A FRAMEWORK FOR DEVELOPING EFFECTIVE MANAGEMENT SOLUTIONS TO FLOODING IN THE ROSS VALLEY USING HYDRAULIC MODELING

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1 INTRODUCTION

This paper provides an overview of flood management issues facing residents of the Ross Valley and describes how and why a new hydraulic model can and should be developed to provide a technical basis for prioritizing and implementing projects needed to reduce the frequency of flooding as much and as soon as possible.

The flooding that occurred on New Year's Eve 2005 has renewed interest in flood management in the Ross Valley.1 This paper describes a framework for developing effective management solutions for flooding in the Ross Valley. The cornerstone of this framework is the use of hydraulic modeling – a computational tool for streamflow analysis – to provide the information required to develop and design management solutions to flooding. This paper also provides a timeline showing how development and use of the model would interact with and support the public decision-making process to select projects singly or in combination.

The goal of reducing the frequency and extent of flooding in the Ross Valley could be achieved by increasing the conveyance capacities of the creeks that drain the watershed at key locations, by reducing the magnitude of peak flood discharges through attenuation, or by a combination of both. A new hydraulic model could be built that specifically focuses on supporting a strategy to implement several realistic and feasible projects, in a technically justified sequence. Intermediate-term[2] projects could include replacement of bridges and culverts that constrict the channel's flood capacity; removal or modification of bank stabilizations or other structures that further constrict channel capacity; and widening the creek where possible to increase channel capacity. Long-term projects could include construction of storage facilities or installation of a number of small-scale features to attenuate peak flood discharges **(Figure 1)**.

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1 For readers who would like more background information, Attachment A to this paper presents details on the hydrologic characteristics of the December 31, 2005 flood event, and Attachment B describes the watershed and provides background on the Army Corps Flood Control Project in the lower Ross Valley.

2 Recent discussions among community groups suggest that short-term projects are those that can be accomplished before the next flood season, approximately December 2006. This paper discusses actions that will take longer to implement.

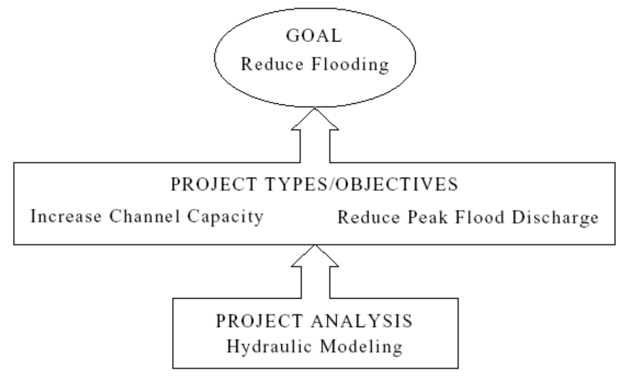

Figure 1 Use of Hydraulic Modeling in Flood Management

Figure 1. Use of hydraulic modeling in developing projects to alleviate flooding

The case study presented in Chapter 3 highlights how the effectiveness of an individual project can depend entirely on the design and implementation of another. Indeed, it is likely that decision makers can determine how best to minimize flooding in the valley only by conducting a fully integrated strategic analysis using hydraulic modeling of the entire stream network. This paper describes this approach in the portion of the watershed above the concrete flood control channel; however, it does not address the cultural and biological resources that must be evaluated before actions are taken to minimize flooding.

2 FACTORS CONTRIBUTING TO FLOODING IN THE ROSS VALLEY

It is important to note at the outset that Ross Valley is naturally prone to flooding by its location and geologic and fluvial geomorphic setting; rainfall can be extremely intense, soils are shallow with limited absorbing capacity, slopes are steep, and the stream channels are incised and narrow offering little in-channel storage. Development in the Ross Valley has created expansive impermeable areas while encroaching onto the banks of the channel, supplanting the natural flood-attenuating capacity of the floodplain. The effects of narrow bridge and culvert openings and poorly designed residential streambank stabilization structures have been superimposed on this naturally flood-prone system, exacerbating the flooding problem. Although the frequency and extent of flooding can be significantly reduced by replacing constricting structures, widening the creek where possible, and building storage, the threat of flooding by very large floods will always remain.

Downtown Fairfax begins to flood when the capacity of the long culvert at the downstream end of Fairfax Creek is exceeded or debris blocks its entrance. Water leaving the creek upstream of the culvert runs through downtown Fairfax and returns to the main channel downstream of Pacheco Avenue, where the channel is deeply incised and is able to convey greater flows. Flood flows are contained in the naturally larger channel until reaching the next downstream constriction at Saunders Avenue in San Anselmo. Sir Francis Drake High School and residences along San Anselmo Creek in and around Saunders Avenue and along Sleepy Hollow Creek upstream from San Anselmo Creek begin to flood when San Anselmo Creek flows exceed approximately 4,500 cfs and Sleepy Hollow Creek flows exceeds approximately 1,500 cfs (FEMA's 1977 FIS and preliminary anecdotal reports of the December 31, 2005 flooding).

Neighborhoods upstream from downtown San Anselmo in and around Madrone Avenue and Nokomis Avenue flood when flows exceed approximately 3,300 cfs (Stetson Engineers Inc. 2004). Downtown San Anselmo begins to flood when discharges exceed the capacity of the culverts at Sycamore Avenue and Bridge Street, approximately 4,000 to 4,200 cfs (Bill Firth, Corps of Engineers, pers. comm., March 25, 2004). Flood overflows originating near downtown San Anselmo run down Sycamore Avenue and San Anselmo Avenue in San Anselmo, along Shady Lane in Ross, through Ross Commons and along Poplar Avenue in Ross and Kent Avenue in Kentfield before finally returning to the concrete channel downstream of College Avenue in Kentfield. Consequently, these flood overflows are not in the channel at the County streamflow gage site, located just upstream of the Lagunitas Road Bridge in Ross.

Historical channel bed sedimentation (Stetson Engineers Inc. 2000) and the construction of the existing Lagunitas Road Bridge at an elevation below floodplain grade cause flood overflow to the west at the Lagunitas Road Bridge when in-channel flood flows exceed approximately 4,000-4,300 cfs (e.g., the 1986 flood peak discharge of approximately 4,150 cfs just overtopped Lagunitas Road Bridge.).

The channel's conveyance capacity in some reaches is limited by a flood backwater effect caused by narrow downstream bridges and culverts. This limits the effectiveness of approaching management solutions on a reach-by-reach basis. For example, the case study described in Chapter 3 demonstrates how flood management actions targeted in the vicinity of Nokomis Avenue Bridge in San Anselmo, ranging from dredging and vegetation clearing to complete bridge removal, are made ineffective by the flood backwater effect of Madrone Avenue Bridge approximately 490 feet downstream. There are similar constrictions in downtown Fairfax, San Anselmo, Ross, and Kentfield. Examples include the 300+ ft-long culvert beneath Bolinas Road in Fairfax, Saunders Avenue Bridge in San Anselmo, Arroyo Bridge in San Anselmo, Sycamore Avenue Bridge in San Anselmo, Center Blvd Bridge in San Anslemo, Bridge Street Bridge in San Anselmo, Sir Francis Drake Boulevard Bridge in San Anselmo, Lagunitas Road Bridge in Ross, the pedestrian bridge in College of Marin campus, Kentfield, and the College Avenue Bridge in Kentfield.

The flow capacity of some of these bridges is generally known from cumulative field observations during floods, as summarized in the table below.

Table 1. Hydraulic Capacities of Selected Bridges in San Anselmo and Ross.

Flow (cfs)	Significance	Reference
3,200	Hydraulic model estimated capacity of Nokomis Avenue Bridge (as influenced by Madrone Ave Bridge). Adjacent residences begin to flood.	Stetson (2004)
3,200	Hydraulic model estimated capacity of Madrone Avenue Bridge. Upstream residences begin to flood.	Stetson (2004)
4,000-4,200	Field observed capacity of Bridge St Bridge. Downtown San Anselmo and Ross begin to flood.	Bill Firth, COE
4,000-4,300	Estimated capacity of existing Lagunitas Road Bridge. Downtown Ross begins to flood.	1986 flood

3 HYDRAULIC MODELING

A hydraulic model is the appropriate tool to efficiently identify obstructions to flow (e.g., bridges, culverts, and other structures) that increase the frequency of flooding. Another use is evaluating the effectiveness of attenuating floodwaters, thereby reducing the magnitude of the peak flood discharge, through storage or other measures. A hydraulic model can be used to assist in designing necessary modifications (e.g., bridge or culvert modification or replacement, detention basin installation), and to support development of a technically based strategy for sequential project implementation.

A preliminary *one-dimensional unsteady-flow hydraulic model* can be developed using historical streamflow gage information, documented historical floodwater surface elevations, and existing and newly developed topographical data. This model would be sufficient to:

- identify problem reaches and specific constriction points that contribute to flooding;
- design projects that work for individual problem reaches;
- analyze the effectiveness of diversion and storage or other means of reducing the peak flood discharge;
- identify where individual projects are influenced by one another, such that one project should not be implemented without the other being implemented first, thereby determining the proper sequencing of implementing projects;
- logically prioritize and schedule projects;
- demonstrate the highest level of flood protection that is ultimately achievable and acceptable to the public; and
- determine the trade-offs between flood protection benefits and impacts on public and private properties and environmental resources and thereby foster informed strategy development and decision-making.

The geographic extent of the model (the model *domain*) would cover the Corte Madera Creek main stem and its major tributaries within the limits of commercial and residential development, as illustrated in **Plate 1.**

3.1 Data Requirements for a Hydraulic Model

Constructing a one-dimensional unsteady-flow hydraulic model first requires input of relatively detailed channel geometry data (topographic data that describe the size, shape, and slope of the channel). Second, it requires upstream, downstream, and lateral boundary conditions (flow or stage hydrographs) and initial conditions (flow or stage). Finally, it requires comparison of raw model output to actual field-observed water surface elevations along the length of the channel during real floods of known discharges, and adjustment of model parameters to match observation—this process is referred to as model *calibration*. For Ross Valley, many of these data exist, but substantial effort will be required to prepare complete input geometry files and extrapolate flow data from the single gage site (Ross Gage) to other parts of the watershed.

3.1.1 Geometric Data

The foundation of a hydraulic model is geometric data describing the channel shape and slope derived from topographic maps or channel cross-sections at many locations. In general, channel and floodplain topography (cross-sections) is necessary at locations where significant changes in slope or cross-sectional area occur, such as at bridges and culverts, above and below tributaries, and at upstream and downstream model boundaries. Although there is a point of diminishing return, in general, the more cross sections the better the model. There is no rule of thumb for spacing between cross-sections, but in urban streams spacing of 100 feet is not unheard of, and this degree of resolution is probably appropriate for accurate modeling of the Corte Madera Creek and its major tributaries. The level of effort required to survey closely spaced cross-sections is similar to that required to develop a 1- to 2-ft resolution topographic map. Such a topographic map could also be used to support later efforts.

Suitable geometric data are available for the reaches listed below. New geometry data would need to be collected everywhere else in the model domain.

- Unit 2 (only the portion from Bon Air Road to the beginning of the concrete channel) bathymetry collected by the County;
- Unit 3 concrete channel and portion of Unit 4 (up to the Ross gage) from topography survey done by the County in Summer 2005;
- Nokomis Avenue Bridge to Madrone Avenue Bridge reach data and model water surface calibration data from Stetson surveys in Summer 2003 and Winter 2003-2004;
- Culvert and bridge opening dimensions and slopes, surveyed by Ross Taylor in Summer 2005 (Taylor 2006);
- Topography data collected by Stetson for various local streambank stabilization projects (multiple, 2003-2005);
- Stetson-supervised HEC-RAS hydraulic model of San Anselmo Creek from Pastori Avenue Bridge to Fairfax Creek (culvert) outlet (UC Berkeley 2001);
- Data from Stetson's 1999-2000 geomorphology study, including historical review of existing model information and microfiche back-up survey data from FEMA's Flood Insurance Study of 1977;
- 5-ft contour interval data from County's recent air photo and photogrammetry survey (Spring 2004); and,
- Philip Williams and Associates 1999 study of culvert capacity in downtown San Anselmo (PWA 2000).

3.1.2 Boundary and Initial Conditions

For a one-dimensional unsteady-flow hydraulic model, data must be provided at the upstream boundary of all reaches and at the downstream boundary of the lowest reach. A time-series of flow or stage is typically needed. Lateral boundary conditions may also be used to represent inflow from tributaries or other sources outside of the model domain. In addition, the model requires initial conditions for the water level within the river system at the start of the simulation.

The observed storm hydrograph at the Ross Gage during the December 31, 2005 flood event could be used to generate a unit hydrograph. This unit hydrograph could initially be used to synthesize the upstream boundary conditions of all reaches within the model domain for selected design flood events.3

The observed tidal stages during the December 31, 2005 flood event could initially be used for the downstream boundary condition, but this would need to be compared with the long-term high-tidal standard to ensure that it represents an appropriately conservative condition. If it is not appropriately conservative, then the long-term high-tidal standard could be used to synthesize a more conservative, normalized daily tidal time series for the downstream boundary condition.

Streamflow measurements from new gages would be needed at hydraulically appropriate sites to provide data for later model refinement. Preliminary site locations are illustrated in **Plate 1** and summarized below:

1) Sleepy Hollow Creek upstream from the San Anselmo Creek backwater effect (in the vicinity of Caleta Avenue Bridge);
2) San Anselmo Creek, upstream from the culverted outlet of Fairfax Creek (in the vicinity of Creek Road Bridge);
3) Fairfax Creek, upstream from the culvert backwater effect (in the vicinity of Scenic Road Bridge); and,
4) Phoenix Lake water level records.

3.1.3 Need for Updated Flood Frequency Analysis at Ross Gage

Flood frequency analysis (FFA) is a method for estimating the probability of the occurrence of particular flows. The end product of an FFA is typically a

[3] Based on the rainfall and river stage data collected during the December 31, 2005 flood event, the system's rainfall to runoff response showed little time lag. This may have resulted from saturated antecedent conditions and little available storage in the system to attenuate intense rainfall. Refer to Appendix A for more detailed characterization about the flood event.

graph, referred to as a flood frequency curve, depicting the probability of a peak flow of a given magnitude occurring in any given year. An accurate flood frequency curve is an important component of the hydraulic modeling effort because it establishes the design flow associated with the desired level of flood protection. An FFA, and the resulting flood frequency curve, is based on historical stage and discharge measurements taken at a stream gage — in this case, the Ross Gage — over a range of low-flow and flood events.

In 1999, the Corps updated the flood frequency analysis for Corte Madera Creek at the Ross Gage, as presented in **Figure 2**. For example, the maximum flow that can probably be accommodated in the channel at the Lagunitas Road Bridge, even with considerable modification, would be 5,400 cfs, which according to the Corps 1999 FFA corresponds to a 30- to 35-year level of protection. Unfortunately, there are problems with the historical measurements taken at the Ross Gage that call into question the accuracy and reliability of the Corps' 1999 FFA and flood frequency curve.[4] The County is taking steps toward preparing a new FFA,[5] and the recurrence intervals for

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[4] Stage (water-surface elevation in feet above mean sea level) and discharge (in cubic feet per second) data have been collected at the USGS flow gage at Ross (behind the Town Hall and Fire Station). The rating curve for the Ross gage is known to be outdated and has historically been rated "poor" by USGS due to bed level fluctuations and escapement of ungaged flow from the channel during large floods. Stetson (2000) reviewed the history of rating curve updates made by USGS during the time they operated the gage (1951 to 1993) and found that the minimum (thalweg) channel bed elevation at the gage cross-section increased steadily from about 8.5 ft (NGVD29) in 1951 to about 12.5 ft (NGVD29) in 1988 and 1991. As of summer 2005 survey by the County, the thalweg elevation at the gage was at about 10.5 ft (NGVD29). The USGS evidently modified the rating curve only once (by 5-ft vertical offset). Notably, most of the bed level increase was completed by 1964, and therefore should not be attributed to the completion of Unit 3 flood control channel or the fish ladder between Unit 3 and Unit 4. The Ross gage does not capture 100 percent of the flow exceeding approximately 4,500 cfs. The Corps did estimate the approximate amounts of out-of-channel flow during the 1982 flood to come up with their total estimate of peak discharge (7,200 cfs).

The USGS discontinued gage operation in 1993. The County resumed operation after that time, but to date, has not updated the rating curve or published discharge data. That is, the County holds stage data but has not converted those data to discharge values, probably knowing that the rating curve should be revised first, requiring new stage-discharge field measurements at the site during low flows and floods.

[5] As part of an on-going study sponsored by Friends of Corte Madera Creek Watershed with funding from the National Fish and Wildlife Foundation, Stetson and the Flood Control District have been working on new rating curve for the Ross Gage covering the low-flow range (under 300 cfs). It is primarily intended to support design of fish passage improvements in the Unit 3 concrete channel. The County DPW is planning to incorporate this low-flow rating curve, anticipated to be available in May

flows described herein should be considered preliminary until the new FFA is available.

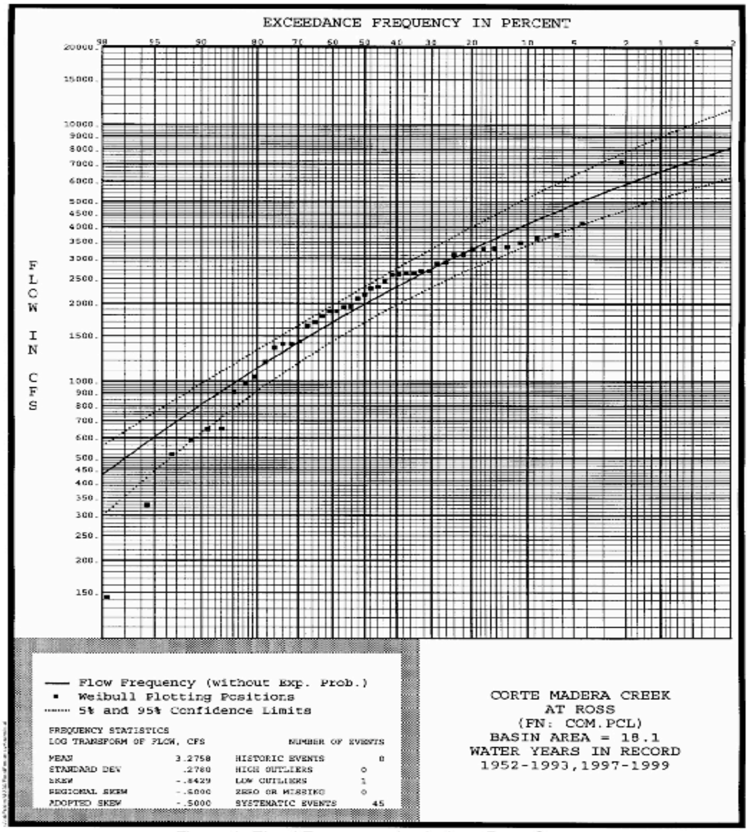

Figure 2 Flood Frequency Analysis at Ross Gage
(Source: Army Corps. of Engineers, 2000)

Figure 2. Flood Frequency Analysis at Ross Gage.

2006, into a complete rating curve that covers the flood range of flows as well. Under contract to County DPW, Jimmy Kulpa, Environmental Data Solutions/San Rafael, has collected at least 3 moderate flood stage-discharge measurements during 2005-2006 that will contribute data to the rating curve update. The complete updated rating curve may be available during Summer 2006.

3.2 Applying Hydraulic Modeling to Developing Flood Management Solutions: Case Study of San Anselmo Creek between Nokomis Avenue Bridge and Madrone Avenue Bridge

The approach taken by Stetson in its 2003 study of San Anselmo Creek is described in this section as an example of how hydraulic modeling could be applied to the greater Corte Madera Creek watershed.

A group of frequently flooded residential property owners and the Town of San Anselmo commissioned Stetson to analyze localized flooding in the vicinity of Nokomis Avenue Bridge in San Anselmo and evaluate ways to reduce the frequency of flooding along their reach **(Plate 1)**. The Nokomis Avenue Bridge deck is situated at the local floodplain grade; when San Anselmo Creek flows overtop the Nokomis Avenue Bridge deck, adjacent residential properties also begin to flood. In summer 2003, Stetson surveyed and prepared a topographic map of an approximately 700-ft-long reach extending from Nokomis Avenue Bridge to Madrone Avenue Bridge, approximately 490 ft downstream. Then Stetson used these topographic data and field-measured high water marks from the December 29, 2003 flood to build and calibrate a one-dimensional steady-flow hydraulic model using HEC-RAS.[6]

The affected property owners were familiar with the recent history of flooding and channel changes and hypothesized that removal of a reportedly progressively aggrading gravel bar immediately downstream from Nokomis Avenue Bridge would increase local channel capacity and thereby lower floodwater surface elevations and flooding frequency. Stetson calibrated the model to match the observed high water marks (profile) for the actual December 29, 2003 (existing conditions) profile. Once the model was calibrated, Stetson simulated removal of the gravel bar. The model simulation showed that removal would have no effect on the floodwater profile and flood frequency. Stetson further simulated removal of all gravel bars between

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[6] HEC-RAS stands for Hydraulic Engineering Center – River Analysis System, which is a publicly-available, generic computer hydraulic model developed and supported by the U.S. Army Corp of Engineers. Use of HEC-RAS is widely accepted as standard engineering practice for hydraulic analysis of streams such as Corte Madera Creek.

Nokomis Avenue and Madrone Avenue, again showing no effect on the flood profile. Stetson again simulated removal of all gravel bars, plus vegetation management, and removal (and replacement) of Nokomis Avenue Bridge. The model simulation showed that these combined actions still would have no effect on the flood profile downstream from Nokomis Avenue, and would only lower the flood profile upstream from Nokomis Avenue by about 0.5 ft. The net benefit of these combined flood management actions would be to reduce the frequency of flooding (estimated to be once every 8 years under existing conditions) by a negligible amount on only half of the affected properties. The property owners group was surprised to learn that the only actions that would lower the flood profile near Nokomis Avenue were combinations of channel widening and bridge replacement in the downstream reach, including replacement of Madrone Avenue Bridge.

Stetson conducted a second round of modeling to determine what combination and sequence of these downstream actions would be most effective in lowering the flood profile and reducing flooding frequency near Nokomis Avenue. First, Stetson performed model simulations in a trial-and-error, iterative manner to determine the effect of channel widening in the reach between Nokomis and Madrone Avenues (referred to as Alternative A). Model simulations showed that widening the channel by as much as 10 ft served only to slightly reduce the flood profile – about 0.5 ft in the reach between Sorich Creek tributary confluence and Nokomis Avenue, and about 1.0 ft upstream from Nokomis Avenue **(Figure 3)**. Implementing the 10-foot widening project alone would increase the capacity of the Nokomis Avenue Bridge from 3,200 cfs to 3,400 cfs, corresponding to a reduction in flood frequency from once every 8 years to once every 10 years. Modeling iterations confirmed that any widening beyond 10 feet would produce a negligible marginal benefit.

The relatively minor benefits of channel widening, and the diminishing marginal benefit of widening more than 10 feet, suggested that the Madrone Avenue bridge opening and/or the naturally limited channel capacity downstream from the bridge were the limiting factors for reducing flood frequency on the residential properties near Nokomis Avenue. Subsequent modeling confirmed this: Stetson modeled a project combining 10-ft channel widening both upstream and immediately downstream from Madrone

Avenue Bridge (Alternative A), and removal (and replacement with correspondingly 10-ft wider structure) of Madrone Avenue Bridge (Alternative B; combined referred to as Alternative A+B). The hydraulic model showed that this combined project would uniformly reduce the flood profile along the entire modeled reach, including Nokomis Avenue Bridge and adjacent affected properties by 2-3 ft **(Figure 3)**. Alternative A+B would reduce the flooding frequency from once every 8 years to about 33 years.

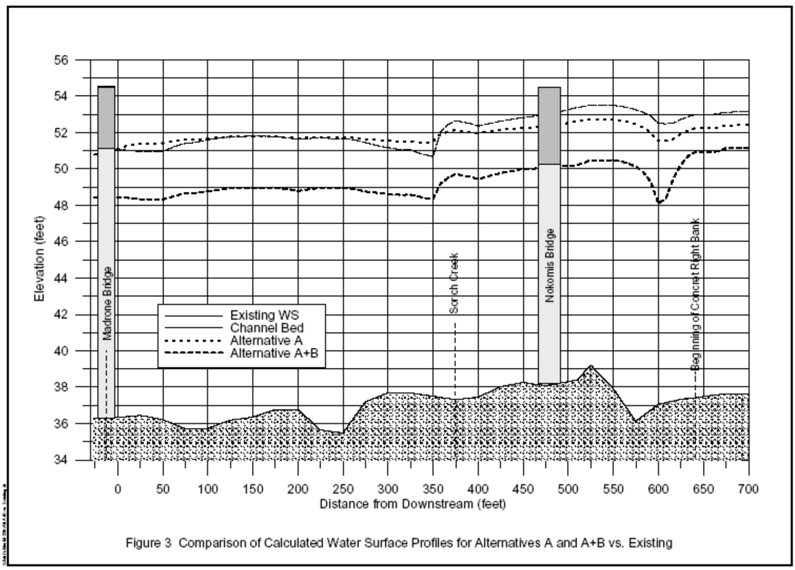

Figure 3 Comparison of Calculated Water Surface Profiles for Alternatives A and A+B vs. Existing

Figure 3. Comparison of Calculated Water Surface Profiles for Alternatives A and A+B vs. Existing

These iterative model simulations suggested again that the controlling factor for floodwater surface elevations near Nokomis Avenue Bridge was the limited capacity of the natural channel downstream from Madrone Avenue Bridge. Project scope and budget limitations prevented extending the model farther downstream from Madrone Avenue, a reach that has a number of constricting channel stabilization structures extending to Center Boulevard and Bridge Street Bridge constrictions. It is hypothesized that also widening the channel in this reach may reduce the flood frequency on the residential properties adjacent to Nokomis Avenue Bridge from 33 years (Alternative A+B) to some lesser frequency.[7] However, it is important to note that Alternative A+B increased the channel capacity from about 3,200 cfs to about 4,300 cfs. The estimated maximum capacity of the collective downtown San Anselmo constrictions is about the same—estimated to be 4,000 to 4,200 cfs (Bill Firth, Corps of Engineers, pers. comm., March 25, 2004). It follows then that the local benefits projected by modeling Alternative A+B are the maximum achievable benefits unless and until a project is implemented to increase the conveyance through downtown San Anselmo.

In summary, this case study demonstrates the applicability and usefulness of hydraulic modeling for evaluating the effectiveness of individual and combined project actions on lowering floodwater profiles and reducing the frequency of flooding. Stetson used the hydraulic model to define a project that would provide the maximum level of local protection. Still, the model's limited domain (not including downtown San Anselmo) prevented additional testing that may have revealed an additional marginal benefit that could be provided for the property owners adjacent to Nokomis Avenue Bridge.

3.3 Analysis of Storage and Attenuation for Flood Management

Later, the hydraulic model would need to be refined based on more extensive streamflow measurements in the watershed in order to yield results sufficiently reliable for analysis of specific projects. In particular, the refined model would be necessary for analyzing and evaluating in more depth the effectiveness of specific flood storage and attenuation as a possible means for alleviating flooding.

As an example, Friends of Corte Madera Creek Watershed has submitted a preliminary proposal for inclusion in the San Francisco Bay Coastal

[7] These flood frequencies are based on the existing Corps of Engineers flood frequency analysis on peak flow data collected at the Ross Gage through 1999. It is expected that ongoing and future stage-discharge relation revision, discharge data revision and augmentation, and flood frequency analysis updates, as discussed earlier in this paper, will show that 3,200 cfs occurs at the Nokomis Avenue site more frequently than once every 8 years and 4,300 cfs occurs more frequently than every 33 years.

Conservancy's Integrated Regional Watershed Management Plan toincrease infiltration and temporary storage of stormwater. We have proposed a 4-year project to develop an inventory of impervious surfaces, identify areas with suitable soil depth and characteristics to make increased infiltration a feasible alternative, and develop stategies and demonstration projects to replace impervious surfaces with pervious. This project would at the same time investigate the feasibility of diverting runoff into on-site temporary storage facilities (swales, sumps, cisterns, detention basins, temporarily flooded park lands) from which it could be released after the peak flow has occurred or stored for irrigation in dry summer months. The project would determine the physical and cost-benefit feasibilty of achieving flood management and water conservation objectives with a combination of infiltration and detention strategies. The demonstrated feasibility of reducing flood damage using these strategies would elevate the credibility of watershed-wide approaches, as a complement and alternative to traditional engineered flood control channel infrastructure improvements.

The goal is to provide an estimated 250 ac-ft of temporary stormwater storage throughout the watershed, which would significantly reduce the frequency of damaging floods. The 4-year project includes construction of five demonstration projects and is expected to provide 78 ac-ft of storage, which preliminary calculations show would reduce the peak discharge at downtown San Anselmo by as much as 750 cfs. Using current FFA information, this translates to a reduction in the frequency of damaging floods from about once every 9 years to about once every 16 years. Implementing the 4-year project would also lay the groundwork for future progress toward the total storage target by streamlining the permitting and standardizing the engineering for installing above-ground on-site runoff rainfall storage facilities and in-ground vegetated swales.

4 THE ROLE OF HYDRAULIC MODELING IN SUPPORTING THE PUBLIC DECISION PROCESS ON PROJECT SELECTION

There is considerable interest in flood management in the Ross Valley. Town councils of Fairfax, San Anselmo, and Ross are actively exploring flood management solutions. Marin County, the local lead agency for flood management, has established a technical team to guide development of a U.S. Army Corps of Engineers project to address flood management on a watershed-wide basis. After the decades-old experience with a narrowly defined project in the lower Ross Valley that has been ineffective in providing protection from flooding, there is agreement that a watershed-wide approach will be the most effective.

4.1 Project Selection

Selecting the preferred combination and sequencing of projects to alleviate flooding in the Ross Valley will require that decision makers and stakeholders be fully informed about the full range of available alternatives, as well as their effectiveness, impacts, costs, and trade-offs. Hydraulic modeling is an appropriate tool for developing this information for input directly into the decision-making process.

Initially, hydraulic modeling could be used to develop a range of general project alternatives by identifying problem reaches and specific constriction points and by analyzing the effectiveness of storage or other means of reducing the peak flood discharge. After decision makers and stakeholders review this range of alternatives, hydraulic modeling could be used to refine the costs and benefits associated with specific project alternatives to support selection of the preferred project.

Figure 4 is a diagram that shows how a hydraulic model could be developed by summer 2006. With input from decision makers about the types of projects acceptable to their communities, a range of project alternatives could be developed over the fall and winter 2006-07, during which time work on refining the model could proceed concurrently using the newly acquired streamflow gaging data (refer to section 3.1.2). The refined model would provide additional information to support development of specific projects and, ultimately, the decision making process of selecting the preferred project.

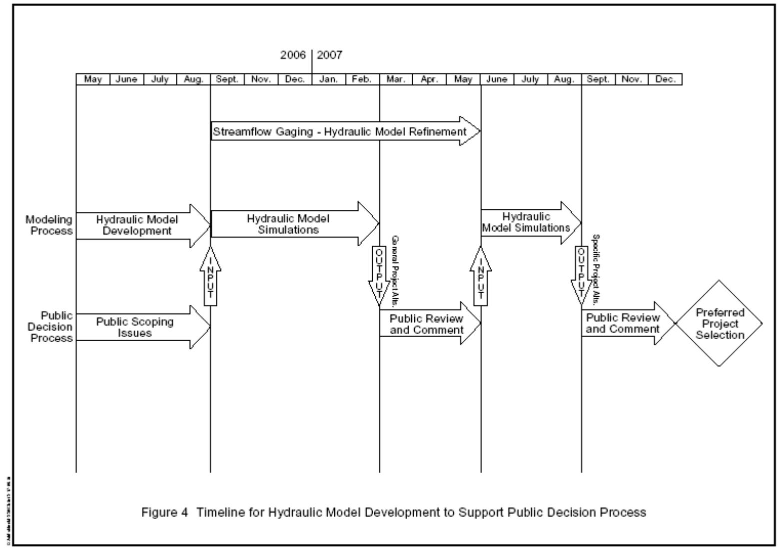

Figure 4 Timeline for Hydraulic Model Development to Support Public Decision Process

Figure 4. Timeline for Hydraulic Model Development to Support Public Decision Process

4.2 Environmental Review and Project Approvals

Although a hydraulic model could be constructed without environmental review or regulatory approvals, the goal of this effort is to identify and construct a suite of on-the-ground projects that will function together to reduce flooding in the Ross Valley. These projects cannot be built without the appropriate environmental review and approvals, so to facilitate quick action to address flooding, we suggest that programmatic environmental review and permitting be provided concurrently with the modeling and selection process.

Table 2 identifies the permits that we expect would be required, under the assumption that Marin County will be the California Environmental Quality Act (CEQA) lead agency and the US Army Corps of Engineers (USACE) will be the National Environmental Policy Act (NEPA) lead agency. A joint Environmental Impact Statement/Environmental Impact Report (EIS/EIR) would almost certainly be the best way to satisfy both NEPA and CEQA requirements.

Table 2: Approvals and Permits

Agency	**Approval**	**Submittal**
US Army Corps of Engineers (USACE)	404 Nationwide Permit (for single projects) or an Individual Permit for groups of projects	Application(s)
National Marine Fisheries Service (NOAA Fisheries)	Biological Opinion(s) through a Section 7 Consultation with USACE or FEMA	Biological Assessment (s)
NEPA Lead Agency (USACE)	Record of Decision	Environmental Impact Statement
Federal Emergency Management Agency (FEMA)	"No-rise" finding	Hydraulic Analysis for each crossing
San Francisco Bay Regional Water Quality Control Board (RWQCB)	Section 401 Water Quality Certification(s)	Application(s)
California Department of Fish and Game (DFG)	Streambed Alteration Agreement	CEQA document
State Historic Preservation Officer (SHPO)	SHPO review and concurrence of inventory/evaluation report	CEQA/NEPA document
CEQA Lead Agency (Marin County)	Certification	Environmental Impact Report
Marin County, Town of Fairfax, Town of Ross, or Town of San Anselmo	Building Permit	CEQA document

APPENDIX A:
SUMMARY HYDROLOGIC CHARACTERIZATION OF THE DECEMBER 31, 2005 FLOOD EVENT, ROSS VALLEY

Following is a summary hydrologic characterization of the December 31, 2005 flood event, illustrated in **Figures A-1 and A-2.**

Antecedent Conditions

Prior to December 30, more than seven inches of rain had fallen on the Ross Valley over the preceding two-week period (December 17 through 30). By December 30, Phoenix Lake was flowing over its spillway, soils were generally saturated or nearly saturated, and the stage of Corte Madera Creek at the Ross Gage was a little above about 13 ft NGVD29.

Flood Event Measurements

The storm began dumping rain on December 30 at about 6:00 am. Thereafter rainfall continued steadily over the ensuing 25-hour period, stopping December 31 at about 7:00 am. The highest intensity rainfall occurred on December 31 over a three-hour period from about 3:00 am to 6:00 am. The stage of Corte Madera Creek at the Ross Gage reached 24 ft NGVD29 (flood threshold) at about 2:00 am. These measurements summarize the event:

- From December 30 at 0600 to December 31 0600, approximately 4.4 inches of rain fell. This equated to about a 6-year, 24-hour rainfall event[8].
- On December 31 from 0300 to 0600, approximately 1.65 inches of rain fell. This equated to about a 10-year, 3-hour rainfall event[7].
- The peak flow of Corte Madera Creek passing the Ross Gage, including in-channel and out-of-channel water, is not precisely known; however, it is estimated at a 50-year flood event. (Corps 1999 FFA).
- The peak discharge from Phoenix Lake during the December 31, 2005 flood event is not precisely known; however, it is roughly estimated to have been in the neighborhood of 225 to 775 cfs[9].

[8] Using methods set forth in the Hydrology Manual, Marin County Department of Public Works, August 2, 2000.

Preliminary Observations and Inferences From the Measurements

A few observations and inferences can be made from the flood-event measurements that would aid in applying hydraulic modeling to developing flood management solutions to the Ross Valley. These are as follows:

- Aside from inherent differences in the statistical bases used to develop these, the reason that the 6-year/24-hour and 10-year/3-hour events resulted in a roughly estimated 50-year flood event could be explained by the wet antecedent conditions (saturated soils, little available storage in the system to attenuate intense rainfall). This demonstrates why it is prudent in flood studies to assume a saturated watershed as the antecedent condition.
- The observed peak stage at the Ross Gage flow coincided with the rising tide approaching the HHW. This demonstrates why it is prudent in flood studies to assume high tide as the downstream boundary condition.
- Corte Madera Creek "broke the banks at both Ross and San Anselmo at approximately 3:30 am, indicating that the entire watershed was "overwhelmed" at the same time." (MCDPW, Rough Time Line at Ross Gaging Station, Winter Storm 12/31/05).
- The rate and volume of out-of-channel flood water passing the Ross Gage between about 2:00 am and 10:00 am are not precisely known **(Figure A-2)**. Opportunities for implementing a few or several attenuation projects throughout the upper watershed that would enable diversion and storage of these amounts may be a promising partial solution to flooding and worthy of investigation in combination with solutions that address increasing channel conveyance capacity.

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[9] This estimate is based on the rating table for the Phoenix Lake spillway obtained from Marin Municipal Water District. The higher value derives from the April 5, 2006 survey by Stetson/Smeltzer of the height of the inferred high water mark along Phoenix Dam relative to the spillway crest, 6.65 ft.

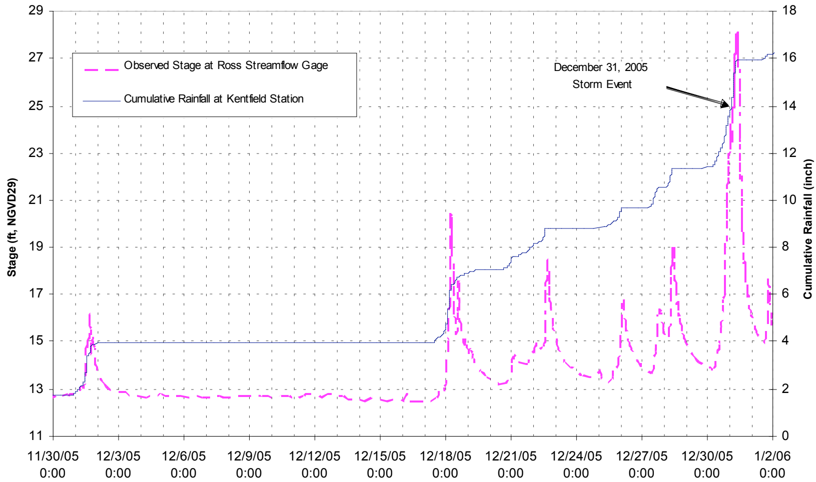

Figure A-1 Hydrograph of Ross Valley Streamflow Gage Stage and Kentfield Station Cumulative Rainfall, December 2005
(Source: Marin County FCWCD Real-Time Weather Website (marin.onerain.com/portal.php)

Figure A-1. Hydrograph of Ross Gage Stage and Kentfield Station Cumulative Rainfall, December 2005

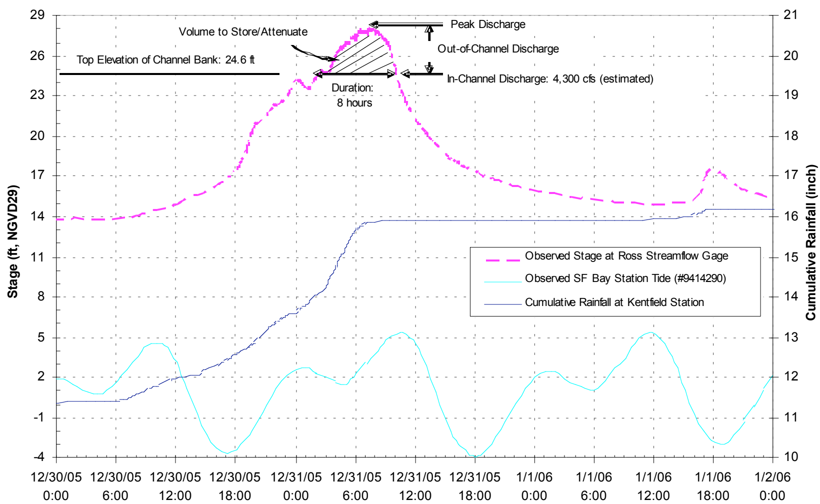

Figure A-2 (Alternative) Hydrograph of Ross Valley Streamflow Gage Stage, SF Bay Station Tide, and Kentfield Station Cumulative Rainfall, December 31, 2005 Flood
(Source: Marin County FCWCD Real-Time Weather Website (marin.onerain.com/portal.php)

Figure A-2. Hydrograph of Ross Gage Stage, San Francisco Bay Station Tide, and Kentfield Station Cumulative Rainfall, December 31, 2005 Flood

APPENDIX B:
BACKGROUND ON FLOODING IN THE ROSS VALLEY WATERSHED

Watershed Description

Corte Madera Creek watershed reaches from San Francisco Bay into the foothills of Mount Tamalpais, in the Coast Range. It is bounded on the west by a steep, forested ridge running northwest from the East Peak of Mt. Tamalpais (elevation 2,571 ft) to Pine Mountain and then north-northeast to White Hill (elevation 1,430 ft) and Loma Alta (elevation 1,592 ft). The hills separating San Rafael from the Ross Valley form the northeastern boundaries of the watershed.

San Anselmo and Fairfax creeks rise along the southern and western ridges and drain steep upland areas onto relatively steep and narrow valley flats; these creeks combine as San Anselmo Creek in the town of Fairfax. San Anselmo Creek then flows southeast through Ross Valley, bounded by a sandstone ridge running southeast. Several intermittent tributaries rise on the grassland and grass-oak woodland-covered hills along the northern and eastern edges of the basin. Sleepy Hollow Creek joins San Anselmo Creek in San Anselmo downstream from Saunders Avenue. Ross Creek is a major tributary descending from the northern flank of Mount Tamalpais to join San Anselmo Creek in Ross. The channel is called Corte Madera Creek from the Ross Creek confluence to San Francisco Bay Estuary, and for a mile of its length it is encased in a concrete-lined channel. It drains into a tidal salt marsh at Kentfield, and then into San Francisco Bay near San Quentin. Larkspur Creek and Tamalpais Creek are the only major tributaries to Corte Madera Creek that enter downstream from the concrete channel. Corte Madera Creek has approximately 29 named tributaries, with an aggregate length of approximately 44 miles. In addition to these streams, Phoenix Lake, which covers 28 acres, is located above Ross, and is an impoundment of Ross Creek.

Flood Control History

The information in this section was summarized and edited by Friends of Corte Madera Creek Watershed, using information in three informational papers prepared by the Marin County Water Conservation and Flood Control District (2000, 1995a, and 1995b), with some updating.

In 1953, the California Legislature created the Marin County Flood Control and Water Conservation District, consisting of all the territory lying within Marin County. In the 1960s, in response to frequent flooding, local communities decided that a flood-control project was in order for Corte Madera Creek. Flood Control Zone Nine, a County agency, was created in 1966 for the sole purpose of being the local sponsor of the project to qualify for Federal funding. Zone Nine's responsibility since its inception has been limited to the main channel Corte Madera Creek Flood Control Project. There are certainly many other issues and concerns related to flooding in the Ross Valley; however, they were not within the mandate of Zone Nine and the project authorized in the 1960s.

As originally conceived the Corte Madera Creek Flood Control Project consisted of a concrete channel 6.5 miles long, reaching from the Bay into Fairfax. It was designed to carry the Standard Project Flood with peak discharge ranging from 9,000 cfs (cubic feet per second) at Bon Air Road to 7,800 cfs at College Avenue Bridge, or the flow associated with what was then considered a 250-year event (a 250-year event is a flow that has a 0.4 percent chance of occurring in any one year). The project as originally conceived was divided into six units: Unit 1, a trapezoidal earth channel, extends from the Bay to Bon Air Road; Unit 2 continues the trapezoidal earth channel from Bon Air Road into the lower portion of the concrete channel to College Avenue in Kentfield; Unit 3 begins at College Avenue and terminates about 600 feet downstream of Lagunitas Road in Ross; and Unit 4 extends from Lagunitas Road in Ross to the Sir Francis Drake Boulevard Bridge near the Ross/San Anselmo border. Units 1 through 4 are shown on Figure 1. Unit 5 and Unit 6 were in San Anselmo and Fairfax.

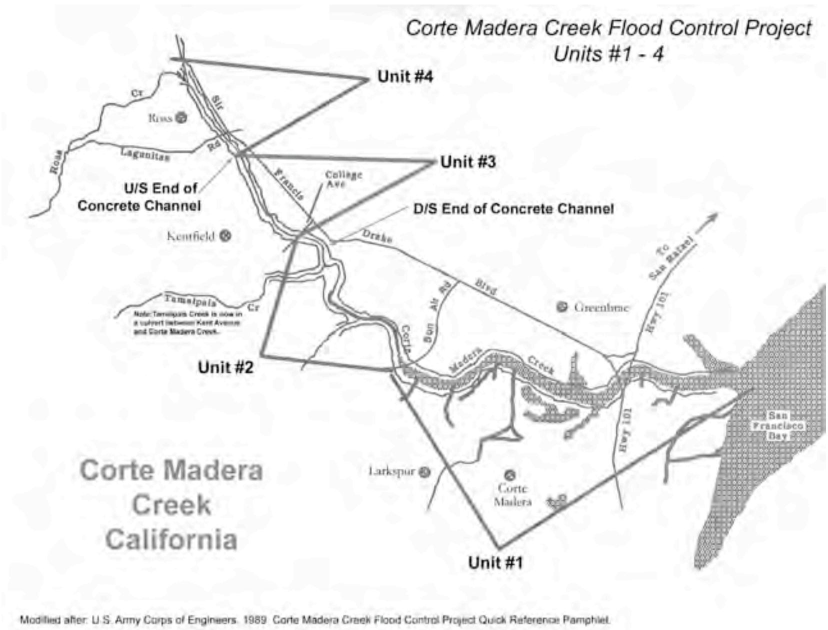

Figure B-1: Corte Madera Creek Flood Control Project Map Units 1-4

After the flood of January 1982 and a subsequent order from the Marin County Superior Court to complete the project, the Marin County Board of Supervisors requested the Corps to re-initiate the project, and Congress reauthorized it at a reduced 100-year level of protection. However, the 1982 flood demonstrated that the existing concrete channel could convey only about 3500 cfs, or less than half the original (7600 cfs) design flow. A comparison of backwater calculations and high water marks collected for the January 1982 flood has shown that the average Manning's roughness coefficient was around 0.030 to 0.035 in the concrete portion of the channel – about twice as high as the design roughness coefficient of 0.014. A roughness of 0.014 is typical for clear-water flow over smooth concrete surfaces, whereas roughness values of 0.030 to 0.035 are typical for natural channels carrying sand, gravel, and cobble-sized bedload, as Corte Madera Creek does. In general, the relatively high channel roughness could be attributed to a number of factors, including: increased skin friction and form drag caused by gravel deposits on the bed of the concrete channel, increased wall roughness due to abrasion by gravel transport in the water column, increased wall roughness caused by tubeworm and barnacle deposits on the walls, and channel sinuosity. In reviewing HEC-2 model simulation of the 1982 flood and the Corps 1989 sedimentation study, PWA (1989) found that sediment deposition within the concrete channel did not reduce the concrete channel capacity because the sediment would have flushed through the channel before the flood peak. PWA (1989) also found that sedimentation downstream of the concrete channel could have affected floodwater surface elevations in the lower portion of the concrete channel, but not in the steeper upper portion of Unit 3. PWA (1989) found instead that the major cause of failure was the increase in roughness due to sediment carried by the flow during the flood, raising the roughness from the design value of 0.014 to about 0.030 to 0.035. Under actual hydraulic roughness conditions, flood flows go through a hydraulic jump from supercritical to subcritical flow depth about 1,500 ft downstream from the Unit 3 inlet drop structure/fish ladder, not 5,000 ft downstream as originally designed. The hydraulic jump raises the water surface about 6 vertical feet. The location of the hydraulic jump is influenced not only by the hydraulic roughness, but also by the location where the channel slope changes from 0.0038 to 0.0007, about 4,000 ft downstream from the Unit 3 inlet.

Completing the project required the Corps to devise an environmentally sensitive redesign of Unit 4 and add height to the already constructed Unit 3 concrete channel walls so that Unit 3 could carry the increased flow delivered by Unit 4. Another period of study and analysis occurred and more than a score of alternatives were considered over the next several years. It became clear that to convey a 100-year flow (then estimated as about 6,900 cfs) would require a project that the community could not support because of its environmental impacts.

On February 1, 1996, the Zone Nine Advisory Board passed a resolution recommending to the Board of Supervisors that they request the Corps to proceed with a project that, by adhering to certain specific design considerations, would be supported by the community. These design considerations include the minimization of the use of concrete, retaining the multi-use pathway along the completed units, using native plants, enhancing riparian and salmonid habitat, and maximizing the channel capacity while retaining the historic Lagunitas Road Bridge. The estimated maximum conveyance of a project that stayed within these constraints is 5,400 cfs (about a 33-year flood flow). On March 5, 1996, the Board of Supervisors adopted Resolution 96-26 requesting the Corps to proceed.

To provide for effective and timely communications between the Corps and the communities, Zone Nine Advisory Board created a Design Advisory Committee (DAC) to periodically review the progress of the design, to serve as a sounding board for Corps staff regarding design decisions, and to provide independent input on the designs. The DAC reported directly to the Advisory Board and was guided by Resolution 96-26. The DAC had nine members: two each from Ross, Kentfield, the Zone Nine Advisory Board, and Friends of Corte Madera Creek Watershed, and one member from the City of Larkspur.

The DAC held a number of meetings between 1998 and 2000 and co-sponsored several public workshops with both Kentfield and Ross in their respective communities. Three alternatives came out of this process: No Project Alternative (~3,200 cfs capacity), one alternative that would provide the full 5,400 cfs capacity, and a Minimal Project (~4,100 cfs capacity). The Corps also proposed the idea of a short bypass culvert around the Lagunitas Road Bridge in Ross that could be combined effectively with any of the alternatives except the No Project alternative. After the Town of Ross reviewed that bypass design, it was rejected.

The level of detail provided by the Corps for the designs was limited and the communities were unable to agree on a Locally Preferred Plan. In early 2005, Friends of Corte Madera Creek Watershed received funding from the National Fish and Wildlife Foundation to pursue conceptual designs for bank stabilization and fish passage in the lower portion of Unit Four for the three alternatives consistent with Resolution 96-26. Because many of the unanswered questions about the alternatives that stymied the selection of a preferred alternative concerned bank stabilization, it is expected that the level of detail provided by the conceptual designs will be adequate for the local communities to agree on an alternative and to move forward.

APPENDIX C:
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