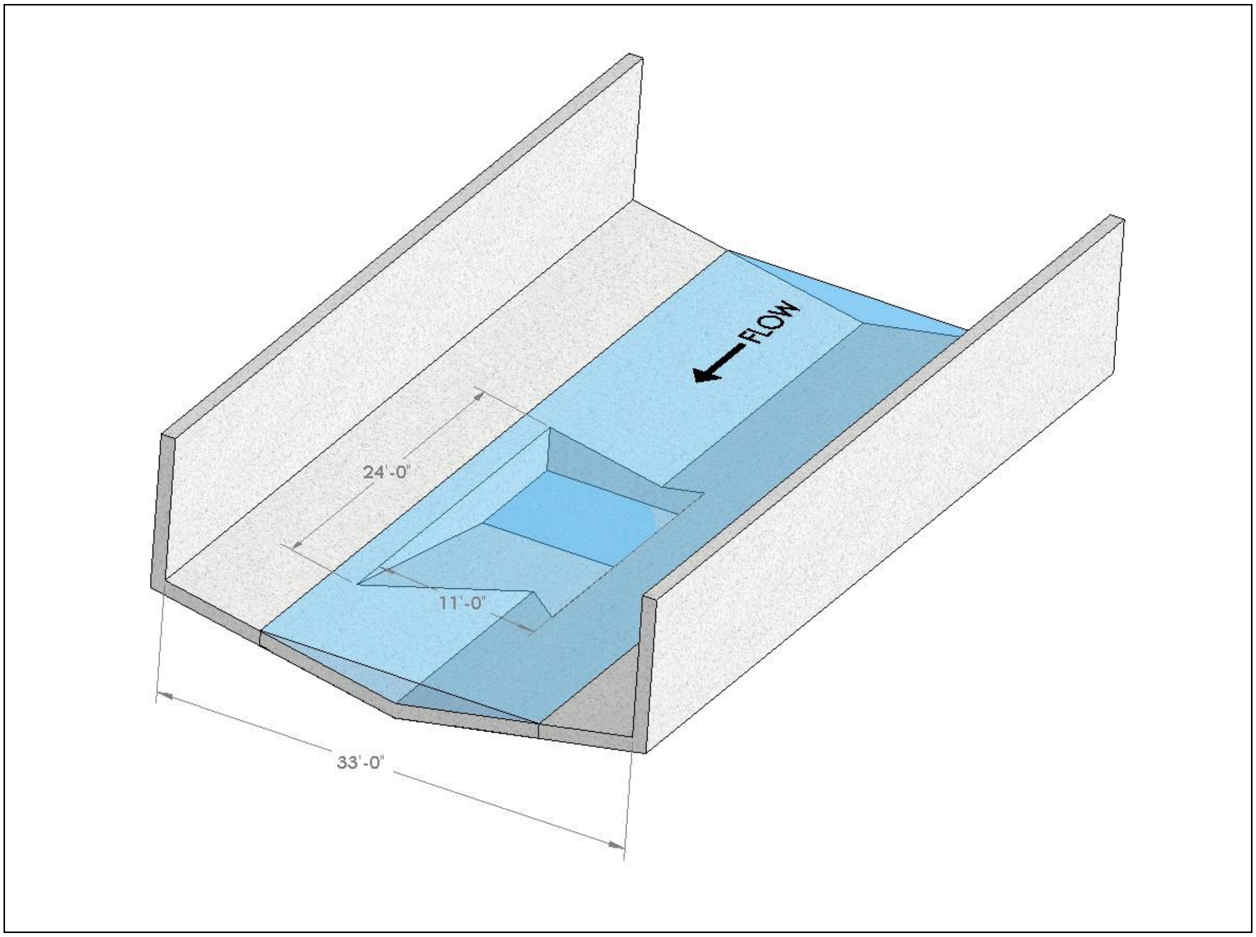


**Figure 6.6** – Isometric drawing of Alternative 1 resting pool.

**Figure 6.7** – Schematic drawing of Alternative 1 resting pool in plan, profile and section.

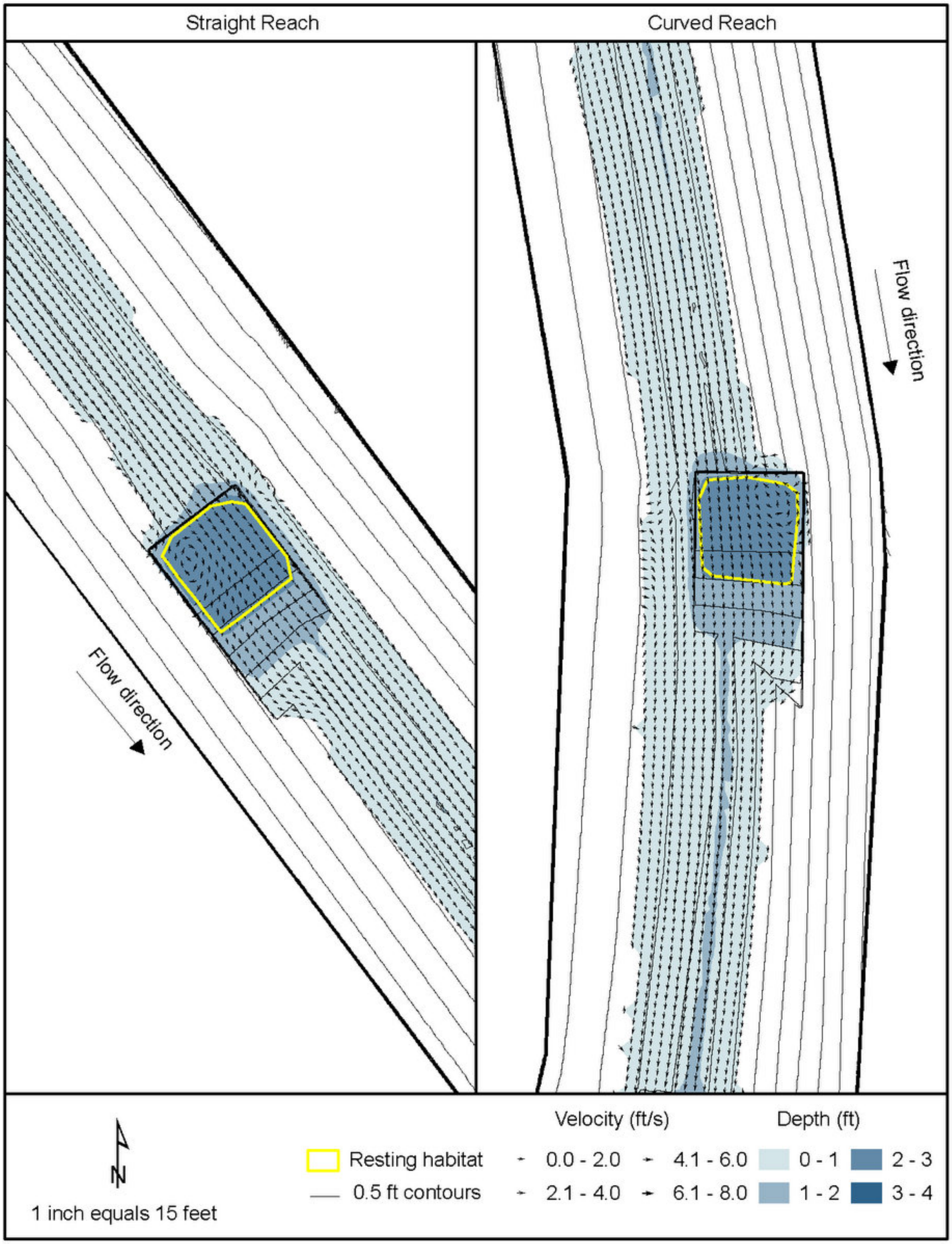


**Figure 6.8** – Alternative 1 water depth, water velocity field, and available resting habitat at the low passage design flow of 114 cfs.

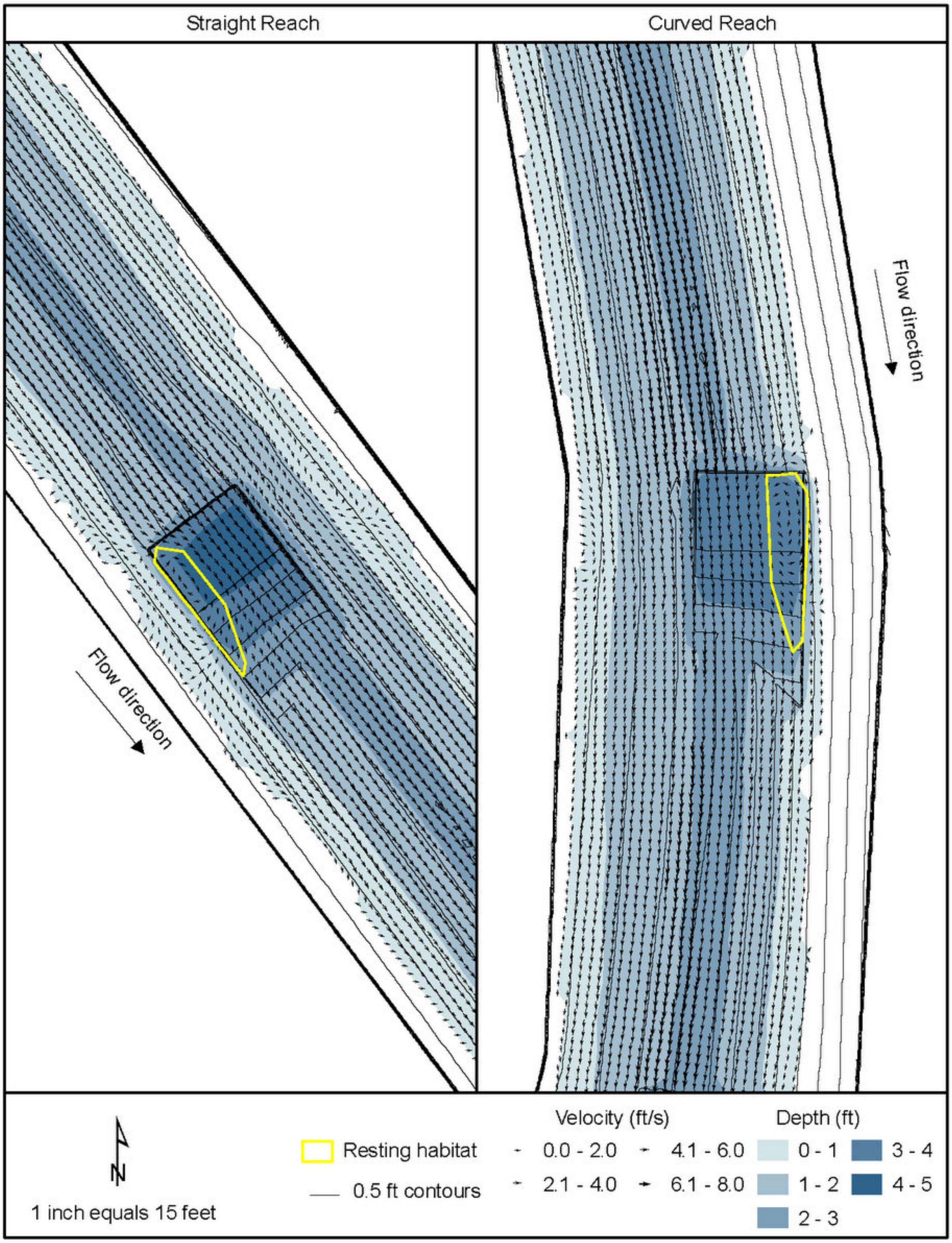


**Figure 6.9** – Alternative 1 water depth, water velocity field, and available resting habitat at high passage design of 177 cfs.

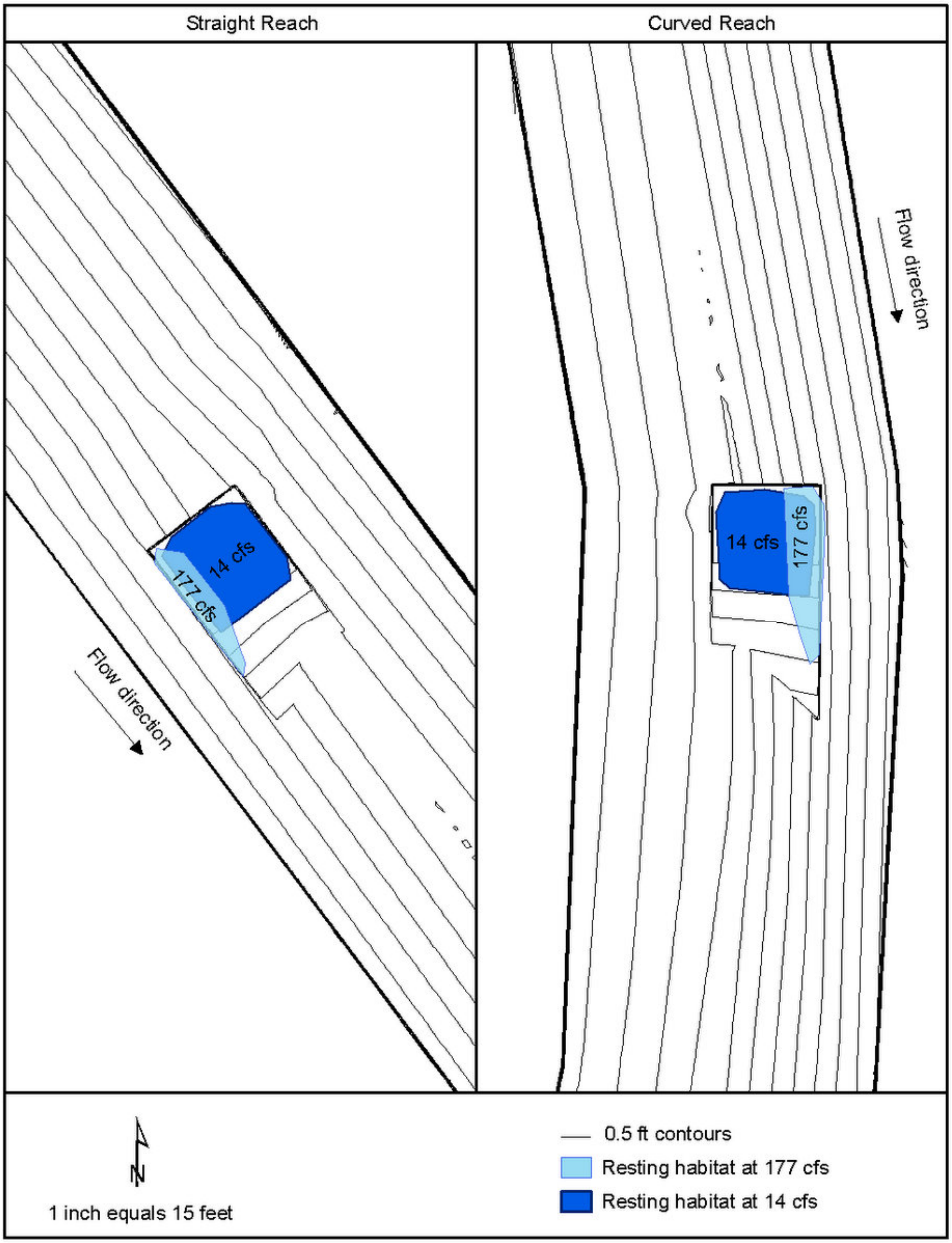


**Figure 6.10** – Alternative 1 available resting pool habitat at 14 cfs and 177 cfs.

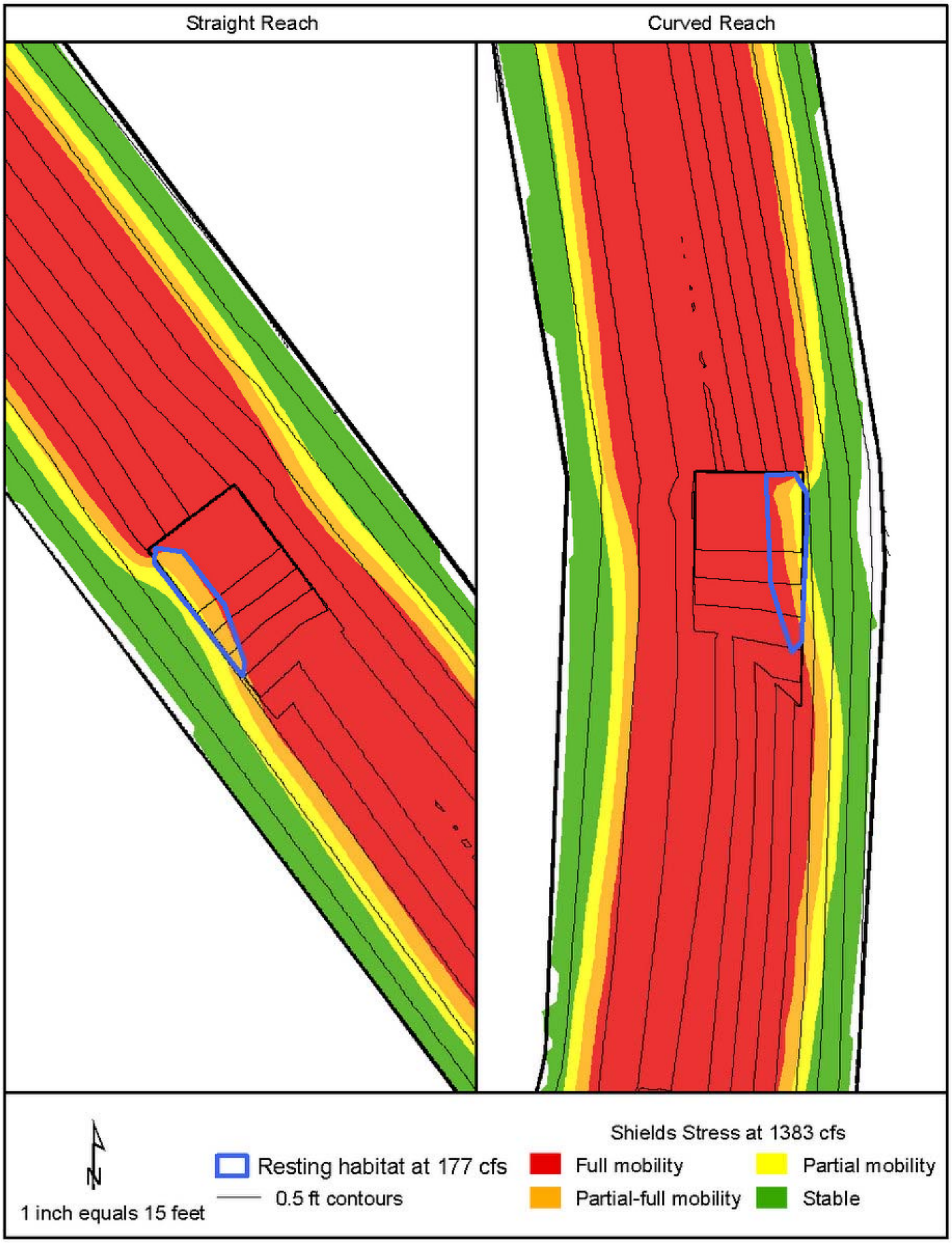


**Figure 6.11** – Alternative 1 predicted mobility of streambed material at the 1.5 year return flow of 1,383 cfs.

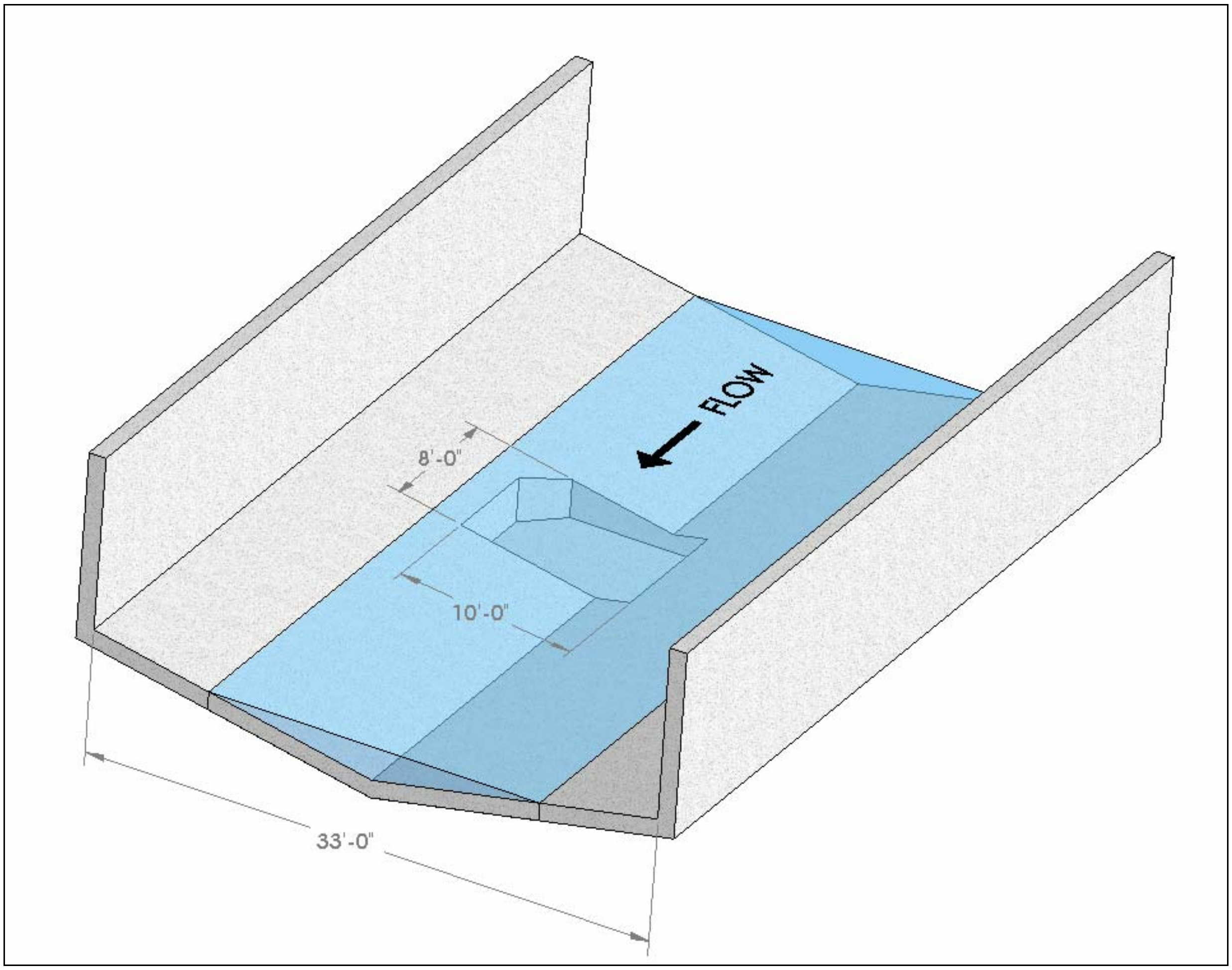


**Figure 6.12** – Isometric drawing of Alternative 2 resting pool.

**Figure 6.13** – Schematic drawing of Alternative 2 resting pool in plan, profile and section.

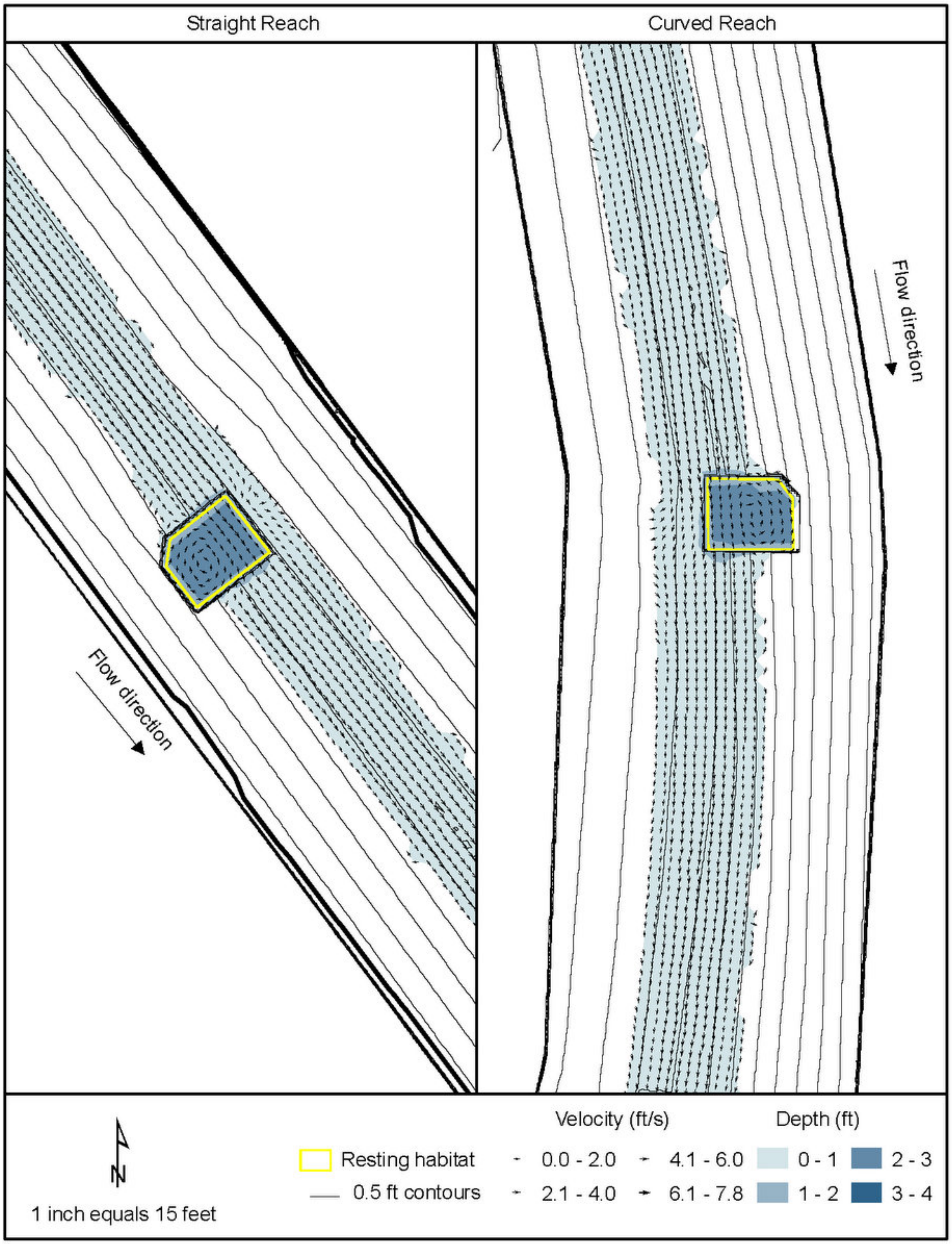


**Figure 6.14** – Alternative 2 water depth, water velocity field, and available resting habitat at the low passage design flow of 114 cfs.

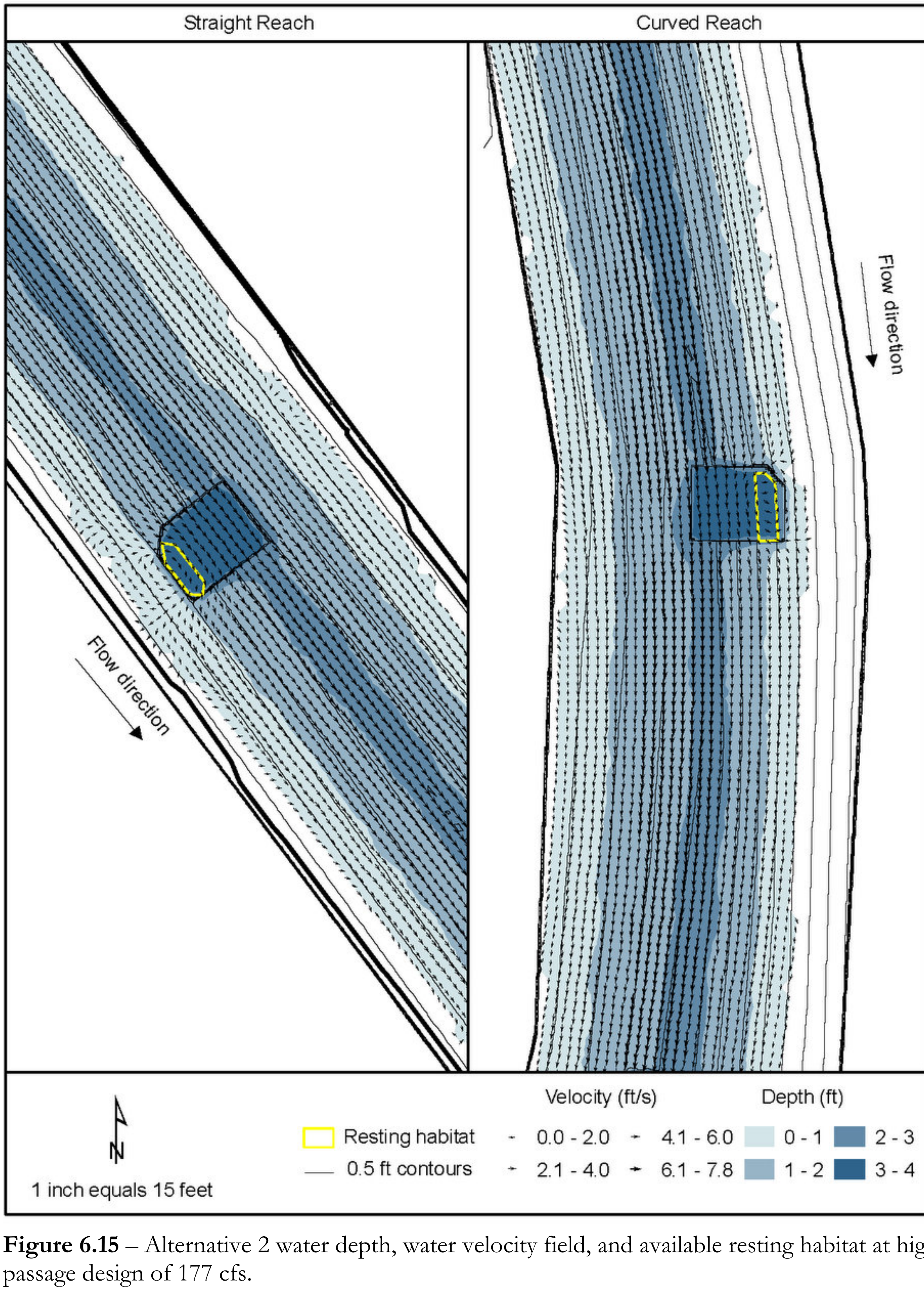


**Figure 6.15** – Alternative 2 water depth, water velocity field, and available resting habitat at high passage design of 177 cfs.

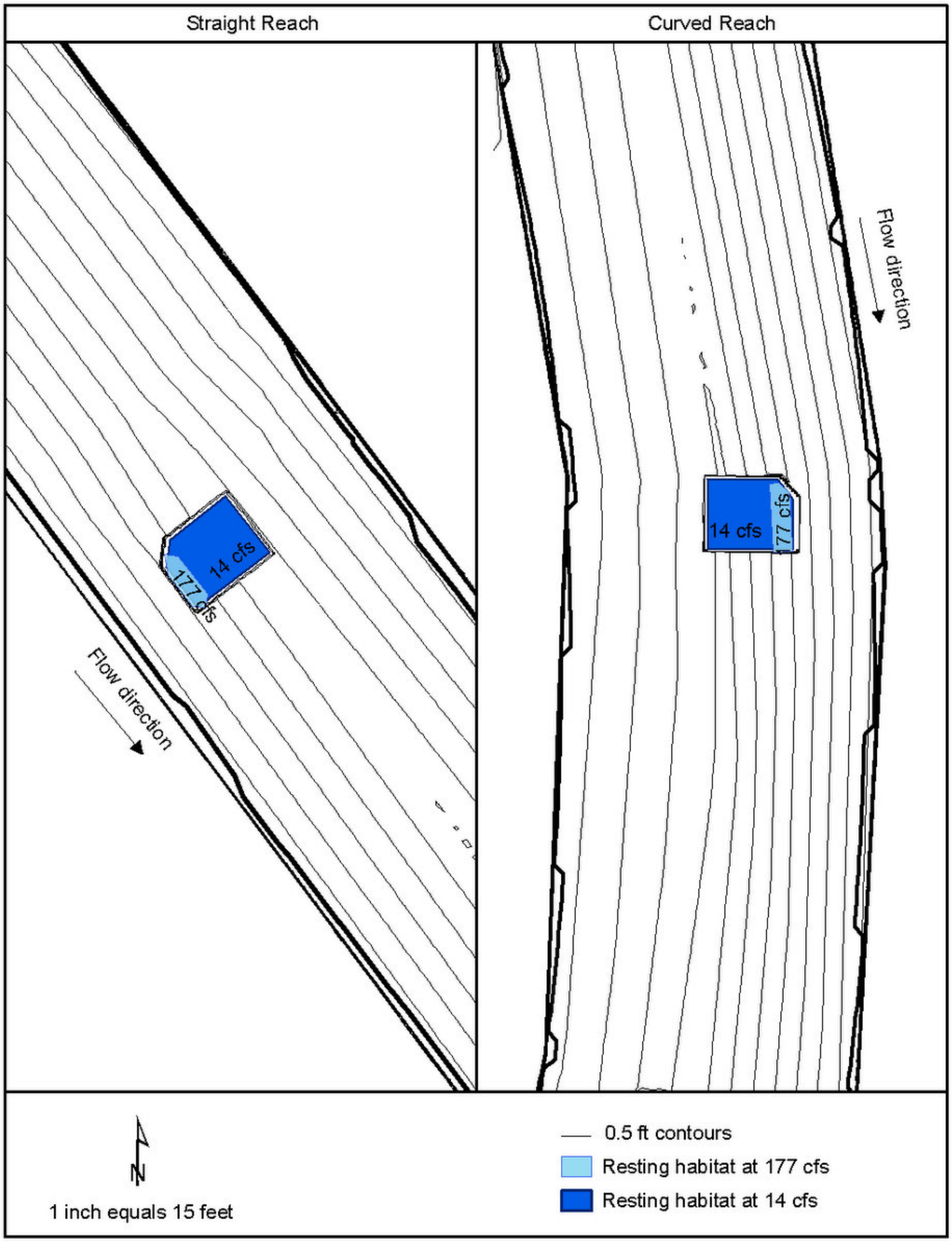


**Figure 6.16** – Alternative 2 available resting pool habitat at 14 cfs and 177 cfs.

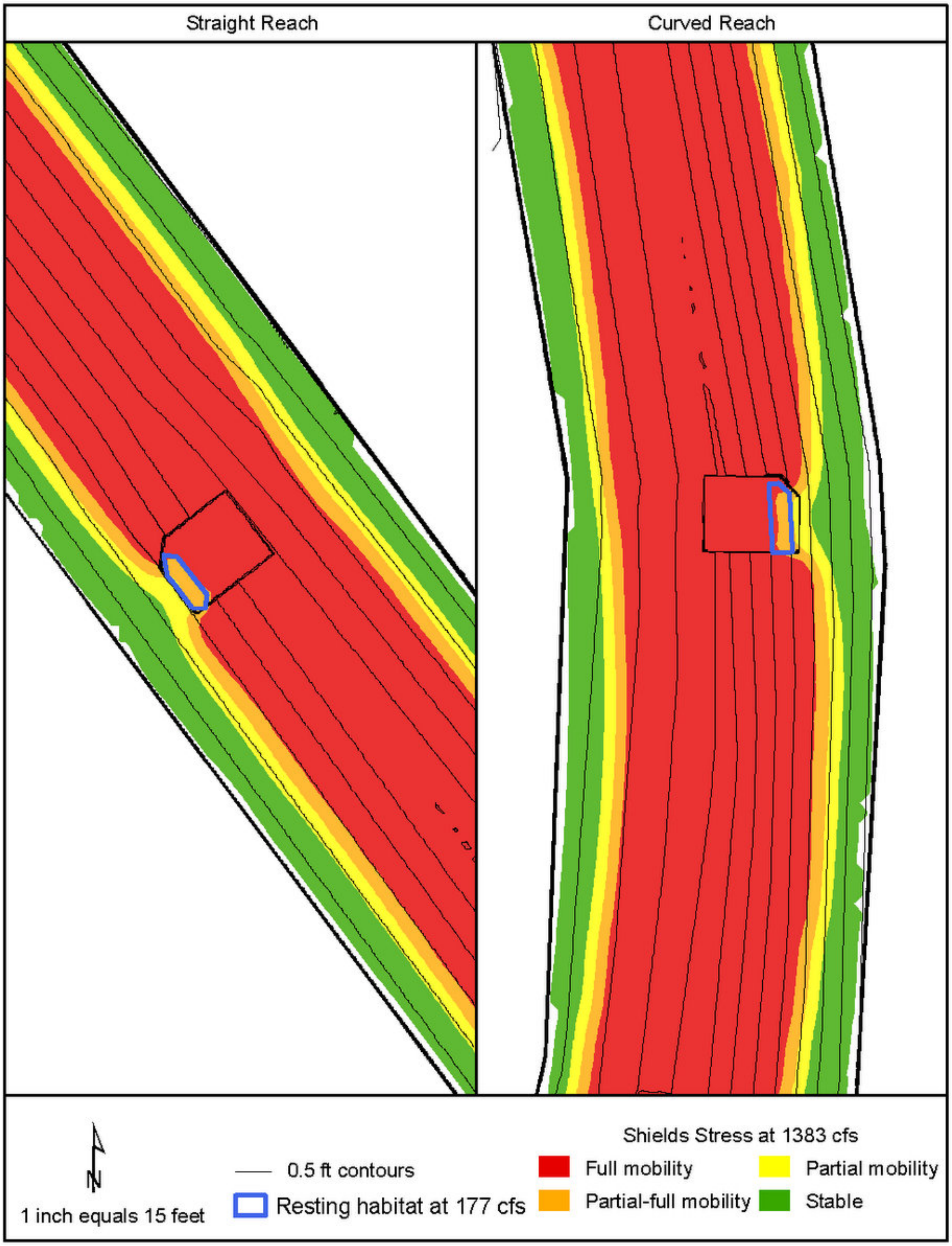


**Figure 6.17** – Alternative 2 predicted mobility of streambed material at the 1.5 year return flow of 1,383 cfs.

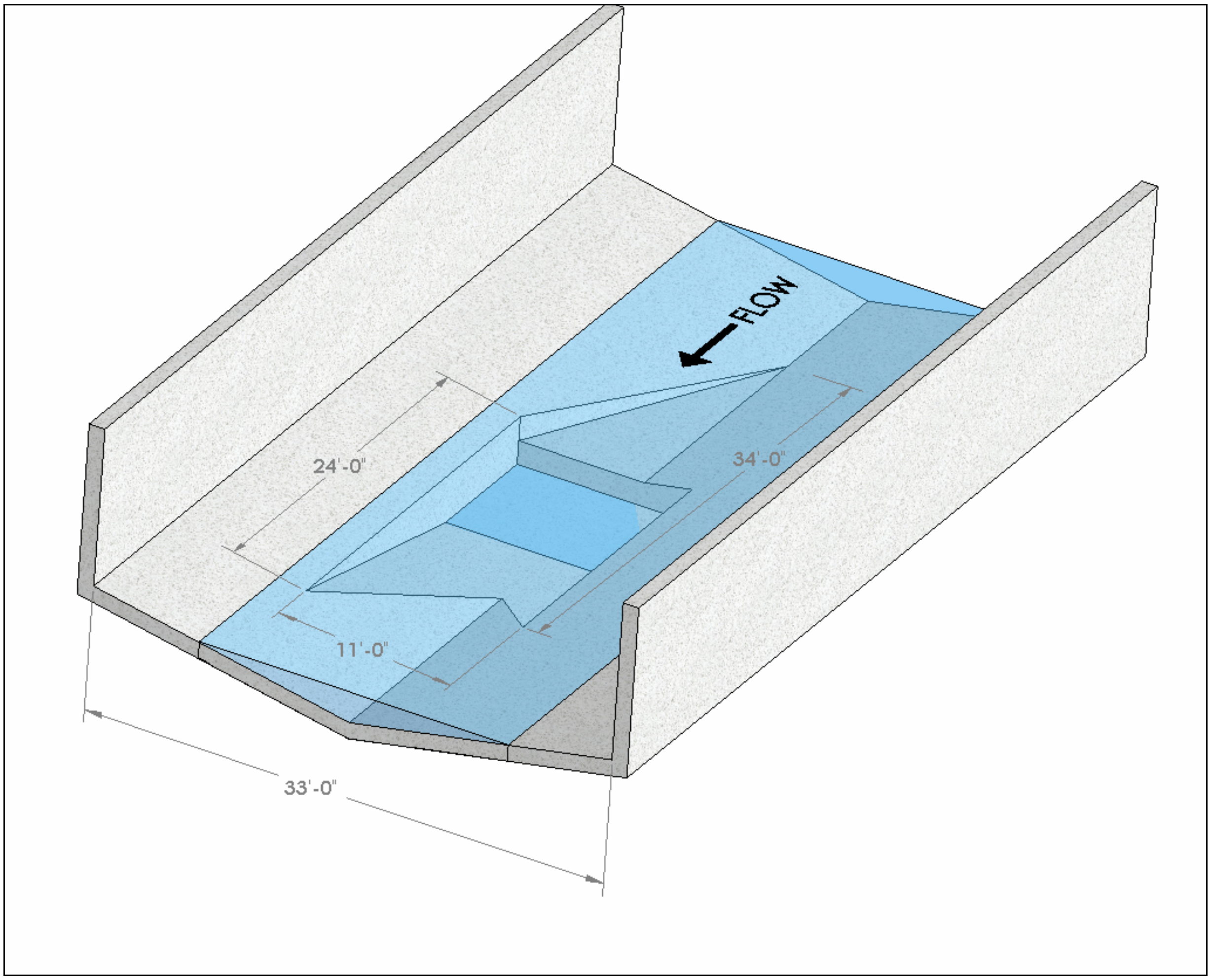

**Figure 6.18** – Isometric drawing of Alternative 2 resting pool.

**Figure 6.19** – Schematic drawing of Alternative 2 resting pool in plan, profile and section.

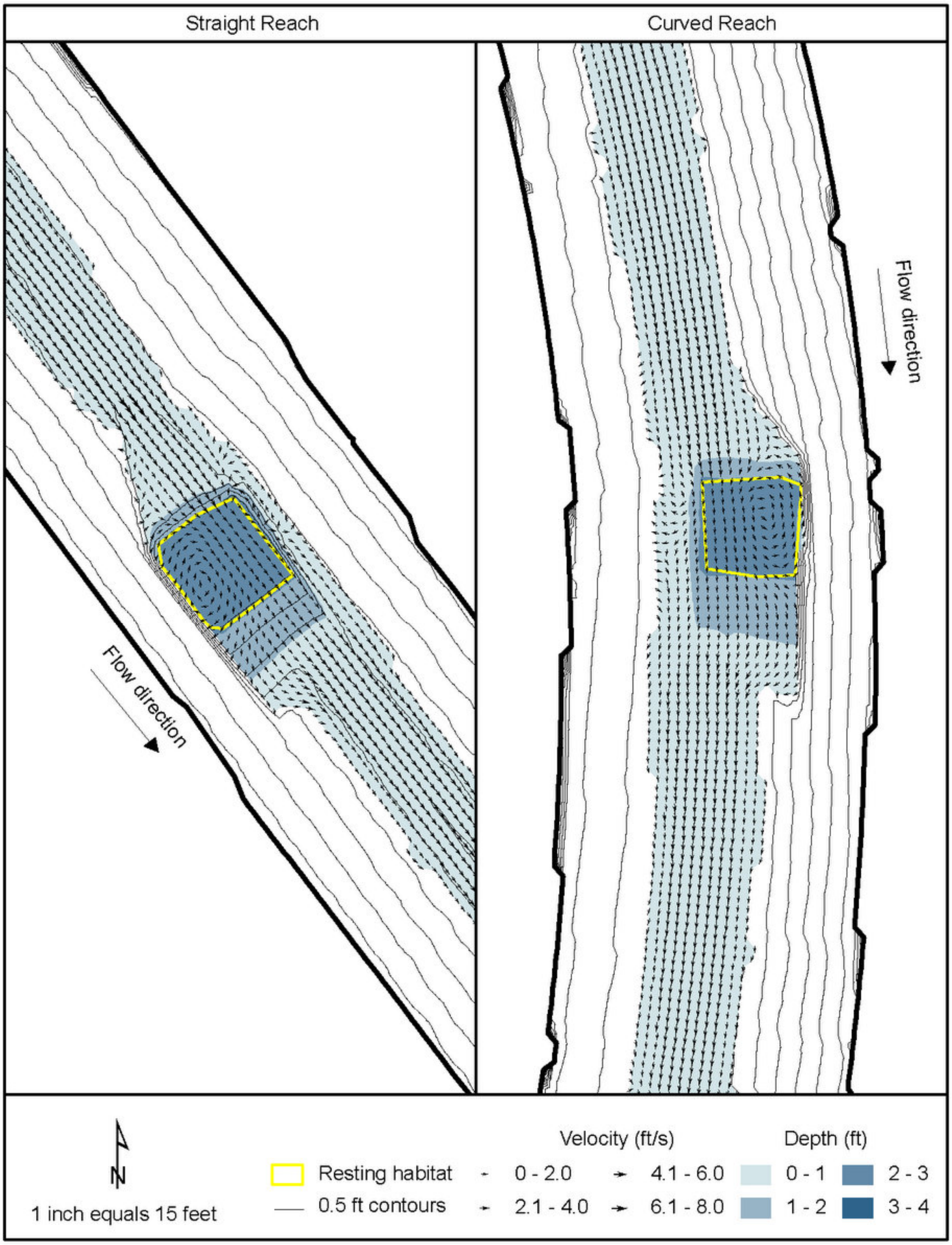


**Figure 6.20** – Alternative 3 water depth, water velocity field, and available resting habitat at the low passage design flow of 114 cfs.

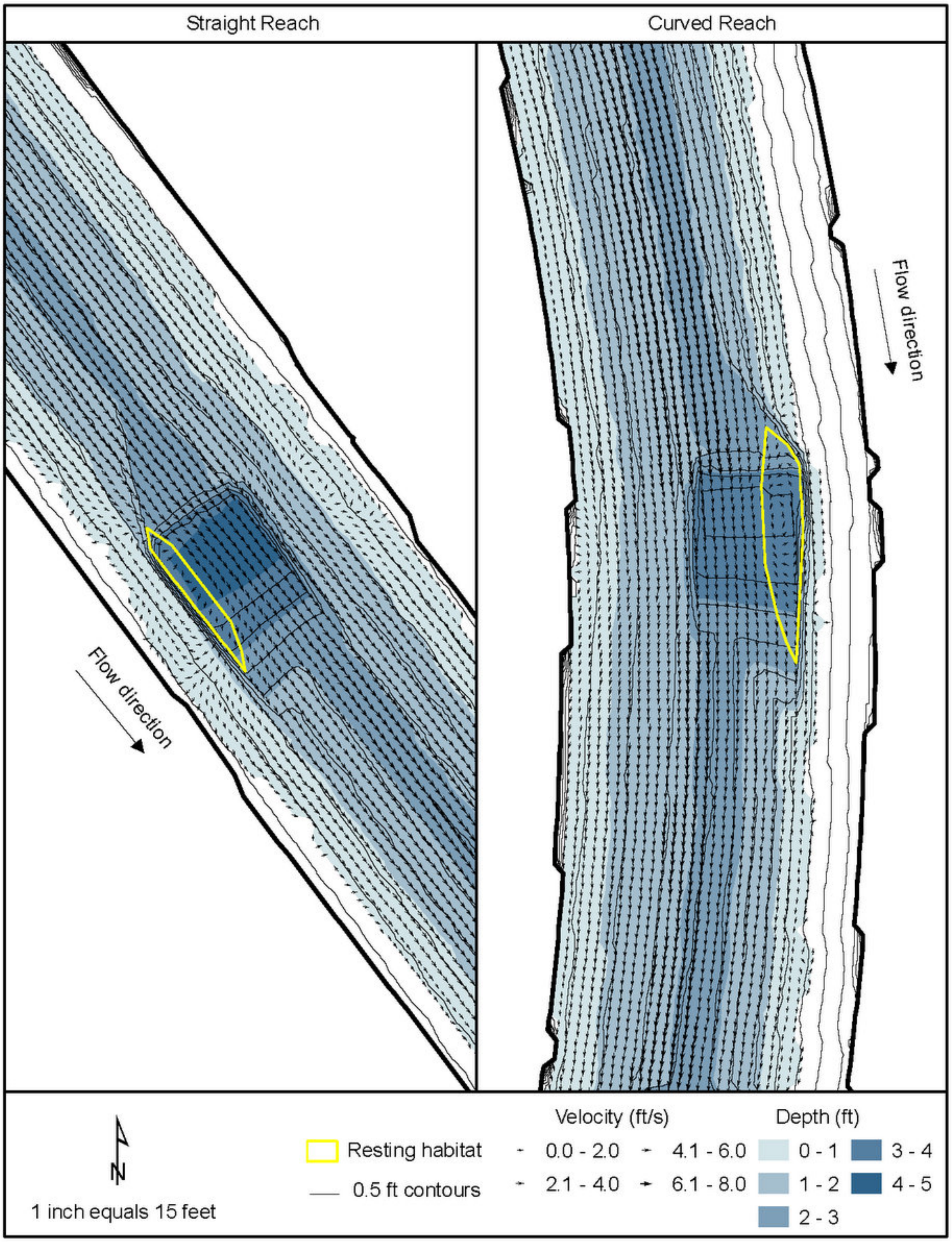


**Figure 6.21** – Alternative 3 water depth, water velocity field, and available resting habitat at high passage design of 177 cfs.

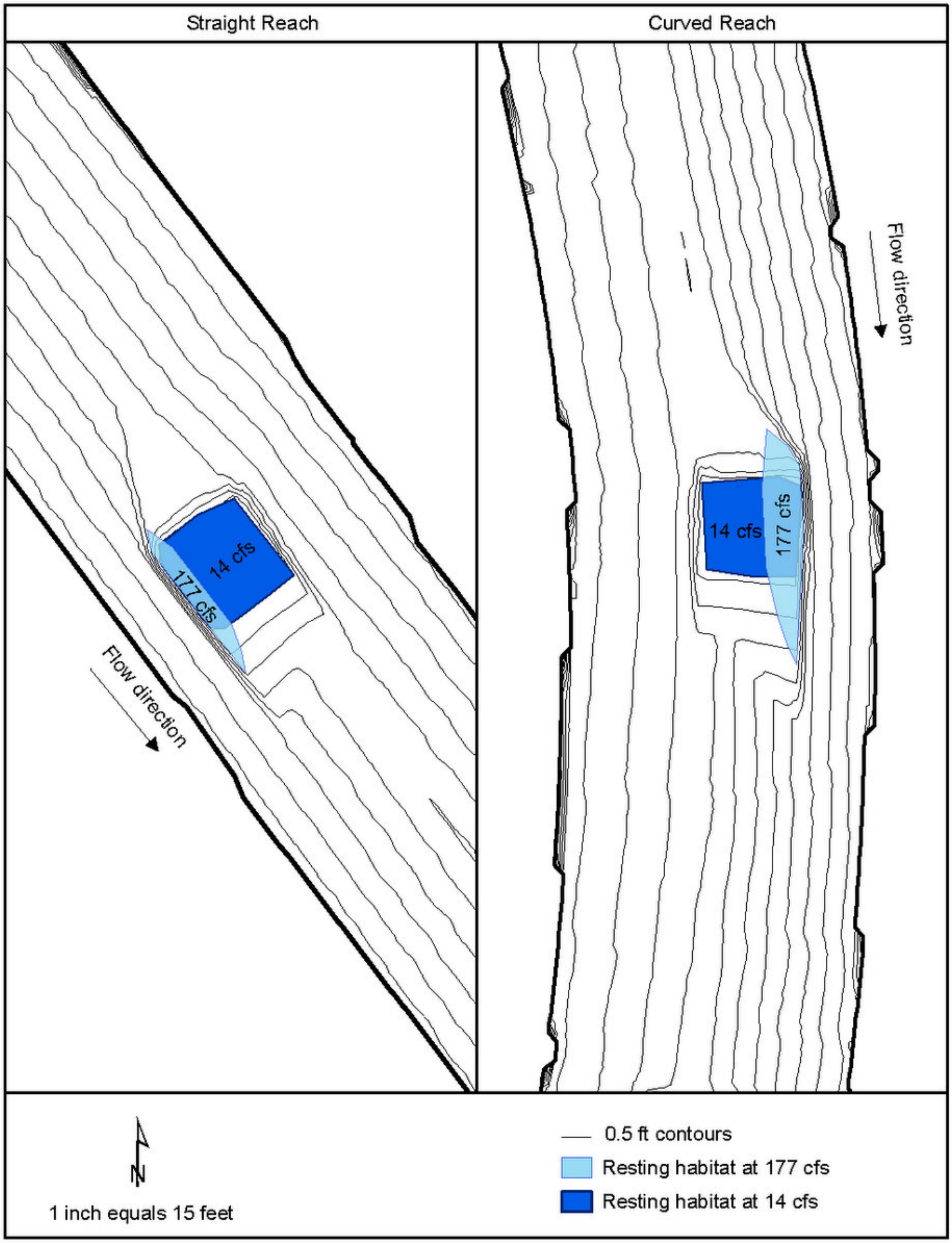


**Figure 6.22** – Alternative 3 available resting pool habitat at 14 cfs and 177 cfs.

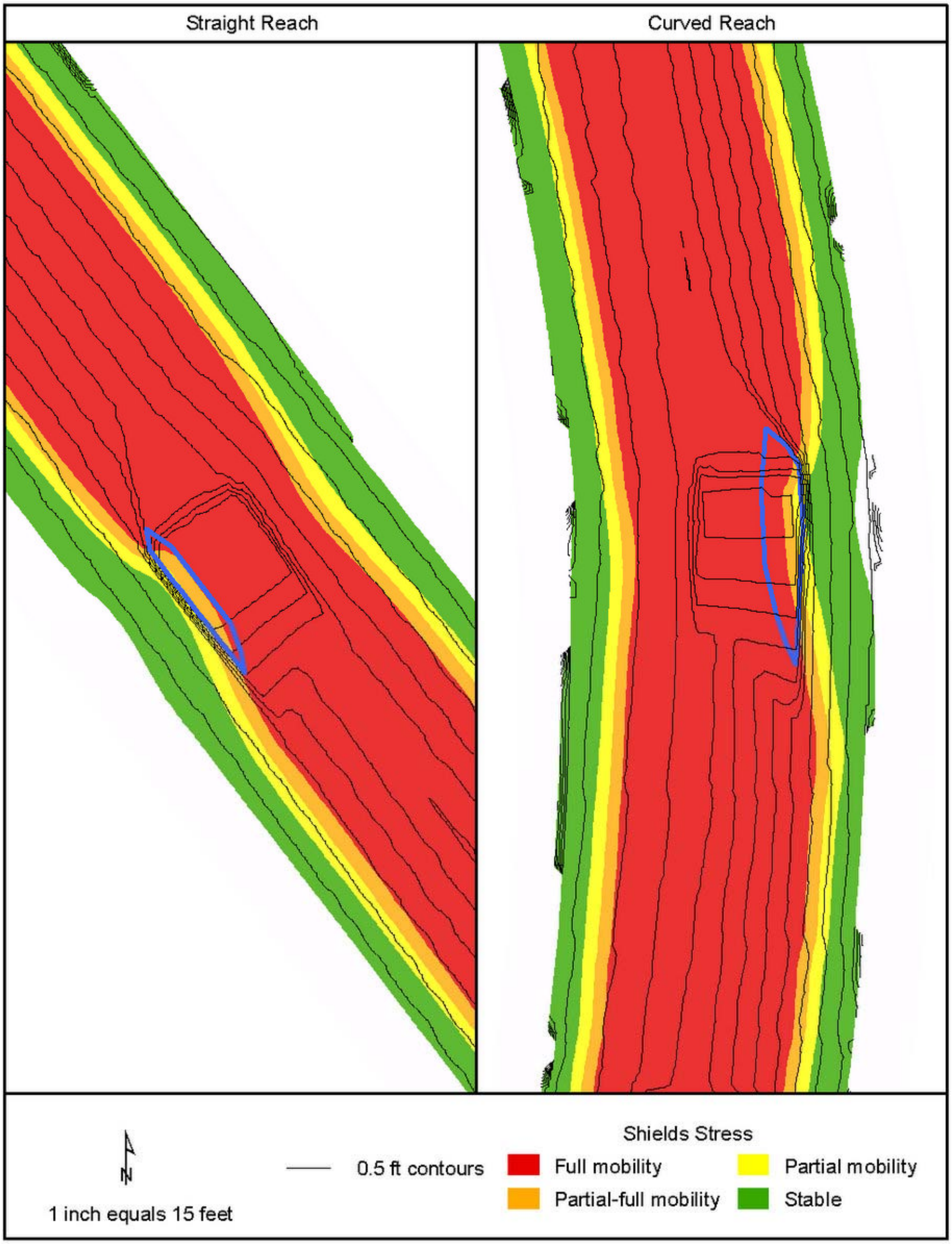


**Figure 6.23** – Alternative 3 predicted mobility of streambed material at the 1.5 year return flow of 1,383 cfs.

## 6.4 Spacing of Resting Pools

Since all three pool alternatives provide resting habitat at all fish passage flows, the preferred pool spacing is independent of the selected pool alternative. To evaluate the influence of pool spacing on fish passage success, new resting pools were inserted into Fish-REALMS at various spacings. Evaluated pool spacings included 300 feet, 200 feet, 150 feet, and 100 feet. The first pool was placed slightly less than one pool spacing upstream from the beginning of the modeled reach. The last pool was positioned at least 100 feet from the upstream end of Unit 3 to keep it out of the hydraulic transition between Units 3 and 4.

For each evaluated pool spacing fish passage success was calculated at 77 cfs and 177 cfs using the MLLW tidal condition (Table 6.2). None of the pool spacings evaluated provide 100% success for the entire population. However, even the largest spacing (300 ft) provides a substantial improvement in fish passage success. As pools are placed closer together, the improvement in passage success continues to climb, but at a diminishing rate.

Following discussions with CDFG members of the Technical Advisory Team, a biologist from CDFG and NOAA Fisheries, the 150 foot spacing was selected for further analysis. This decision is based on the percent of steelhead able to swim through Unit 3 with 150 foot spacing, and is also intended to allow for the possibility of sedimentation in some of the pools that could decrease their ability to provide resting habitat at higher fish passage flows.

Fish passage conditions with new resting pools at 150 foot spacing were analyzed with the three different tidal conditions at all six fish passage flows (Table 6.3). At 177 cfs, regardless of the tidal condition, the model predicted that 65% of the steelhead would be capable of ascending Unit 3. At 114 cfs and below, passage success ranges between 74% and 99%. This is a substantial improvement over existing conditions.

**Table 6.2** – Effect of pool spacing on fish passage. Proportion of steelhead able to successfully ascend Unit 3 with new pools spaced as indicated.

| | Percent of Steelhead Capable of Ascending Unit 3 at MLLW | | | | |
|---|---|---|---|---|---|
| **Flow** | **Existing Conditions** | **300 ft Spacing** | **200 ft Spacing** | **150 ft Spacing** | **100 ft Spacing** |
| **77 cfs** | 2 | 40 | 65 | 78 | 87 |
| **177 cfs** | 1 | 25 | 53 | 65 | 74 |

**Table 6.3** – Proportion of steelhead able to successfully ascend Unit 3 with new pools spaced as 150 feet apart .

| | 150 ft Pool Spacing<br>Percent of Steelhead Capable of Ascending Unit 3 | | | | | |
|---|---|---|---|---|---|---|
| **Tide** | **14 cfs** | **23 cfs** | **40 cfs** | **77 cfs** | **113 cfs** | **177 cfs** |
| **MLLW** | 95 | 85 | 82 | 78 | 74 | 65 |
| **MTL** | 98 | 86 | 82 | 79 | 75 | 65 |
| **MHHW** | 99 | 95 | 98 | 86 | 80 | 65 |

## 6.5 Preferred Resting Pool Configuration

A preferred pool configuration was selected for modeling at high flows to illustrate the potential impacts of larger fish resting pools on channel capacity. This configuration should not be perceived as the only acceptable configuration, but indicative of the magnitude of impact that larger pools have on water surface elevation and benefits that can be achieved for fish passage..

Results for the analysis of the three resting pool alternatives within the pilot reaches indicate that Alternative 1 and Alternative 3 preformed similarly, but have some distinct differences. In the straight reach Alternative 1 provides more resting habitat than Alternative 3 at 114 cfs. The difference in Shields stress between the two alternatives (0.052 verses 0.057) is negligible in terms of sediment mobility. However, in the curved reach Alternative 3 provided the most resting habitat at 177 cfs and a significantly higher Sheilds stress at the 1.5 year flow.

The 150 foot pool spacing appears to provide a substantial improvement in passage conditions. Closer spacing only provides a small incremental improvement. Based on these findings and recommendations from the technical advisory group, the 150 foot spacing is considered suitable.

**Based on these findings, the selected "preferred pool configuration" for Unit 3 uses Alternative 1 for the straight channel sections and Alternative 3 for the curved channel sections, with pools spaced 150 feet apart.**

## 6.6 Impact of Resting Pools on Channel Capacity

To assess the effects of the preferred pool configuration on high flow channel capacity in Unit 3, the geometry of the 1-D existing conditions model developed for this project was modified to incorporate the proposed pool configuration and spacing. This section discusses the impacts of the resting pools on Unit 3 channel capacity and also discusses some differences between the 1-D model developed for this project and the original ACOE HEC-RAS 1-D models (ACOE 1-D model) previously developed for the Corte Madera channel planning efforts and modified by both Copeland, 2000 and more recently by Stetson Engineering in 2006.

### 6.6.1 Inherent Differences between 1-D Models

Some inherent differences between our 1-D model and the ACOE 1-D model are briefly discussed below. These differences help explain the difference in predicted results between the two models.

The ACOE 1-D model consisted of the following assumptions and/or observations:

- The Unit 3 project reach channel used a Manning's n roughness coefficient of 0.018 (Copeland, 2000).
- No existing fish pools were incorporated into the channel geometry (Figure 6.24).
- 26 cross sections existed within the Unit 3 project reach.

- Unit 3 channel geometry was constructed at a uniform slope which appears steeper then the actual surveyed channel slope within the project reach (Figure 6.24).
- Kentfield Hospital Bridge was incorporated into the ACOE 1-D model as a culvert, rather than a bridge. It appears that the culvert routines in HEC-RAS cause an unrealistic rise in the water surface elevation at the Kentfield Hospital Bridge for the 5400 cfs high flow discharge (Figures 6.25). For the model comparison discussed below, the Kentfield Hospital Bridge was removed from the ACOE 1-D model.
- The original ACOE 1-D model did not include the existing grade control structure/fish ladder at the upstream end of the Unit 3 channel. For this analysis the grade control structure/fish ladder was incorporated into the ACOE 1-D model for existing condition high flow comparison.

The existing conditions 1-D HEC-RAS model developed for this project consists of the following assumptions and/or observations:

- The Unit 3 project reach (starting upstream of the College of Marin Pedestrian Bridge) used a Manning's n roughness coefficient of 0.013 for the channel, which was based on calibration to field observations (refer to Section 4.2).
- The existing fish pools were incorporated into the channel geometry (Figure 6.24).
- The Unit 3 project reach consisted of 283 cross sections.
- The Unit 3 channel geometry was based on the recent Unit 3 channel survey conducted by the County of Marin.
- The Kentfield Hospital Bridge was not incorporated into the model.
- The existing grade control structure/fish ladder was incorporated into the model.

### 6.6.2 Comparison of 1-D Models to an Observed High Flow Event

Predicted water surface elevations for the existing conditions 1-D model developed for this project and for the ACOE 1-D model discussed above were compared to crest stage gage measurements at an observed high flow of 1,328 cfs that occurred on December 18, 2006 (Figure 6.24). The ACOE 1-D model predicts higher water surface elevations in the downstream reaches of Unit 3 due to the higher roughness coefficient of 0.018. Both models appear to be over-predicting the middle crest stage gage, which could be due to an erroneous measurement at this gage. Both models appear to be predicting observed water surface elevations reasonably well for the upstream and downstream crest stage gages. The existing pools included in our 1-D model produces water surface elevation rises at each pool. The ACOE 1-D model does not capture this effect. However, in the upper reaches of the Unit 3 channel our 1-D model water surface elevations consistently converge to the ACOE 1-D model elevations upstream of each existing pool as the backwater effects from each pool dissipates. The large difference in water surface elevations between models near Station 355+00, which is within the channel bend, appears to be due to cross section spacing and the lack of detail in this area of the ACOE 1-D model.

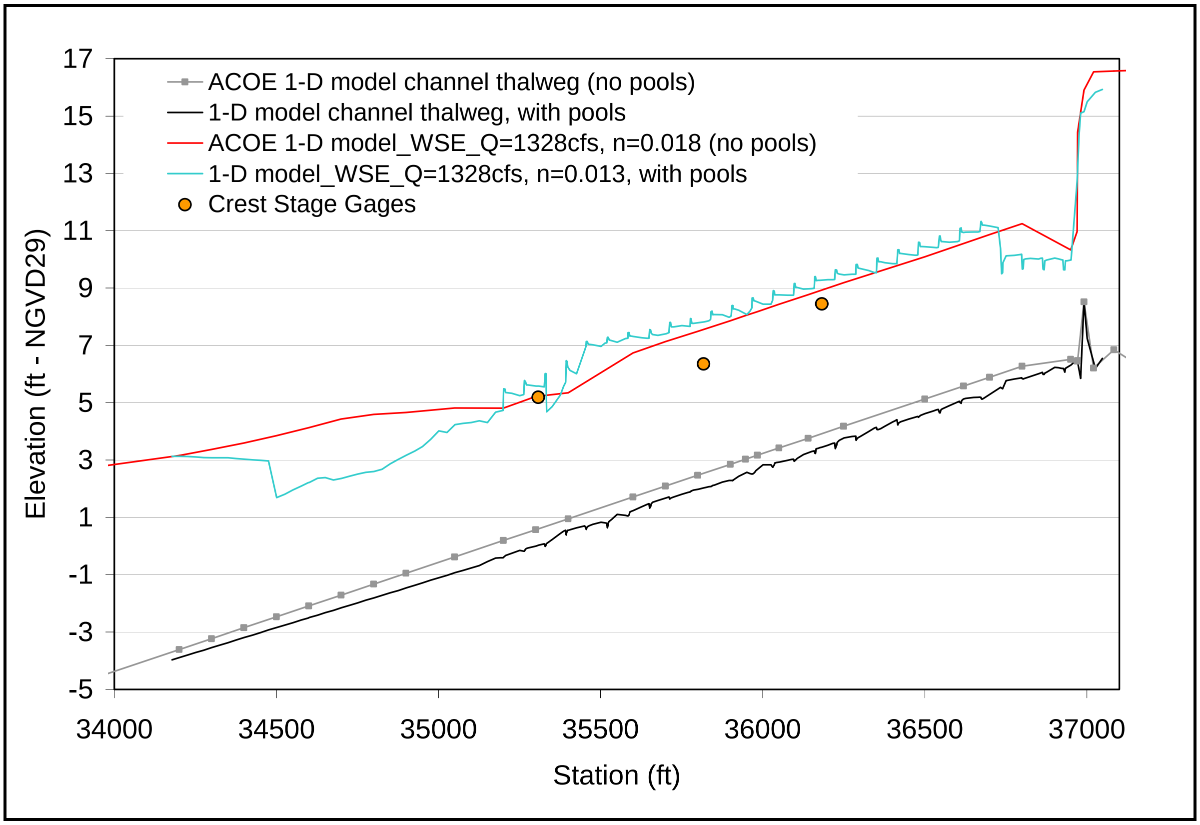


**Figure 6.24** – Comparison of water surface elevations predicted from 1-D models versus crest stage gage elevations at observed high flow of 1328 cfs on December 18, 2006.

### 6.6.3 Comparison of Existing 1-D Models at 5,400 cfs High Flow

The 1-D existing conditions model developed for this project was run at the 5,400 cfs target design flow, and was compared to the ACOE 1-D model results for the PWA Alt II analysis at 5,400 cfs (Figure 6.25). The PWA Alt II results were downloaded from the County of Marin website in a spreadsheet format. The downstream boundary condition of the 1-D model was set equal to the interpolated water surface elevation (12.99 feet) from the PWA Alt II results. It should be noted that the ACOE 1-D model used in the PWA analysis (1) used a Manning's n coefficient of 0.018, (2) modeled the Kentfield Hospital Bridge as a culvert, and (3) did not include the grade control structure at the upstream end of Unit 3.

The difference in water surface elevations in the downstream reaches of Unit 3 is due to the difference in the Manning's n value between the two models. In the upper reaches of the project our 1-D model predicts higher water surface elevations than the ACOE 1-D model. The backwater effects at the Kentfield Hospital Bridge, which results because the bridge was modeled as a culvert, are quite apparent in the ACOE 1-D model results. Without this backwater effect the ACOE 1-D water surface elevations would be lower than currently predicted.

Based on our 1-D model results the predicted water surface elevations are at the top or slightly above the existing walls along the upper reaches of the Unit 3 channel.

### 6.6.4 Comparison of Preferred Pool Alternative on Existing Channel Capacity at 5,400 cfs High Flow

To illustrate the potential impact of the preferred pool alternative on existing channel capacity at the 5,400 cfs target design flow, the predicted water surface elevations from the existing condition 1-D model and the preferred alternative 1-D model are compared (Figure 6.26). Both models were run at 5,400 cfs, the downstream boundary condition was set equal to same boundary condition of 12.99 feet described above, and the Manning's n coefficient was set equal to the calibrated value of 0.013.

The preferred pool alternative increases water surface elevations along the entire Unit 3 project reach, and are typically above the existing wall elevations. In general, the proposed fish pools increase the water surface elevation by approximately 0.7 to 0.8 feet with higher increases in the vicinity of pools (Figure 6.26). Based on the 1-D model results, it appears that the existing concrete walls will need to be raised in the upper reaches of Unit 3 by to accommodate the preferred pool alternative at the 5,400 cfs design flow.

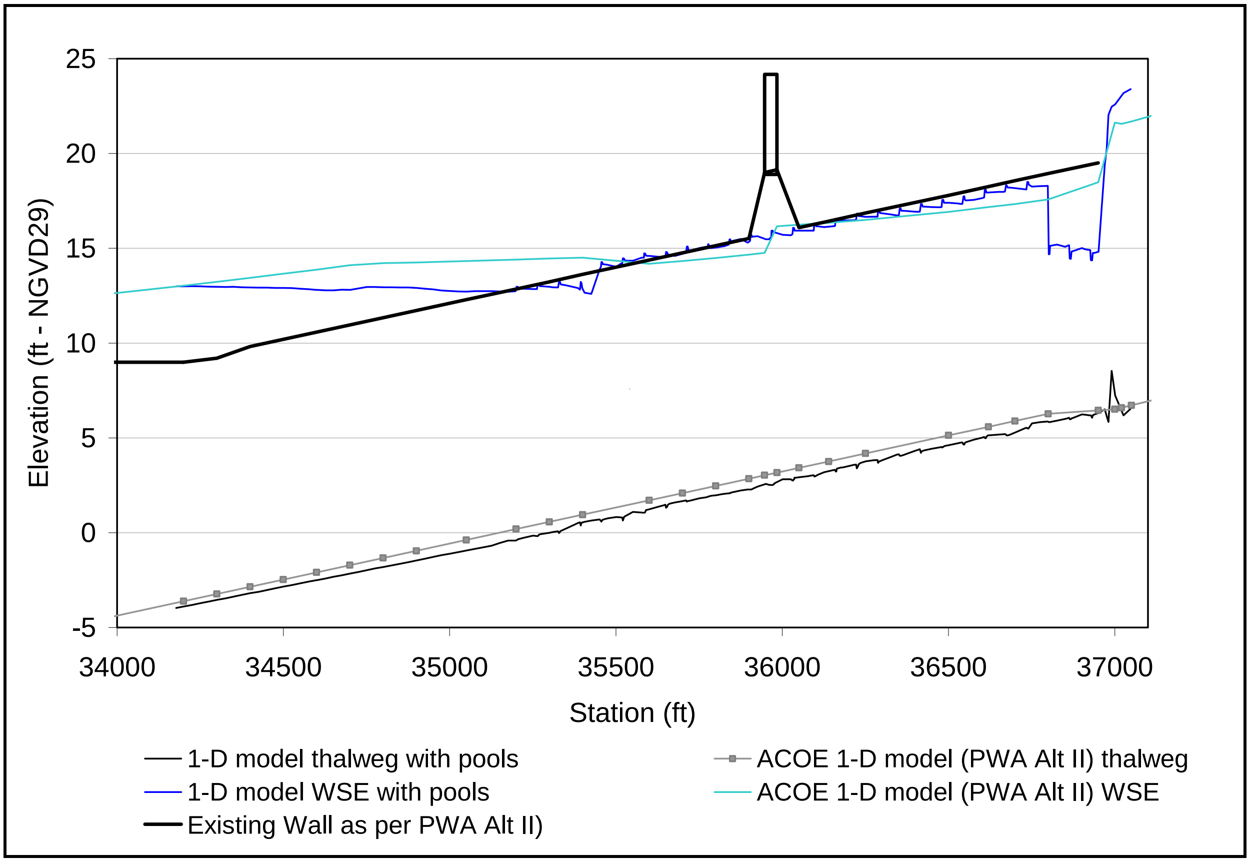


**Figure 6.25** – Comparison of predicted water surface elevations for the 5,400 cfs target design flow for the 1-D model and the ACOE 1-D model.

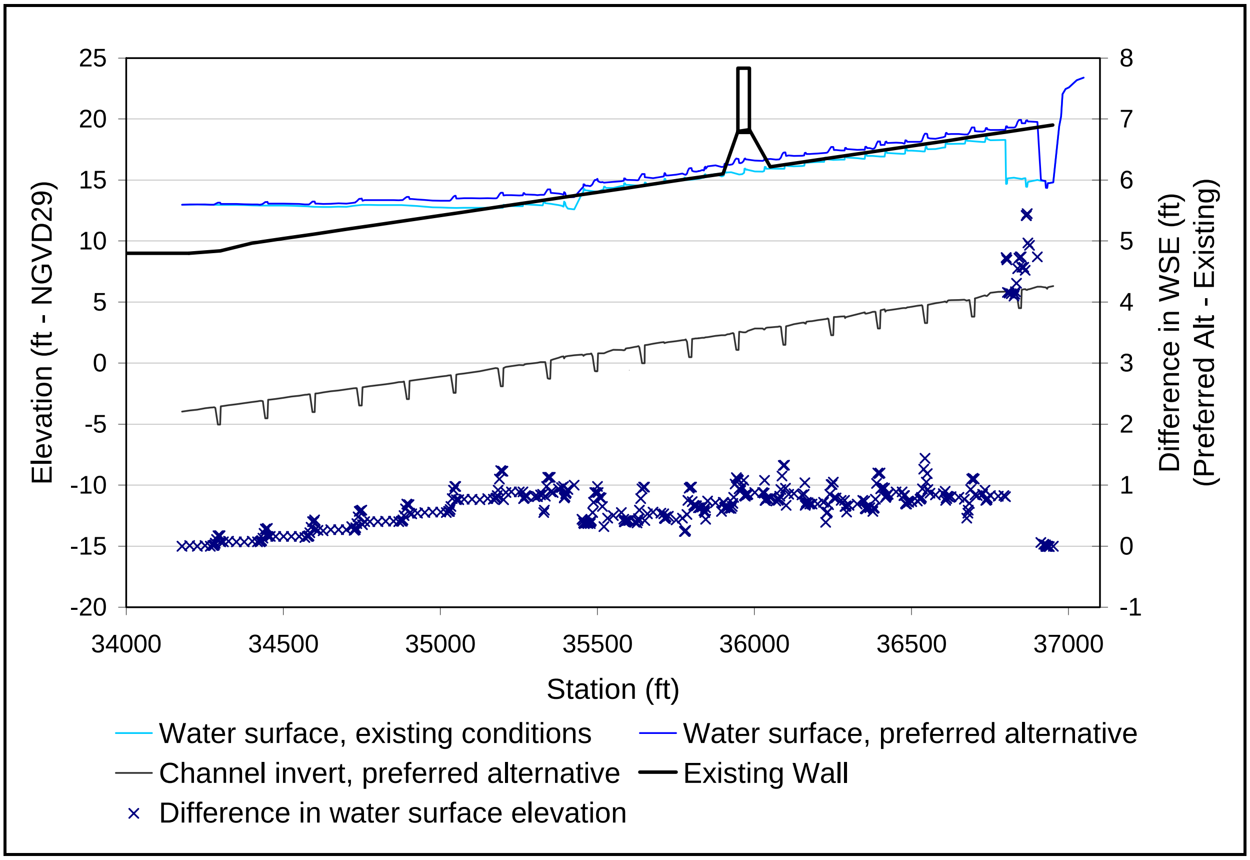


**Figure 6.26**– Comparison of predicted water surface elevations for the 5,400 cfs target design flow for existing conditions and the preferred pool alternative.

# 7 Conclusions and Recommendations

## 7.1 Fish passage

The primary objective of this study was to optimize fish passage in the Corte Madera channel within the existing site constraints. All pool shapes evaluated provided improvement in resting habitat. The limiting factor in fish passage success was pool spacing. None of the pool spacing alternatives evaluated provide 100% success for the entire population. However, even the largest spacing (300 ft) provides a substantial improvement in fish passage success. As pools are placed closer together, the improvement in passage success continues to climb, but at a diminishing rate, and the impact on channel capacity increases.

The preferred alternative dramatically improves fish passage success. At low flows, fish passage success rises from 2% to 78%. At high flows, fish passage success rises from 1% to 65%. Resting area created in each pool enables multiple fish to rest in each pool.

Meeting the objective of improving fish passage has an effect on existing channel capacity within the Unit 3 project reach. There are other combinations of pool spacing that would still improve fish passage and potentially reduce impacts to channel capacity. Further analysis of alternative pool spacing configurations that alter the fish passage success, channel capacity, and sedimentation of the pools will require explicit targets or constraints by all stakeholders, agencies and public. The appropriate place to address the balance between fish passage and flooding impacts in the Unit 3 Corte Madera channel is in the upcoming NEPA/CEQA process.

## 7.2 Channel Capacity

### 7.2.1 Existing Pools

The results of existing channel capacity in this study differ from previous studies. The model presented in this study includes channel topography from the most recent survey (County of Marin, 2006) which includes existing pools. Existing channel capacity is lower when topographic detail is improved and channel geometry of the pools is incorporated into the 1-D model.

Regardless of whether the proposed alternative is implemented, the existing channel capacity should be re-evaluated to determine whether the existing concrete channel has adequate capacity to receive the target design flows proposed for Unit 4.

If a 1-D model is selected to re-evaluate the existing high flow capacity of Unit 3, the model should be revised to include the existing pool geometry, utilize the most current survey of the channel (available from the County of Marin, survey date 2005), and appropriately represent bridges. For example, bridge crossings could be represented as either bridges or cross-sections with lids as appropriate.

The results of the study demonstrate that water surface elevations between pools at lower flows are better represented with a 2-D model and this is likely to be the case at higher flows. The 1-D model simplifies channel hydraulics in comparison to a 2-D model. An important difference relevant to assess channel capacity is the ability of the 2-D model to predict varying water surface elevations across the channel which may illustrate that rises in water surface elevation are focused at the pools and may not extend to channel edges or propagate upstream to the same extent as predicted by the 1-D model. Therefore, we recommended a 2-D model, at a minimum, be used to evaluate Unit 3 channel capacity. Potential public domain models include: MD_SWMS used in this study, HIVEL2D or FESWMS.

High flow calibration data is required to properly verify existing channel capacity for any modeling approach. We recommend installation of a crest stage gage network that can withstand the highest flow events to obtain additional verification data. Crest stage gages should be placed on both sides of the channel, at and between pools, and provide adequate coverage of straight and curved reaches.

The rating curve at Ross should be maintained, checked and updated regularly, and attempts should be made to extend the rating curve measurements to higher discharges.

Tides significantly affect fish passage and exacerbates flooding at a given stream flow. Improved tidal data will improve channel capacity estimates. We recommend installing a stage recorder just upstream of the College of Marin Pedestrian Bridge to assist in calibrating Unit 3 capacity estimates. A second stage recorder should be installed downstream of Unit 2 for use in defining the boundary conditions for future hydraulic modeling efforts.

### 7.2.2 Preferred Alternative

The preferred alternative increases water surface elevation an average of 0.75 ft, and locally up to 1.5 ft in the vicinity of new pools above predicted water surface elevation with existing pools at 5,400 cfs design flow.

An improved prediction of the effects of pools on channel capacity can be better represented by a 2-D model as discussed above.

## 7.3 Sedimentation of Fish Pools

The ability of the proposed pools to provide resting habitat could be diminished if the pools accumulate sediment. The results from the mobility analysis suggest that the pools will reduce sediment mobility and therefore are more likely to accumulate sediment than the existing pools. We recommend sedimentation considerations be incorporated into Unit 3 planning efforts. Prior to implementation, a sediment management plan should be in place to assure long-term functioning of the resting pools.

One approach could involve conducting a sediment transport study to predict the rate of fill over a range of potential water years coupled with a fish energetic study to evaluate the impact of pool filling on fish passage. This approach could help quantify the level of effort required to keep the pools sufficiently clean and may identify alternative pool designs that further reduce sedimentation. This type of sediment study would require collecting sediment transport data. Sediment transport measurements should be acquired at higher discharges to improve high flow predictions. Since sediment supply is critical to evaluate sedimentation of the pools, Unit 4 should also be included in the sediment transport study.

With or without an analytical sediment transport study, sedimentation of fish pools will need to be addressed through an adaptive management approach. The adaptive management approach would involve monitoring fish passage and pool sedimentation and identify or refine the frequency of pool cleaning to maintain passage based on the frequency and magnitude of flows that transport sediment. This adaptive management approach would also identify the means for cleaning the pools (mechanical and manual removal). The adaptive management approach requires a long-term commitment by the County to monitor and maintain fish passage.

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# APPENDIX A

# MONITORING PROTOCOL
# AND
# MONITORING RESULTS

August 17, 2005

**Video Documentation Protocol for Channel and Steelhead Monitoring**
**Friends of Corte Madera Creek Watershed**

This protocol is intended to guide volunteers in the monitoring and documentation of flow conditions and fish presence in the Corte Madera Flood Control Channel located between the College of Marin and the fish ladder near behind the Ross Post Office parking lot.

Objectives

The primary objectives of the video monitoring effort are to:

1) Document changes in channel flow characteristics with changing flow within the flood control channel,
2) Observe adult steelhead swimming in the channel and at the fish ladder to gain a better understanding of:
    - Migration timing with respect to flows,
    - Swimming abilities (speed and endurance),
    - Resting patterns and locations, and
    - General behavior.
3) Document any interesting flow phenomena happening in the channel, either within or outside the field of view of the "monitoring-point."

Two types of video footage will result from this monitoring effort:

1) Monitoring point footage - changes happening at the established monitoring point, using a fixed and repeatable field of view
2) Non-monitoring point footage - miscellaneous shots of interesting things happening in the channel, e.g. fish moving, notable hydraulics, etc.

When to Video

These video observations will be used in the development and analysis of alternatives for improving fish passage conditions. Although some video monitoring during low flow conditions will be useful, the primary objective is to film flow in the channel during higher streamflows resulting from winter storms, likely occurring between November and March.

Besides filming flow conditions, we are also interested in capturing footage of steelhead in the concrete channel and at the fish ladder. Most steelhead will wait off-shore until a storm occurs before migrating upstream. Typically the best time to observe steelhead in streams, such as Corte Madera Creek, is in the hours just after the peak of the storm.

Materials

- ☐ Video Camera (Digital or Hi-8)
- ☐ Tripod
- ☐ Umbrella
- ☐ Notebook/pencil (preferably waterproof/Write-In-The-Rain paper)
- ☐ Lens tissue for wiping drops of lens
- ☐ Spare batteries, tape, memory cards for camera
- ☐ Binoculars for reading stage plates
- ☐ A copy of these instructions

Stage Plate Locations

There are five locations within the channel between the fish ladder and the College of Marin campus containing stage plates. These plates are used to document the depth of water within the channel during observations. The locations are numbered 1 through 5, starting at the upstream plate:

(1) Located 60-ft downstream of the fish ladder, at the north end of the bike path near the Ross Post Office parking lot. View from bike path.

(2) Located 200-ft upstream of the bridge at Kentfield Hospital. View from bike path or bridge.

(3) Located 130-ft downstream of the bridge. View from the office parking lot on the left bank or from bridge.

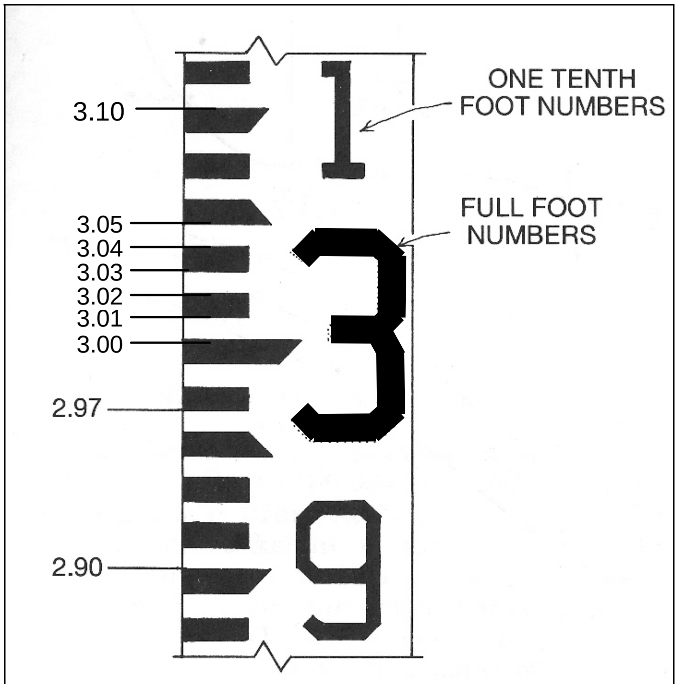
(4) Located 500-ft downstream of bridge, near first resting pool. View from bike path, next to trailside bench.

(5) Located upstream of Marin Community College pedestrian bridge near parking lot. View from bike path.

See the attached map for exact locations of stage plates.

Reading a Stage Plate

Stage plates are designed to be read to the nearest 100th of a foot. If water is sloshing up and down along the plate, try to take the average reading.




How to read a stage plate to the nearest 100th of a foot.

**Video Monitoring Locations**

Ideal monitoring locations are (1) at the fish ladder, (2) directly across from each stage plate location, and (3) looking upstream and downstream from the bridge at Kentfield Hospital. At each of these locations, establish a "monitoring point" where you will set up the camera each time you return. By having the same field-of-view each time you film, variations in water depth and flow patterns can be directly compared at different streamflows. If you discover later the monitoring point is not in the ideal location, consider creating a new monitoring point located in a more ideal location.

You may mark the monitoring point using flagging tied to the fence or placing a nail or stake into the ground. In your notebook, describe the location and make a site map for each of your monitoring points. Give each monitoring point a unique number or name.

Check list for each video location:

At each site please do the following:

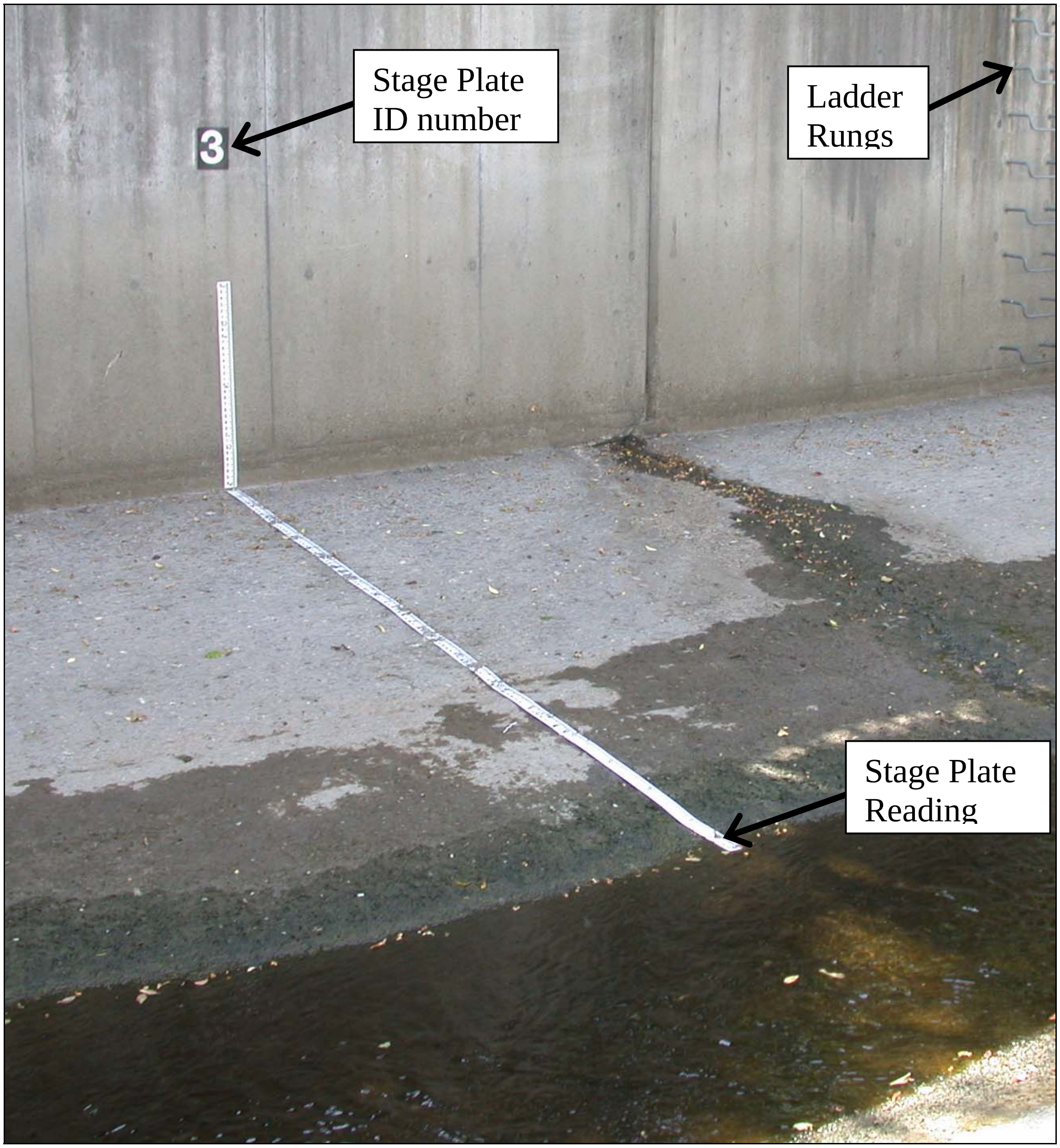
- ☐ Set up the tripod and camera at the designated monitoring point. Use of a tripod is essential for recording suitable video.
- ☐ During each shot the following info should be recorded in the notebook and spoken into the microphone:
    - o Date and Time, name of videographer
    - o Name or number of the monitoring-point
    - o Stage plate ID number and stage reading.
    - o Tape number (number each video tape to avoid confusion: Date_Location_TapeNumber_Videographer_Initials) and starting and ending time-code readings (Hrs:Min:Sec)
    - o Description of any interesting features or events captured on video (e.g. standing waves, fish moving, debris floating by, etc) along with corresponding time-codes.

- ☐ Start filming with a wide frame of view showing the painted number next to the stage plate. Maintain the shot for a minimum of 5 seconds.
- ☐ Zoom in and focus on the stage plate. If fully viewable from the monitoring point, make sure the numbers on the plate are readable and that the water surface line is clearly in the shot. Hold this shot still for at least 5 seconds.
- ☐ After filming the stage plate, return to a wide frame of view of the channel and hold for at least 10 seconds to show flow patterns and water velocities.
- ☐ Pan slowly upstream and downstream where possible. Hold shot at end of pan for at least 5 seconds followed by filming any interesting features you observe.

Remember to number each tape, avoid recording over previously recorded tapes, set the correct date and time stamp on the camera (if using), and zero the camera's time-code when starting a new tape (only necessary on Hi-8 cameras).

Special Case – Stage Plates are Submerged during High Flows

If the flow is so high that the top of the stage plate is submerged, use the ladder rungs to gage the water depth. Find the ladder closest to the stage plate and count and record the number of rungs above the water surface. Also note the location of the ladder relative to the stage plate (upstream or downstream). This will provide an estimate of the water depth. In this situation, make sure to also include a wide and close-up shot of the ladder at the beginning of your filming.




**Concrete channel showing the stage plate and the Stage Plate ID Number. Ladder rungs can used to gage water depth if the plate is fully submerged.**

## Tracking Important Shots

If something interesting happens during a video session, describe the phenomenon into the microphone and record in your notebook the time code. This can be very helpful later on, especially if the event is not clearly captured on film. Interesting things to capture on film include unique flow patterns (standing or rolling waves, eddies, regions of low velocity), debris floating down the channel, or steelhead trout swimming in the channel.

Follow the Action

If a steelhead appears on the scene, it may be necessary to abandon a fixed camera shot, and follow the action of the fish migrating through the reach. Try to minimize zooming in and out. When you reframe the shot, get an establishing shot for at least 5 seconds, and then zoom in enough to capture the action, and follow the fish as steadily as possible.

This footage will be invaluable for describing the swimming abilities and behavior of different steelhead, such the distance they travel before resting, the time it takes for them to travel a given distance, the locations they use for resting, and conditions or locations that pose the most difficulty.

Some other things to keep in mind:

- Zoom and pan *SLOWLY*.
- Try to have outside references in the shot… for example by aligning the edge of the viewfinder with one or more objects in the field of view, it will be easy to maintain a consistent view from session to session.
- Narrate the action as you see it.

## Providing Tapes and Field Notes to Video Editor

All recorded footage and accompanying field notes will be given to Friends of Corte Madera Creek Watershed for editing and examination. Please turn in tapes and field notes on a regular basis (as often as monthly). Also, make regular photocopies of your field notebook and store in safe location along with all previously recorded video tapes.

Contact Information

Any questions and to submit recorded video and field notes, please contact:

Friends of Corte Madera Creek Watershed
Sandy Guldman,
Project manager
**456-5052**

# Video Monitoring - General Information

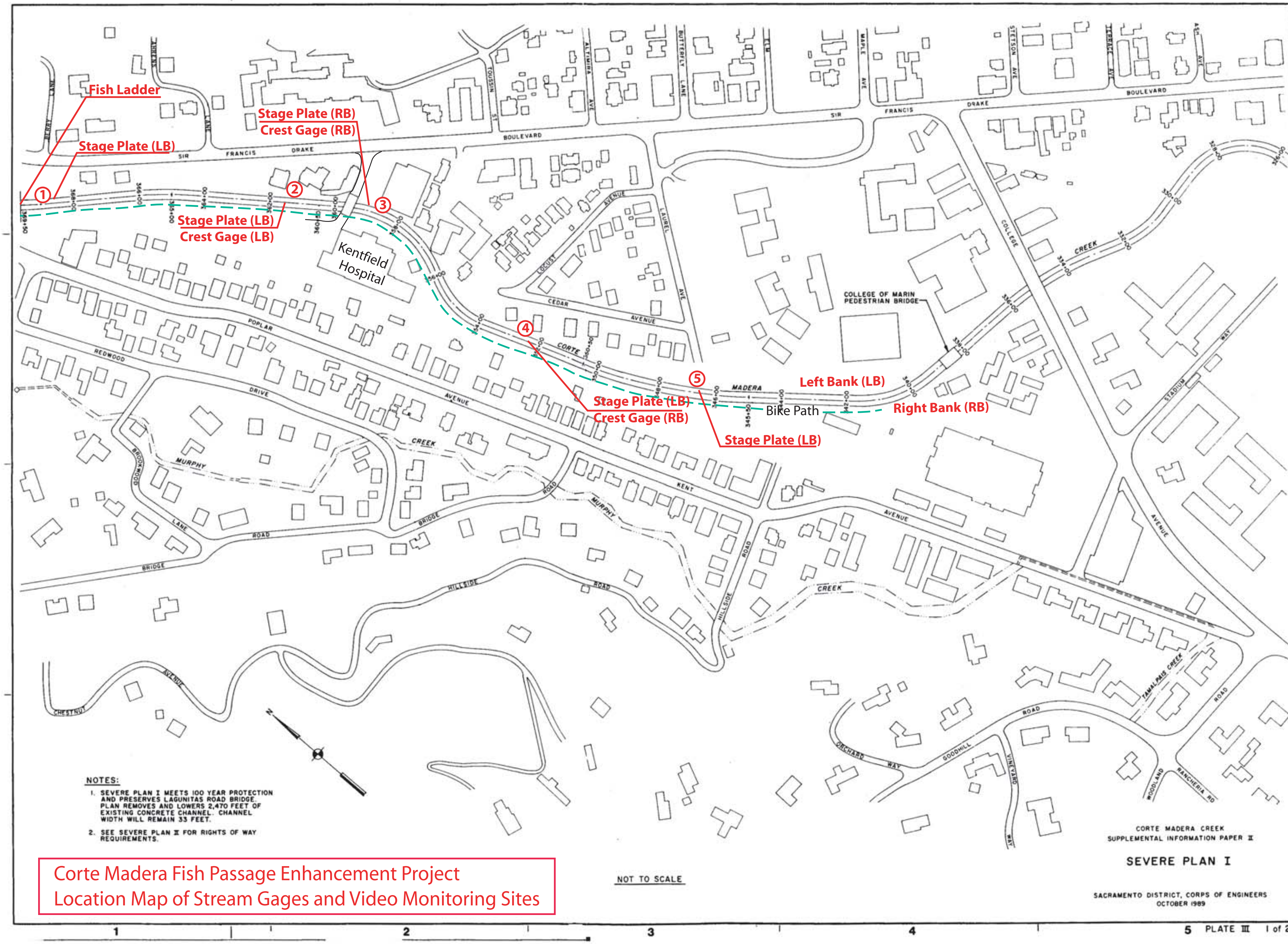
**Establish "monitoring-point" for Repeat Video Viewing**
A monumented monitoring-point (also known as photo-points) should be established by making a permanent or semi-permanent mark on the ground. Where possible, the tripod should be set up directly above the monument for each video session.

**Framing the Shot for Repeat Filming**
To show the range of flows, and hydraulic differences at the different flows, it is necessary to reoccupy the same field of view for each video session. Once a field of view has been established, it should be maintained. To re-establish the same field of view for each filming session, frame the shot in such a way that notable objects are placed consistently in the frame each time. For example by aligning the edge of the viewfinder with one or more objects in the field of view, it will be easy to maintain a consistent view from session to session. The camera person should make a simple sketch in the field notebook showing the viewfinder and the objects used for framing.

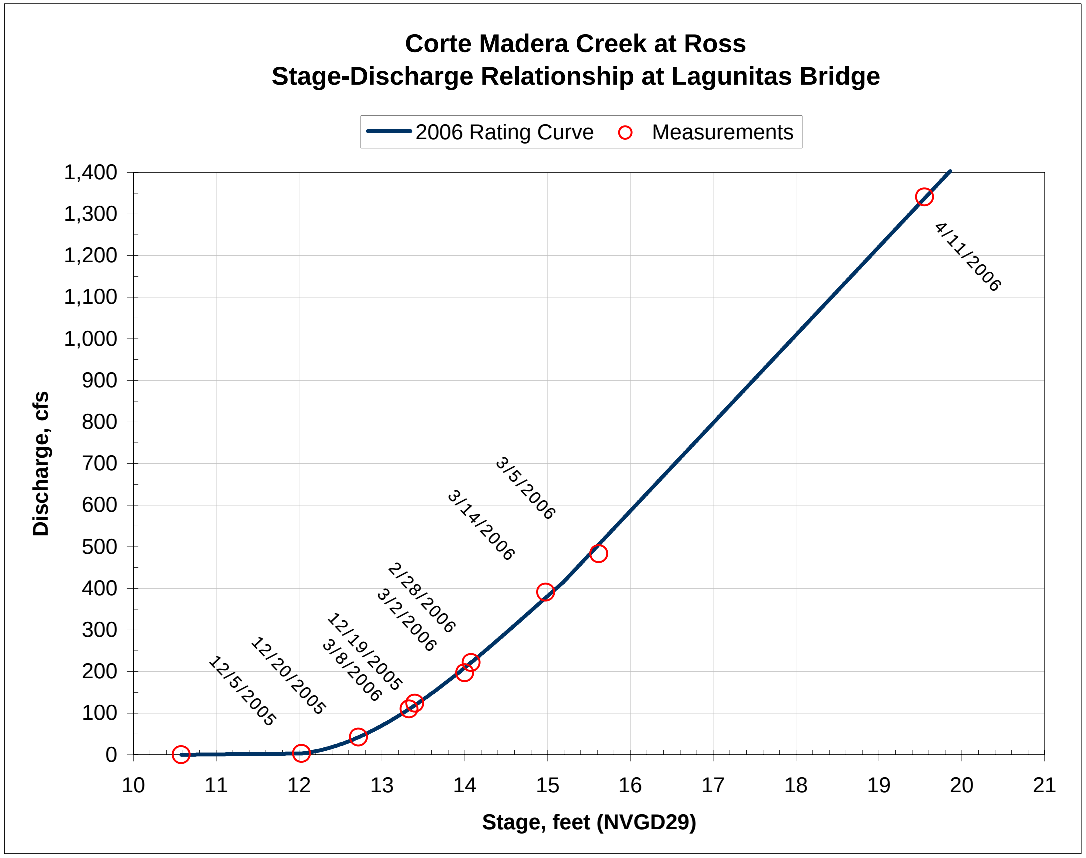
**Date/Time Stamps**
Use of the Date/Time Stamp is optional. If you choose to use this feature, make sure the date and time are correct and that you change the clock for day-light savings.

<u>MiniDV Cameras</u>
MiniDV cameras include the time and date as a separate "data code" which can be switched on or off when editing the tape. If you are using a MiniDV camera, you may leave the date and time stamp on throughout the filming since we will be able to easily remove it during editing.

<u>Other Camera Types</u>
If you wish to use the date/time stamp and your camera is not a MiniDV, make sure that the date/time stamp is only on during the initial 5 to 10 seconds. Some cameras have an option to have the date/time stamps recorded for the first 6 seconds of a shot, and then turn off. If the date/time stamp is left turned on the camera may burn it into the image permanently, preventing viewing the image without the time/date stamp. This is generally undesirable and should be avoided.




Corte Madera Fish Passage Enhancement Project
Location Map of Stream Gages and Video Monitoring Sites




**Field Measurements (Stetson 2006, EDS 2006)**

| Stage (ft, NGVD29) | Discharge (cfs) | Date | Collected by |
|---|---|---|---|
| 10.58 | 0.0 | 12/5/2005 | Stetson |
| 12.03 | 3.1 | 12/5/2005 | Stetson |
| 12.72 | 42.6 | 12/20/2005 | Stetson |
| 13.33 | 109.9 | 3/8/2006 | Stetson |
| 13.40 | 123.6 | 12/19/2005 | Stetson |
| 14.00 | 196.6 | 3/2/2006 | EDS |
| 14.08 | 221.5 | 2/28/2006 | Stetson |
| 14.98 | 390.4 | 3/14/2006 | EDS |
| 15.62 | 482.7 | 3/5/2006 | EDS |
| 19.55 | 1340.7 | 4/11/2006 | EDS |

**Discharge Rating Curve**
**Corte Madera Creek at Ross**
MLA 7/11/06

**Fit to observations**
***Stage in NGVD29***

**Stage** <12.03 ft
y = 2.1379x - 22.619

12.03 ft < **Stage** <15.18 ft
y = -6.2976x^3 + 281.22x^2 - 4009.2x + 18499.44

**Stage** >15.18 ft
y = 211.64x - 2800

## 2006 Discharge Rating Table For Corte Madera Creek at Ross

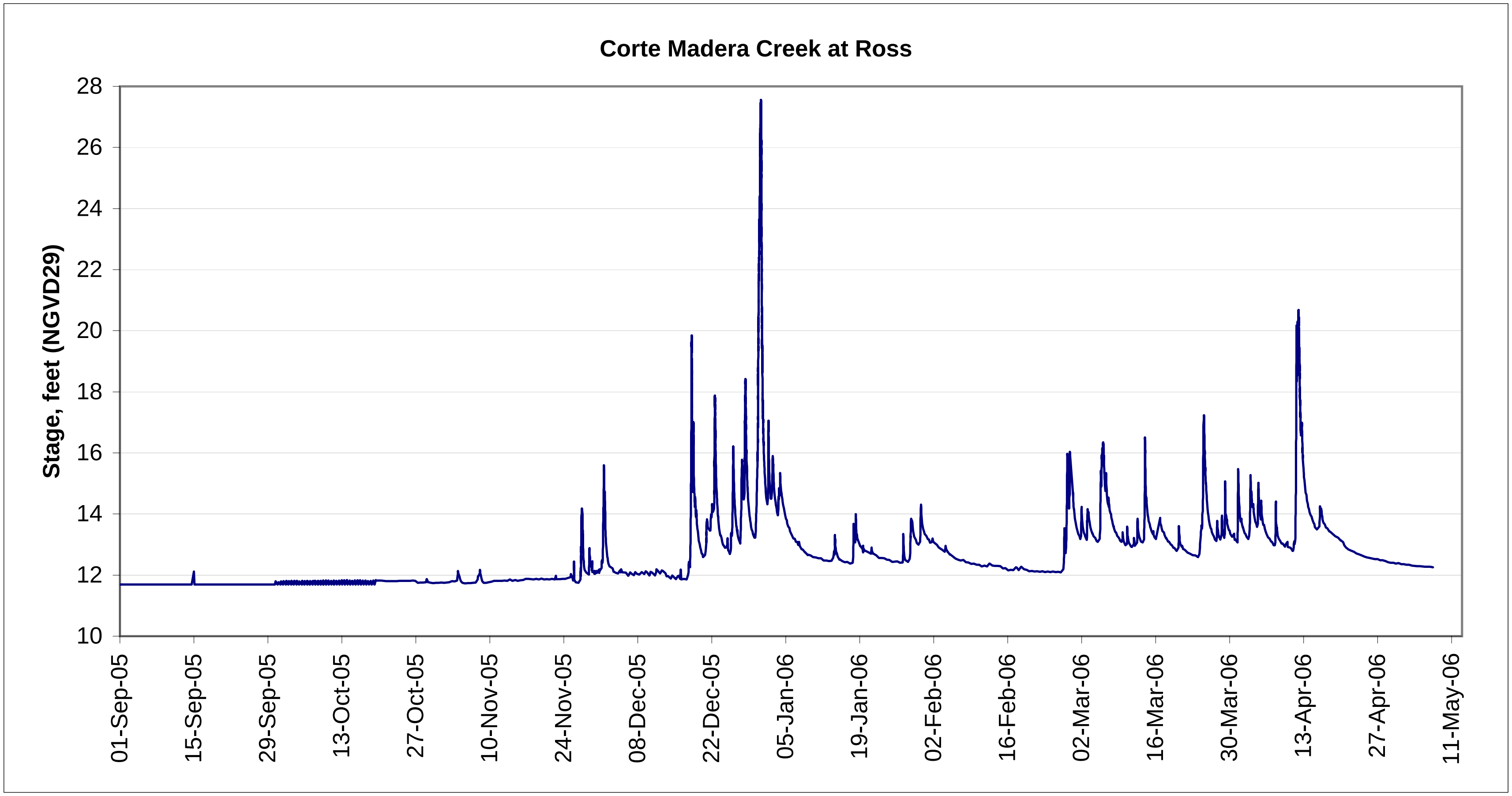
| Stage, feet (NVGD29) | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10.5 | | | | | | | | | 0.00 | 0.02 |
| 10.6 | 0.04 | 0.06 | 0.09 | 0.11 | 0.13 | 0.15 | 0.17 | 0.19 | 0.21 | 0.24 |
| 10.7 | 0.26 | 0.28 | 0.30 | 0.32 | 0.34 | 0.36 | 0.38 | 0.41 | 0.43 | 0.45 |
| 10.8 | 0.47 | 0.49 | 0.51 | 0.53 | 0.56 | 0.58 | 0.60 | 0.62 | 0.64 | 0.66 |
| 10.9 | 0.68 | 0.71 | 0.73 | 0.75 | 0.77 | 0.79 | 0.81 | 0.83 | 0.86 | 0.88 |
| 11.0 | 0.90 | 0.92 | 0.94 | 0.96 | 0.98 | 1.00 | 1.03 | 1.05 | 1.07 | 1.09 |
| 11.1 | 1.11 | 1.13 | 1.15 | 1.18 | 1.20 | 1.22 | 1.24 | 1.26 | 1.28 | 1.30 |
| 11.2 | 1.33 | 1.35 | 1.37 | 1.39 | 1.41 | 1.43 | 1.45 | 1.48 | 1.50 | 1.52 |
| 11.3 | 1.54 | 1.56 | 1.58 | 1.60 | 1.62 | 1.65 | 1.67 | 1.69 | 1.71 | 1.73 |
| 11.4 | 1.75 | 1.77 | 1.80 | 1.82 | 1.84 | 1.86 | 1.88 | 1.90 | 1.92 | 1.95 |
| 11.5 | 1.97 | 1.99 | 2.01 | 2.03 | 2.05 | 2.07 | 2.10 | 2.12 | 2.14 | 2.16 |
| 11.6 | 2.18 | 2.20 | 2.22 | 2.24 | 2.27 | 2.29 | 2.31 | 2.33 | 2.35 | 2.37 |
| 11.7 | 2.39 | 2.42 | 2.44 | 2.46 | 2.48 | 2.50 | 2.52 | 2.54 | 2.57 | 2.59 |
| 11.8 | 2.61 | 2.63 | 2.65 | 2.67 | 2.69 | 2.72 | 2.74 | 2.76 | 2.78 | 2.80 |
| 11.9 | 2.82 | 2.84 | 2.86 | 2.89 | 2.91 | 2.93 | 2.95 | 2.97 | 2.99 | 3.01 |
| 12.0 | 3.04 | 3.06 | 3.08 | 3.10 | 3.33 | 3.58 | 3.83 | 4.10 | 4.37 | 4.66 |
| 12.1 | 4.96 | 5.27 | 5.58 | 5.91 | 6.25 | 6.60 | 6.96 | 7.33 | 7.71 | 8.10 |
| 12.2 | 8.50 | 8.91 | 9.33 | 9.76 | 10.20 | 10.65 | 11.12 | 11.59 | 12.07 | 12.56 |
| 12.3 | 13.1 | 13.6 | 14.1 | 14.6 | 15.2 | 15.7 | 16.3 | 16.8 | 17.4 | 18.0 |
| 12.4 | 18.6 | 19.2 | 19.8 | 20.4 | 21.1 | 21.7 | 22.4 | 23.0 | 23.7 | 24.4 |
| 12.5 | 25.1 | 25.8 | 26.5 | 27.2 | 27.9 | 28.6 | 29.4 | 30.1 | 30.9 | 31.7 |
| 12.6 | 32.4 | 33.2 | 34.0 | 34.8 | 35.6 | 36.5 | 37.3 | 38.1 | 39.0 | 39.8 |
| 12.7 | 40.7 | 41.5 | 42.4 | 43.3 | 44.2 | 45.1 | 46.0 | 46.9 | 47.9 | 48.8 |
| 12.8 | 49.7 | 50.7 | 51.6 | 52.6 | 53.6 | 54.6 | 55.6 | 56.6 | 57.6 | 58.6 |
| 12.9 | 60 | 61 | 62 | 63 | 64 | 65 | 66 | 67 | 68 | 69 |
| 13.0 | 70 | 71 | 72 | 74 | 75 | 76 | 77 | 78 | 79 | 80 |
| 13.1 | 82 | 83 | 84 | 85 | 86 | 87 | 89 | 90 | 91 | 92 |
| 13.2 | 93 | 95 | 96 | 97 | 98 | 100 | 101 | 102 | 104 | 105 |
| 13.3 | 106 | 107 | 109 | 110 | 111 | 113 | 114 | 115 | 117 | 118 |
| 13.4 | 119 | 121 | 122 | 123 | 125 | 126 | 128 | 129 | 130 | 132 |
| 13.5 | 133 | 135 | 136 | 137 | 139 | 140 | 142 | 143 | 145 | 146 |
| 13.6 | 147 | 149 | 150 | 152 | 153 | 155 | 156 | 158 | 159 | 161 |
| 13.7 | 162 | 164 | 165 | 167 | 168 | 170 | 171 | 173 | 174 | 176 |
| 13.8 | 177 | 179 | 181 | 182 | 184 | 185 | 187 | 188 | 190 | 192 |
| 13.9 | 193 | 195 | 196 | 198 | 199 | 201 | 203 | 204 | 206 | 208 |
| 14.0 | 209 | 211 | 212 | 214 | 216 | 217 | 219 | 221 | 222 | 224 |
| 14.1 | 226 | 227 | 229 | 230 | 232 | 234 | 235 | 237 | 239 | 240 |
| 14.2 | 242 | 244 | 246 | 247 | 249 | 251 | 252 | 254 | 256 | 257 |
| 14.3 | 259 | 261 | 262 | 264 | 266 | 268 | 269 | 271 | 273 | 274 |
| 14.4 | 276 | 278 | 280 | 281 | 283 | 285 | 287 | 288 | 290 | 292 |
| 14.5 | 294 | 295 | 297 | 299 | 300 | 302 | 304 | 306 | 307 | 309 |
| 14.6 | 311 | 313 | 314 | 316 | 318 | 320 | 322 | 323 | 325 | 327 |
| 14.7 | 329 | 330 | 332 | 334 | 336 | 337 | 339 | 341 | 343 | 344 |
| 14.8 | 346 | 348 | 350 | 351 | 353 | 355 | 357 | 359 | 360 | 362 |
| 14.9 | 364 | 366 | 367 | 369 | 371 | 373 | 374 | 376 | 378 | 380 |
| 15.0 | 382 | 383 | 385 | 387 | 389 | 390 | 392 | 394 | 396 | 397 |
| 15.1 | 399 | 401 | 403 | 404 | 406 | 408 | 410 | 411 | 413 | 415 |
| 15.2 | 417 | 419 | 421 | 423 | 425 | 428 | 430 | 432 | 434 | 436 |
| 15.3 | 438 | 440 | 442 | 444 | 447 | 449 | 451 | 453 | 455 | 457 |
| 15.4 | 459 | 461 | 463 | 466 | 468 | 470 | 472 | 474 | 476 | 478 |
| 15.5 | 480 | 483 | 485 | 487 | 489 | 491 | 493 | 495 | 497 | 499 |

# 2006 Discharge Rating Table For Corte Madera Creek at Ross

| Stage, feet (NVGD29) | 0.00 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.07 | 0.08 | 0.09 |
|---|---|---|---|---|---|---|---|---|---|---|
| **15.6** | 502 | 504 | 506 | 508 | 510 | 512 | 514 | 516 | 519 | 521 |
| **15.7** | 523 | 525 | 527 | 529 | 531 | 533 | 535 | 538 | 540 | 542 |
| **15.8** | 544 | 546 | 548 | 550 | 552 | 554 | 557 | 559 | 561 | 563 |
| **15.9** | 565 | 567 | 569 | 571 | 574 | 576 | 578 | 580 | 582 | 584 |
| **16.0** | 586 | 588 | 590 | 593 | 595 | 597 | 599 | 601 | 603 | 605 |
| **16.1** | 607 | 610 | 612 | 614 | 616 | 618 | 620 | 622 | 624 | 626 |
| **16.2** | 629 | 631 | 633 | 635 | 637 | 639 | 641 | 643 | 645 | 648 |
| **16.3** | 650 | 652 | 654 | 656 | 658 | 660 | 662 | 665 | 667 | 669 |
| **16.4** | 671 | 673 | 675 | 677 | 679 | 681 | 684 | 686 | 688 | 690 |
| **16.5** | 692 | 694 | 696 | 698 | 701 | 703 | 705 | 707 | 709 | 711 |
| **16.6** | 713 | 715 | 717 | 720 | 722 | 724 | 726 | 728 | 730 | 732 |
| **16.7** | 734 | 737 | 739 | 741 | 743 | 745 | 747 | 749 | 751 | 753 |
| **16.8** | 756 | 758 | 760 | 762 | 764 | 766 | 768 | 770 | 772 | 775 |
| **16.9** | 777 | 779 | 781 | 783 | 785 | 787 | 789 | 792 | 794 | 796 |
| **17.0** | 798 | 800 | 802 | 804 | 806 | 808 | 811 | 813 | 815 | 817 |
| **17.1** | 819 | 821 | 823 | 825 | 828 | 830 | 832 | 834 | 836 | 838 |
| **17.2** | 840 | 842 | 844 | 847 | 849 | 851 | 853 | 855 | 857 | 859 |
| **17.3** | 861 | 863 | 866 | 868 | 870 | 872 | 874 | 876 | 878 | 880 |
| **17.4** | 883 | 885 | 887 | 889 | 891 | 893 | 895 | 897 | 899 | 902 |
| **17.5** | 904 | 906 | 908 | 910 | 912 | 914 | 916 | 919 | 921 | 923 |
| **17.6** | 925 | 927 | 929 | 931 | 933 | 935 | 938 | 940 | 942 | 944 |
| **17.7** | 946 | 948 | 950 | 952 | 954 | 957 | 959 | 961 | 963 | 965 |
| **17.8** | 967 | 969 | 971 | 974 | 976 | 978 | 980 | 982 | 984 | 986 |
| **17.9** | 988 | 990 | 993 | 995 | 997 | 999 | 1001 | 1003 | 1005 | 1007 |
| **18.0** | 1010 | 1012 | 1014 | 1016 | 1018 | 1020 | 1022 | 1024 | 1026 | 1029 |
| **18.1** | 1031 | 1033 | 1035 | 1037 | 1039 | 1041 | 1043 | 1045 | 1048 | 1050 |
| **18.2** | 1052 | 1054 | 1056 | 1058 | 1060 | 1062 | 1065 | 1067 | 1069 | 1071 |
| **18.3** | 1073 | 1075 | 1077 | 1079 | 1081 | 1084 | 1086 | 1088 | 1090 | 1092 |
| **18.4** | 1094 | 1096 | 1098 | 1101 | 1103 | 1105 | 1107 | 1109 | 1111 | 1113 |
| **18.5** | 1115 | 1117 | 1120 | 1122 | 1124 | 1126 | 1128 | 1130 | 1132 | 1134 |
| **18.6** | 1137 | 1139 | 1141 | 1143 | 1145 | 1147 | 1149 | 1151 | 1153 | 1156 |
| **18.7** | 1158 | 1160 | 1162 | 1164 | 1166 | 1168 | 1170 | 1172 | 1175 | 1177 |
| **18.8** | 1179 | 1181 | 1183 | 1185 | 1187 | 1189 | 1192 | 1194 | 1196 | 1198 |
| **18.9** | 1200 | 1202 | 1204 | 1206 | 1208 | 1211 | 1213 | 1215 | 1217 | 1219 |
| **19.0** | 1221 | 1223 | 1225 | 1228 | 1230 | 1232 | 1234 | 1236 | 1238 | 1240 |
| **19.1** | 1242 | 1244 | 1247 | 1249 | 1251 | 1253 | 1255 | 1257 | 1259 | 1261 |
| **19.2** | 1263 | 1266 | 1268 | 1270 | 1272 | 1274 | 1276 | 1278 | 1280 | 1283 |
| **19.3** | 1285 | 1287 | 1289 | 1291 | 1293 | 1295 | 1297 | 1299 | 1302 | 1304 |
| **19.4** | 1306 | 1308 | 1310 | 1312 | 1314 | 1316 | 1319 | 1321 | 1323 | 1325 |
| **19.5** | 1327 | 1329 | 1331 | 1333 | 1335 | 1338 | 1340 | 1342 | 1344 | 1346 |
| **19.6** | 1348 | 1350 | 1352 | 1354 | 1357 | 1359 | 1361 | 1363 | 1365 | 1367 |
| **19.7** | 1369 | 1371 | 1374 | 1376 | 1378 | 1380 | 1382 | 1384 | 1386 | 1388 |
| **19.8** | 1390 | 1393 | 1395 | 1397 | 1399 | 1401 | 1403 | 1405 | 1407 | 1410 |
| **19.9** | 1412 | 1414 | 1416 | 1418 | 1420 | 1422 | 1424 | 1426 | 1429 | 1431 |

## Corte Madera Creek at Ross

Source: http://marin.onerain.com/portal.php
Stage readings converted to NGVD29 datum using conversion of +4.97 feet (Stetson, 2006)



## Corte Madera Creek Flood Control Channel - Unit 3

### Video Observations

Discharge estimated from corresponding stage at County Gage near Lagunitas Bridge and MLA 2006 Rating Table

**Station 1**
**At Fish Ladder**

| | | | Staff Plate at Sta. 1 (feet) | | Corte Madera Creek Gage At Ross (feet) | | 2006 rating curve |
|---|---|---|---|---|---|---|---|
| Video Clip | Date | Time | Stage | Elev. (NGVD29) | Stage | Elev. (NGVD29) | Discharge (cfs) |
| 1_011006_1628_2.7 | 1/10/2006 | 16:28 | 2.7 | 7.20 | 7.61 | 12.58 | 30.89 |
| 1_122005_1110_3.2 | 12/20/2005 | 11:10 | 3.2 | 7.30 | 7.62 | 12.59 | 31.66 |
| 1_010706_1602_3.9 | 1/7/2006 | 16:02 | 3.4 | 7.33 | 7.98 | 12.95 | 64.80 |
| 1_122405_1326_4.2 | 12/24/2005 | 13:26 | 3.8 | 7.41 | 7.92 | 12.89 | 58.57 |
| 1_010606_1007_4.4 | 1/6/2006 | 10:07 | 4.4 | 7.54 | 8.23 | 13.20 | 93.49 |
| 1_122305_1607_5.0 | 12/23/2005 | 16:07 | 5.0 | 7.67 | 8.33 | 13.30 | 106.12 |
| 1_122105_1010_6.0 | 12/21/2005 | 10:10 | 5.8 | 7.85 | 8.59 | 13.56 | 141.65 |
| 1_121905_1201_6.0 | 12/19/2005 | 12:01 | 6.0 | 7.89 | 8.25 | 13.22 | 95.97 |
| 1_013006_1700_7.0 | 1/30/2006 | 17:00 | 6.4 | 7.98 | 8.94 | 13.91 | 194.71 |
| 1_010406_1333_8.5_GageDamage | 1/4/2006 | 13:33 | 8.5 | 8.37 | 9.31 | 14.28 | 255.67 |
| 1_010406_1335_8.5 | 1/4/2006 | 13:35 | 8.5 | 8.37 | 9.31 | 14.28 | 255.67 |
| 1_022706_1123_11 | 2/27/2006 | 11:23 | 11.0 | 8.81 | 9.83 | 14.80 | 346.20 |

**Station 2**
**U/S Kentfield Bridge**

| | | | Staff Plate at Sta. 2 (feet) | | Corte Madera Creek Gage At Ross (feet) | | 2006 rating curve |
|---|---|---|---|---|---|---|---|
| Video Clip | Date | Time | Stage | Elev. (NGVD29) | Stage | Elev. (NGVD29) | Discharge (cfs) |
| 2_121505_1145_-0.2 | 12/15/2005 | 11:45 | -0.2 | | 6.90 | 11.87 | 2.76 |
| 2_022606_????_0.0 | 2/26/2006 | | 0.0 | 4.10 | 7.48 | 12.45 | 21.71 |
| 2__112905_????_0.1 | 11/29/2005 | | 0.1 | 4.11 | 7.31 | 12.28 | 12.07 |
| 2_120205_1400_3.0 | 12/2/2005 | 14:00 | 3.0 | 4.52 | 7.41 | 12.38 | 16.83 |
| 2_122005_????_4.5 | 12/20/2005 | | 4.5 | 4.78 | 7.62 | 12.59 | 31.66 |
| 2_011906_????_5 | 1/19/2006 | | 5.0 | 4.88 | 7.88 | 12.85 | 54.57 |
| Crest gage | 12/1/2006 | | | 6.37 | 10.62 | 15.59 | 485.90 |
| Crest gage | 12/28/2006 | | | 7.67 | 13.45 | 18.42 | 1070.5 |
| Crest gage | 12/18/2006 | | | 8.45 | 14.48 | 19.45 | 1328.1 |

**Station 3**
**D/S Kentfield Bridge (Potential Tidal Effects)**

| | | | Staff Plate at Sta. 3 (feet) | | Corte Madera Creek Gage At Ross (feet) | | 2006 rating curve |
|---|---|---|---|---|---|---|---|
| Video Clip | Date | Time | Stage | Elev. (NGVD29) | Stage | Elev. (NGVD29) | Discharge (cfs) |
| 3_121905_1425_11.3 | 12/19/2005 | 14:25 | 10.5 | 3.64 | 8.15 | 13.12 | 83.85 |
| 3_010506_0900_11.5 | 1/5/2006 | 9:00 | 11.0 | 3.70 | 8.72 | 13.69 | 160.73 |
| 3_121805_1440_14.2 | 12/18/2005 | 14:40 | 14.0 | 4.69 | 10.40 | 15.37 | 452.91 |
| 3_030606_1430_14.3 | 3/6/2006 | 14:30 | 14.3 | 4.99 | 10.30 | 15.27 | 431.74 |
| Crest gage | 12/1/2006 | | | 4.34 | 10.62 | 15.59 | 485.90 |
| Crest gage | 12/28/2006 | | | 5.67 | 13.45 | 18.42 | 1070.54 |
| Crest gage | 12/18/2006 | | | 6.35 | 14.48 | 19.45 | 1328.10 |

# Corte Madera Creek Flood Control Channel - Unit 3

## Video Observations

Discharge estimated from corresponding stage at County Gage near Lagunitas Bridge and MLA 2006 Rating Table

### Station 4

**At D/S Fish Pool (Tidal Effects Present)**

| | | | Staff Plate at Sta. 4 (feet) | | Corte Madera Creek Gage At Ross (feet) | | 2006 rating curve |
|---|---|---|---|---|---|---|---|
| **Video Clip** | **Date** | **Time** | **Stage** | **Elevation** | **Stage** | **(NGVD29)** | **Discharge (cfs)** |
| 4_010506_0910_9.2 | 1/5/2006 | 9:10 | 8.5 | 1.91 | 8.72 | 13.69 | 160.73 |
| 4_030606_1425_13.6 | 3/6/2006 | 14:25 | 13.6 | 3.04 | 10.26 | 15.23 | 423.28 |
| 4_121805_1452__13.6 | 12/18/2005 | 14:52 | 13.6 | 3.04 | 10.30 | 15.27 | 431.74 |
| 4_121905_1420_13.8 | 12/19/2005 | 14:20 | 13.7 | 3.14 | 8.15 | 13.12 | 83.85 |
| Crest gage | 12/28/2006 | | | 5.40 | 13.45 | 18.42 | 1070.54 |
| Crest gage | 12/18/2006 | | | 5.19 | 14.48 | 19.45 | 1328.10 |

### Station 5

**At College of Marin Ped Bridge (Tidal Effects Present)**

| | | | Staff Plate at Sta. 5 (feet) | | Corte Madera Creek Gage At Ross (feet) | | 2006 rating curve |
|---|---|---|---|---|---|---|---|
| **Video Clip** | **Date** | **Time** | **Stage** | **Elev. (NGVD29)** | **Stage** | **Elev. (NGVD29)** | **Discharge (cfs)** |
| 5_122105_0904_1.0 | 12/21/2005 | 9:04 | 1.0 | 1.17 | 8.59 | 13.56 | 141.65 |
| 5_122105_0904_1.0_DS | 12/21/2005 | 9:04 | 1.0 | 1.17 | 8.59 | 13.56 | 141.65 |
| 5_122105_0904_1.0_US | 12/21/2005 | 9:04 | 1.0 | 1.17 | 8.59 | 13.56 | 141.65 |
| 5_010406_1323_2.4 | 1/4/2006 | 13:23 | 2.4 | 2.57 | 9.31 | 14.28 | 255.67 |
| 5_010305_1323_?? | 1/3/2005 | 13:23 | | | 8.50 | 13.47 | 128.94 |
| 5_013006_1715_minus | 1/30/2006 | 17:15 | | | 8.94 | 13.91 | 194.71 |

**Notes**

1) **Video Clips** provided by Friends of Corte Madera Watershed
2) **Stage** at each station in the flood channel is read from staff plates installed by MLA in July 2005
3) **Elevation** is water surface elevation in the floodway and at the gage for the associated stage reading
4) **Stage** for the county gage is read from data provided on web portal using the date and time of observation
5) **Stage** at county gage was converted NVGD29 using conversion of +4.97 ft (Stetson, 2006)
6) **Discharge** for each observation is obtained from the 2006 rating table (MLA) using corresponding water surface elevation

# Video Observations (Unit 3 Corte Madera Creek)

## Fish Observations

| Video Clip | Date | Time | Corte Madera Creek Gage At Ross, ft Stage | (NGVD29) | 2006 rating curve Discharge (cfs) |
|---|---|---|---|---|---|
| Fish_FL_120205_1350 | 12/2/2005 | 13:50 | 7.41 | 12.38 | 16.83 |
| FL_Fish?_122005_1252_3.2 | 12/20/2005 | 12:52 | 7.62 | 12.59 | 31.66 |
| FL_fish_122005_1250_3.2 | 12/20/2005 | 12:50 | 7.62 | 12.59 | 31.66 |
| FL_Fish2_122005_1207_3.2 | 12/20/2005 | 12:07 | 7.62 | 12.59 | 31.66 |
| RP_011006_1656_FishHolding | 1/10/2006 | 16:56 | 7.61 | 12.58 | 30.89 |
| RP_011006_1704_FishMove | 1/10/2006 | 17:04 | 7.61 | 12.58 | 30.89 |
| RP_011006_1713_fishholding | 1/10/2006 | 17:13 | 7.61 | 12.58 | 30.89 |
| FL_010706_1733_FISH | 1/7/2006 | 17:33 | 7.98 | 12.95 | 64.80 |
| Fish_SH_022406_wide | 2/24/2006 | | | | |
| Fish_SH_022406_wide | 2/24/2006 | | | | |
| Fish_SH_022406_pair_close | 2/24/2006 | | | | |
| Fish_SH_022406_PairUstrRiffle | 2/24/2006 | | | | |
| Fish_SH_022406_ducks | 2/24/2006 | | | | |
| Fish_SH_021506_pair | 2/15/2006 | | | | |
| Fish_SH_021506_moving | 2/15/2006 | | | | |
| Fish_SH_021506_merganser | 2/15/2006 | | | | |
| Fish_SH_021506 | 2/15/2006 | | | | |
| Fish__SH_021506_holding | 2/15/2006 | | | | |
| Fish_SH_holding_movesUSTRdark | | | | | |
| Leap_020206_1439_Fairfax | 2/2/2006 | 14:39 | 8.03 | 13.00 | 70.19 |
| Leaps_020206Fairfax | 12/2/2006 | 14:25 | 8.5 | 13.47 | 128.94 |

**Key:**
FL = Fish Ladder
Fairfax = Pastori Crossing on San Anselmo Creek
RP = Concrete Resting Pools
SH = Steelhead

# Video Observations (Unit 3 Corte Madera Creek)

## Other Observations

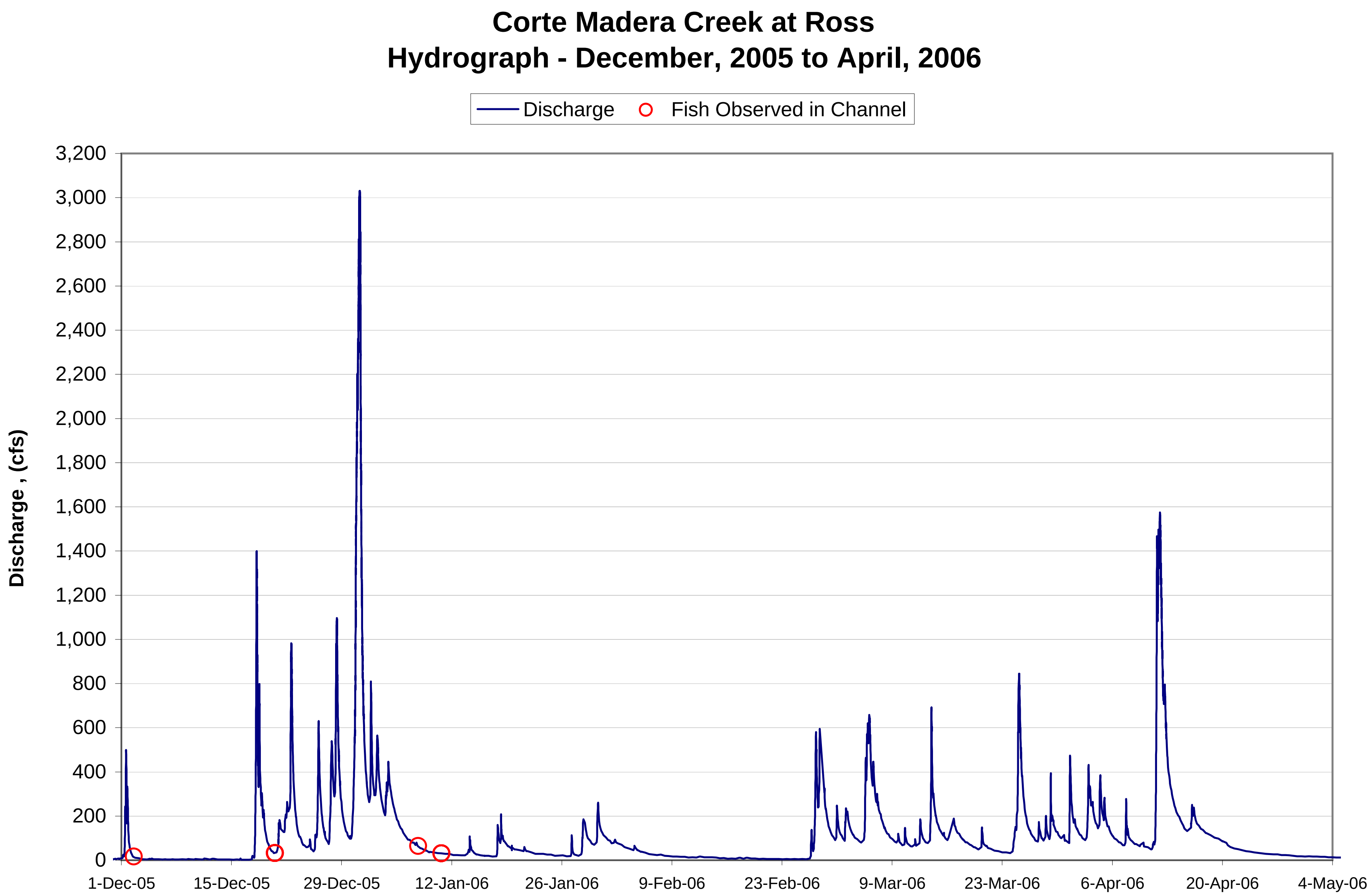
| Video Clip | Date | Time | Corte Madera Creek Gage At Ross, ft Stage | (NGVD29) | 2006 rating curve Discharge (cfs) |
|---|---|---|---|---|---|
| BrightPath_FloodingClips | 1/1/2006 | | | | |
| FL_011006_1626_2.9 | 1/10/2006 | 16:26 | 7.61 | 12.58 | 30.89 |
| FL_122005_1103_3.2 | 12/20/2005 | 11:03 | 7.62 | 12.59 | 31.66 |
| FL_010906_1630_debris | 1/9/2006 | 16:30 | 7.67 | 12.64 | 35.63 |
| FL_010906_1636_wide | 1/9/2006 | 16:36 | 7.67 | 12.64 | 35.63 |
| FL_122405_1323_4.2 | 12/24/2005 | 13:23 | 7.92 | 12.89 | 58.57 |
| FL__010706_1604_3.9 | 1/7/2006 | 16:04 | 7.98 | 12.95 | 64.80 |
| FL_121905_1155_6.0 | 12/19/2005 | 11:55 | 8.25 | 13.22 | 95.97 |
| FL_122305_1605_5.0 | 12/23/2005 | 16:05 | 8.33 | 13.30 | 106.12 |
| FL_010306_1255_?? | 1/3/2006 | 12:55 | 8.99 | 13.96 | 202.69 |
| FL__013006_1657_7.0 | 1/30/2006 | 16:57 | 9.04 | 14.01 | 210.77 |
| FL_010406_1335_8.5 | 1/4/2006 | 13:35 | 9.31 | 14.28 | 255.67 |
| FL_022706_1121_11 | 2/27/2006 | 11:21 | 9.83 | 14.80 | 346.20 |
| FL__010606_LWDRemoval | 1/6/2006 | | | | |
| FL_010706_close views_inlet | 1/7/2006 | | | | |
| FL_122305_TopViews | 12/23/2005 | | | | |
| KBr_122005_RestPool | 12/20/2005 | | | | |
| KBr_DSTR_120205_????_3.0 | 12/2/2005 | | | | |
| KBr_USTR_011906_????_5.0 | 1/19/2006 | | | | |
| KBr_USTR_120205_3.0 | 12/2/2005 | | | | |
| KBr_USTR_122005_????_4.5 | 12/20/2005 | | | | |
| KBr_USTR_121505_1200_-0.2 | 12/15/2005 | 12:00 | 6.9 | 11.87 | 2.76 |
| KBridge_030606_1432 | 3/6/2006 | 14:32 | 10.26 | 15.23 | 423.28 |

**Key:**
FL = Fish Ladder
KBr = Kentfield Bridge

# Video Observations (Unit 3 Corte Madera Creek)

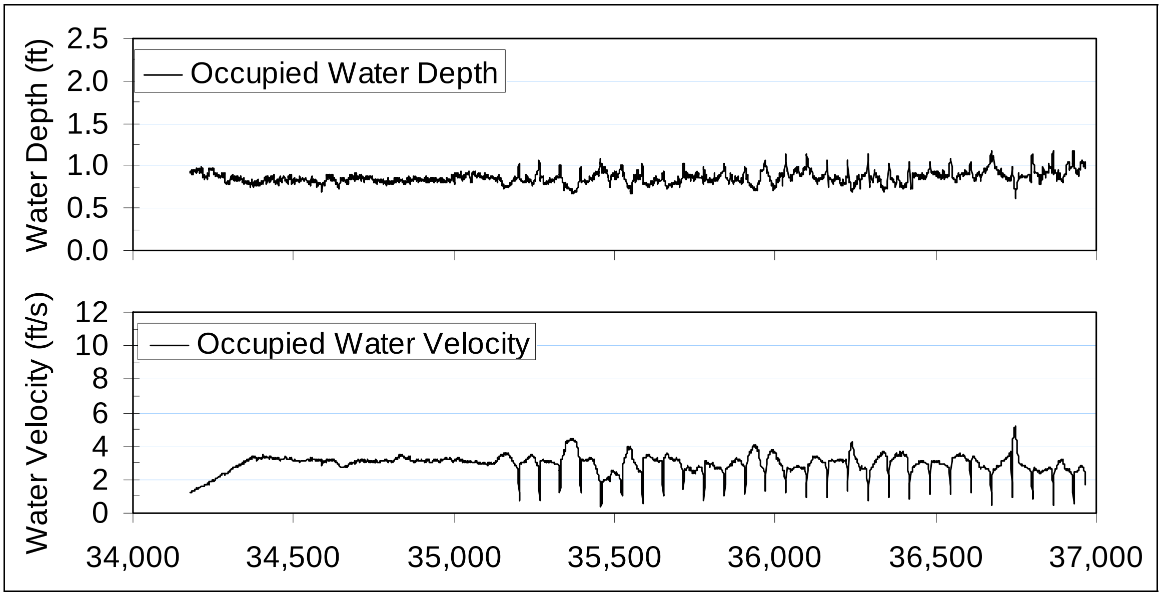
## Corte Madera Creek Watershed Fish Sightings - Winter 2004 -05

| Picture | Date | Observer | Description | Location |
|---|---|---|---|---|
| IM000802.JPG | 10/26/2004 | Jack Curley | Chinook (?) | CM Creek: fish ladder at top of |
| 102604-001.JPG; 102604-003.JPG; 102604-004.JPG | 10/26/2004 | Alice Rich | | CM Creek; natural channel below Lagunitas Rd bridge, Ross |
| 102604-005.JPG; 102604-008.JPG | 10/26/2004 | Alice Rich | Dead Chinook | CM Creek; above Lagunitas Rd bridge, |
| | 10/28/2004 | Charles Kennard | Big fish w/ white spot | SA Creek: downtown, under middle pedestrian bridge by Chinese herbalist |
| Creek Chronicles Winter 2005 | 10/28/2004 | Bob Snyder | Big fish w/ white spot | SA Creek: pool downstream of Bridge St. |
| | 10/30/2004 | M. Von Buchau | Spawning female steelhead ? | SA Creek in San Anselmo |
| Kennard. big fish.Park Dr SA 12.03.jpg | 12/3/2004 | Charles Kennard | Big fish | SA Creek Park Drive, San Anselmo |
| CIMG0252_20041206.AVI; bubbles.jpg; overflow.jpg | 12/6/2004 | Parker Pringle | Steelhead | CM Creek: fish ladder at top of concrete channel, Ross |
| CIMG0280_20041207.AVI | 12/7/2004 | Parker Pringle | Steelhead | CM Creek: concrete channel, Ross |
| MVI_1489_20041209.AVI; MVI_1498_20041209.AVI; MVI_1500_20041209.AVI | 12/9/2004 | Parker Pringle | Steelhead | CM Creek: fish ladder at top of concrete channel, Ross |
| MVI_1506_20041211.AVI | 12/11/2004 | Parker Pringle | Steelhead | CM Creek: concrete channel, Kentfield or Ross |
| | 12/12/2004 | Mike Cronin | Large salmonid | Downstream of confluence of SH and |
| | 12/24/2004 | Phyllis Lucas-Haddon | Dead fish, ~2 feet long | Nokomis Avenue |
| | c. 1/5/05 | Ash Wood | Large fish | Ross Creek, near Shady Lane |
| | 1/7/2005 | Mike Cronin | Several salmonids, variable size, at least one a steelhead | Pool below Pastori Avenue fish ladder |

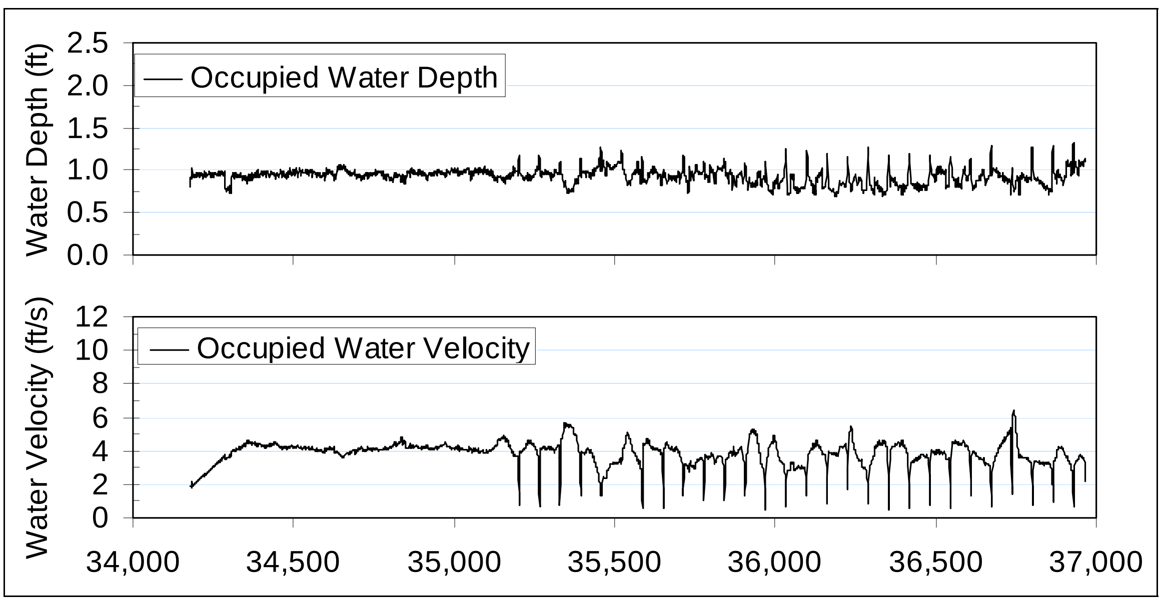

Corte Madera Creek at Ross
Hydrograph - December, 2005 to April, 2006
Discharge
Fish Observed in Channel
Discharge , (cfs)
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
1-Dec-05
15-Dec-05
29-Dec-05
12-Jan-06
26-Jan-06
9-Feb-06
23-Feb-06
9-Mar-06
23-Mar-06
6-Apr-06
20-Apr-06
4-May-06

# APPENDIX B

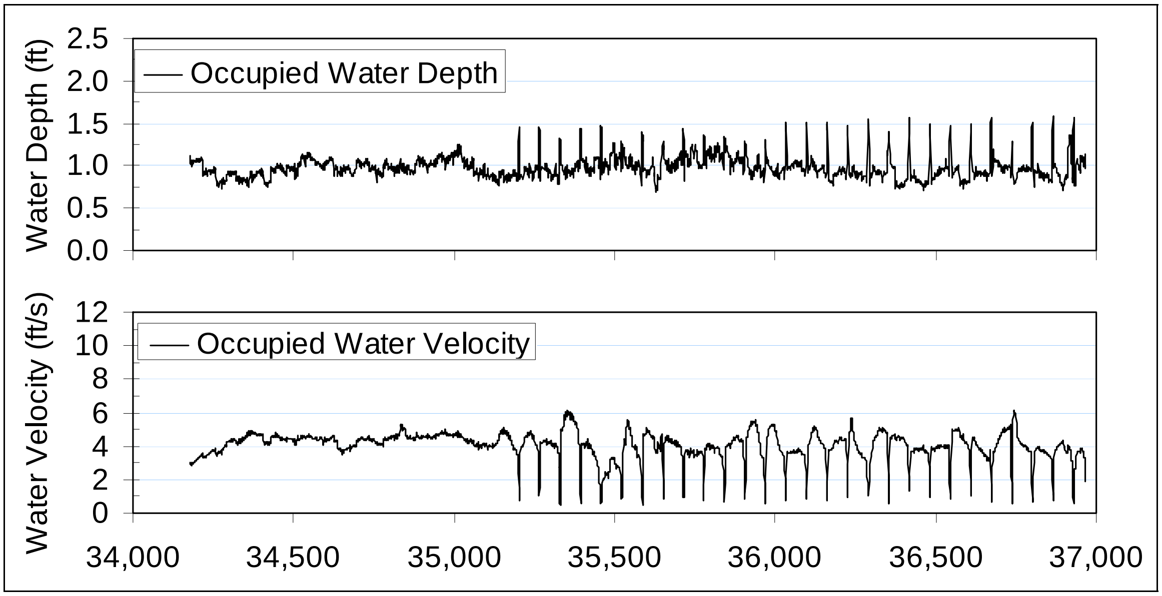
## Water Depths and Velocities along the Fish Swimming Routes



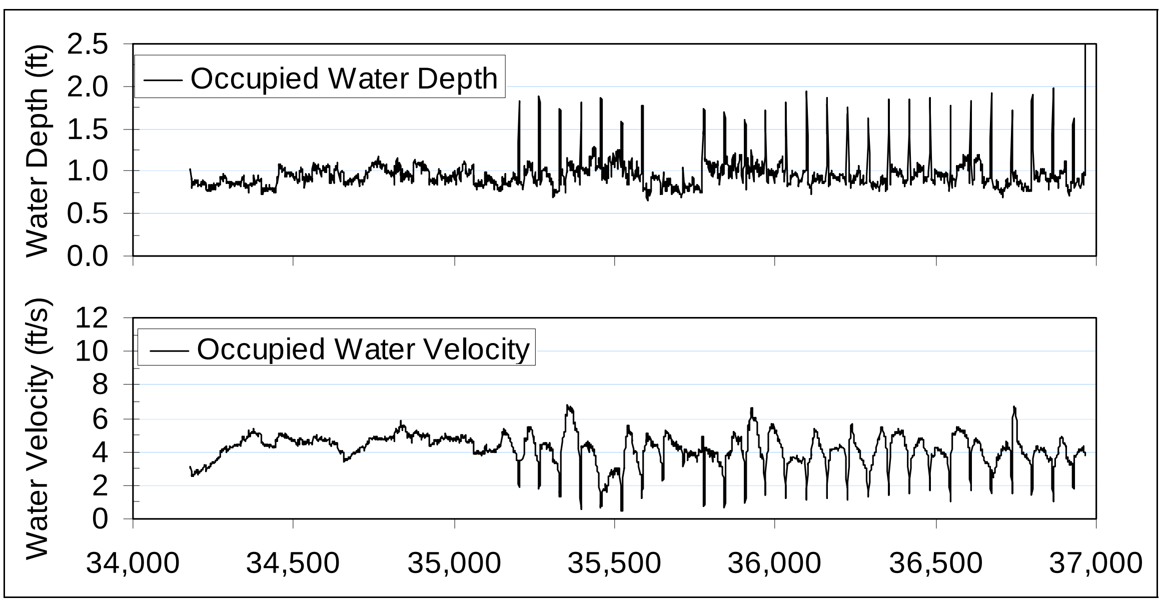
**Fish occupied water depths and velocities at 14 cfs.**



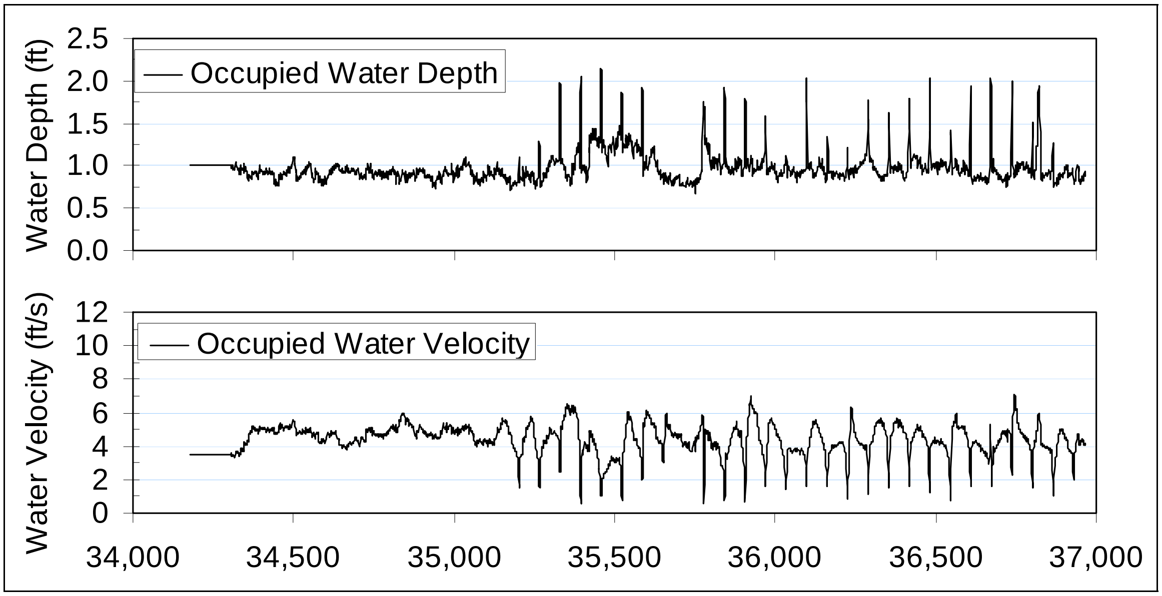
**Fish occupied water depths and velocities at 23 cfs.**



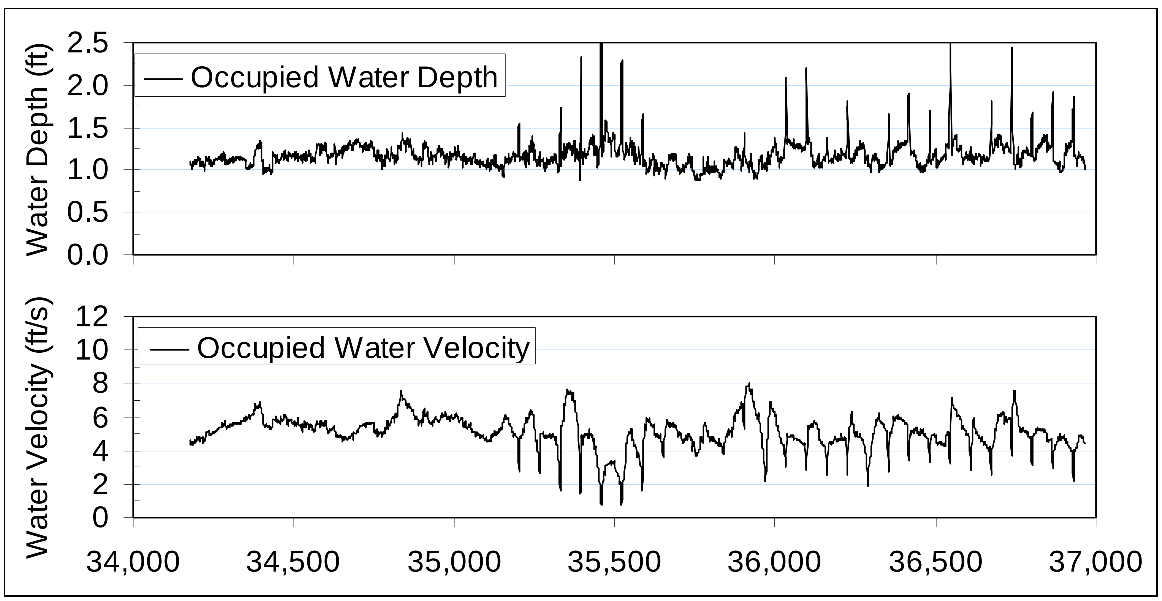

**Fish occupied water depths and velocities at 40 cfs.**




**Fish occupied water depths and velocities at 77 cfs.**




**Fish occupied water depths and velocities at 113 cfs.**




**Fish occupied water depths and velocities at 177 cfs.**