International Conference on Estuaries and Coasts
November 9-11, 2003, Hangzhou, China

EXPERIENCE OF CREEK AND LAGOON RESTORATION FEASIBILITY STUDY

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Abstract: Topanga Creek watershed is a beautiful and relatively small area within Southern California that is only partially developed. It is one of the few natural coastal watersheds remaining in proximity to urban Los Angeles. This small watershed possesses extensive resources including a historically large population of the endangered Steelhead Trout and other sensitive species. However, problems exist within the watershed that include loss of habitat for endangered and sensitive species, flooding, bank erosion, and poor water quality in the downstream lagoon.
To solve the existing problems, a restoration feasibility study was conducted. The goal was to generate optimum solutions that lead to a self-sustaining creek and lagoon system into perpetuity. The study involved identifying the existing conditions, testing alternative solutions, recommending the preferred alternative, and refining the alternative for future planning actions of environmental review, permitting and funding applications. This paper summarizes the feasibility study and application of the MIKE11 one-dimensional numerical modeling suite.

Key words: Topanga Creek, Topanga Lagoon, Hydraulic, Hydrology, Sediment transport, restoration, Watershed, Habitat, And MIKE11

1. INTRODUCTION

Topanga Creek watershed is a small 47 square kilometer area within the eastern Santa Monica Mountains in Southern California of the United States as shown in Fig. 1. The area is steep and rugged, reaching elevations of 670 m above sea level. The steep and narrow creek is characterized typically by low flows passing through small falls and pools that present a challenge to restoration and numerical modeling. Episodic catastrophic flood flows also occur, as well as wildfires to add to the complexity of the modeling system. The Resource Conservation District of the Santa Monica Mountains (the RCD) seeks to remedy these problems; enhance sensitive habitat; and improve flood protection, sediment transport to the beach and water quality in the lagoon. A restoration feasibility study was funded by California State Coastal Conservancy to address these problems and implemented by the RCD. The objectives of the study were to generate optimum solutions that lead to a self-sustaining system.

The MIKE11 modeling suite developed by DHI Water and Environment was applied in assessing the existing problems and formulating the optimal restoration alternative. The model was selected since it can perform comprehensive modeling of the entire watershed, creek and river mouth system. Also, it includes programs to model hydrology, hydraulics, sediment transport and water quality in an integrated fashion. Finally, it provides an integrated interface to GIS.

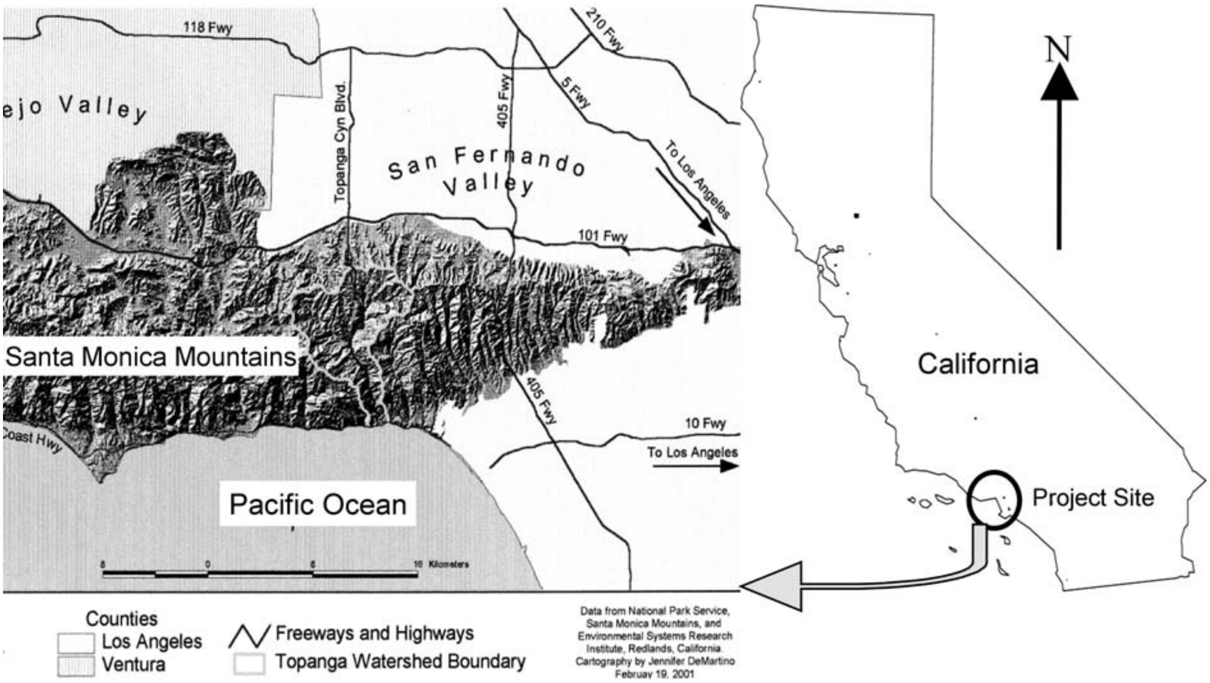

Fig. 1 Vicinity map

2. PROBLEMS AND RESTORATION ALTERNATIVES

The RCD indicated that problems associated with the downstream lagoon are large areas of fill in the former lagoon reducing its area to 15% of its historic footprint, and a very narrow cross-section under the downstream Pacific Coast Highway (PCH) bridge constraining flood flows. Therefore, the following four improvement alternatives are proposed at the lagoon and PCH Bridge:

- Alternative 1 - maintain existing 0.4 hectare wetland and short 30m long bridge at the lagoon with no expansion;
- Alternative 2 – expand the lagoon to 2 hectares and install culverts under the highway adjacent to the existing bridge to bypass the excessive flow during flooding;
- Alternative 3 – expand the lagoon to 4 hectares and lengthen the bridge to 91 m long to expand the cross-section during flooding; and
- Alternative 4 – expand the lagoon to 8 hectares and lengthen the bridge to 152 m long to expand the cross-section during flooding.

Solving problems at Topanga Creek involves implementing measures from the ocean to areas up to 8,850 m upstream of the lagoon. Problem locations upstream of the lagoon are shown in Fig. 2. Their improvement measures are not presented as alternatives, but are included for each lagoon option proposed above. Upstream problems and their remediation measures are listed in Table 1.

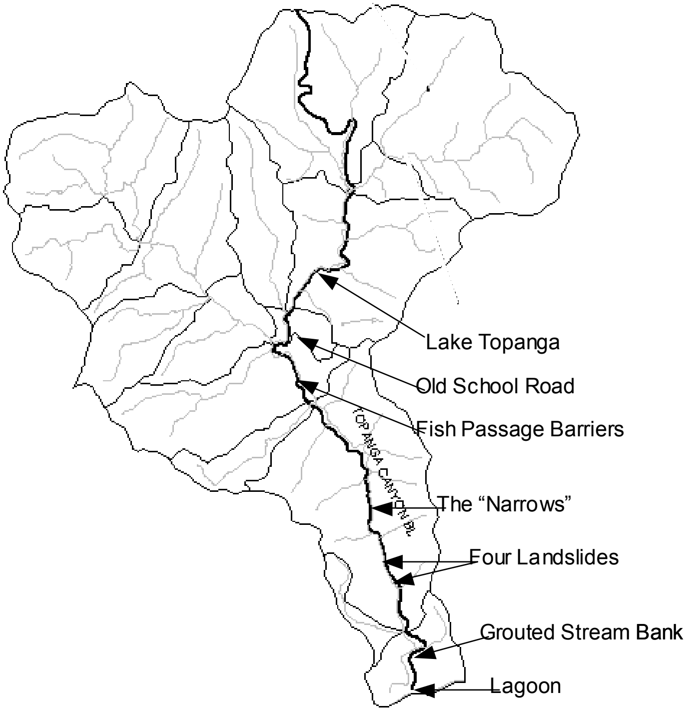

Fig. 2 Topanga watershed and its restoration sites

Table 1 Upstream problems and improvement measures

Location	Problems	Improvement Measures
Four Landslides	Encroachment into the channel by fill and bank protection devices associated with private property and a state highway. Constraining creek flows, causing increased bank undermining, and resulting in placement of more fill as maintenance, in some instances inducing landslides.	“Pull back” or remove fill and bank protection devices from the channel cross-section. Reconstruct them farther from the active creek bed or replace them with native plantings.
The Narrows	Direct channel infilling of two-thirds of the creek for construction of the highway. Resulting in a chronic condition of bank undermining requiring placement of more fill for bank maintenance perpetuating the problem.	Remove the fill in the narrowest reach and replace it with a highway segment that is on piles to expand the cross-section and convey the flood.
Fish Passage Barriers	Natural formation of a boulder dam by a flood in 1980 (the 83-year flood) blocking the upstream migration route of steelhead trout.	Dislodge the natural boulder dam to restore the migration route for Steelhead Trout.
Old School Road	Undermining of the state highway along the outer bank of a meander resulting in placement of a grouted rip-rap bank section and a vertical wall section that are in a poor state of repair.	Remove the grouted rip-rap and vertical wall section and install a new vertical wall founded in bedrock with a planted façade to expand the cross-section.
Lake Topanga	Damming of the creek by a large landslide that occurred in an earthquake in 1995 causing flooding of the highway during storms.	Remove the landslide and expand the cross-section to eliminate flooding.

3. MODEL DEVELOPMENT

The MIKE11 hydrodynamic and hydrological models are coupled and modeled simultaneously. The runoff generated by the MIKE11-RR model in each individual sub-watershed is merged into the creek network either at the outlet of the sub-watershed or in the reach where the creek intersects the sub-watershed. After the flow merges into the creek, the flow is routed downstream through the stream network by the hydrodynamic model MIKE11-HD. The purpose of the coupled model runs is to generate the stream flows for evaluating the efficacy of improvement measures upstream of the stream gage shown in Fig. 3, which is located about 3.5 km upstream from the lagoon.

The modeling area includes the entire Topanga Creek watershed, major creeks and the lagoon. The entire watershed is delineated into 22 sub-watersheds as shown in Fig. 3. Fig. 3 also shows the major creek networks. The topography of creek networks, which is approximately 18 km river miles, was characterized by 124 cross-sections.

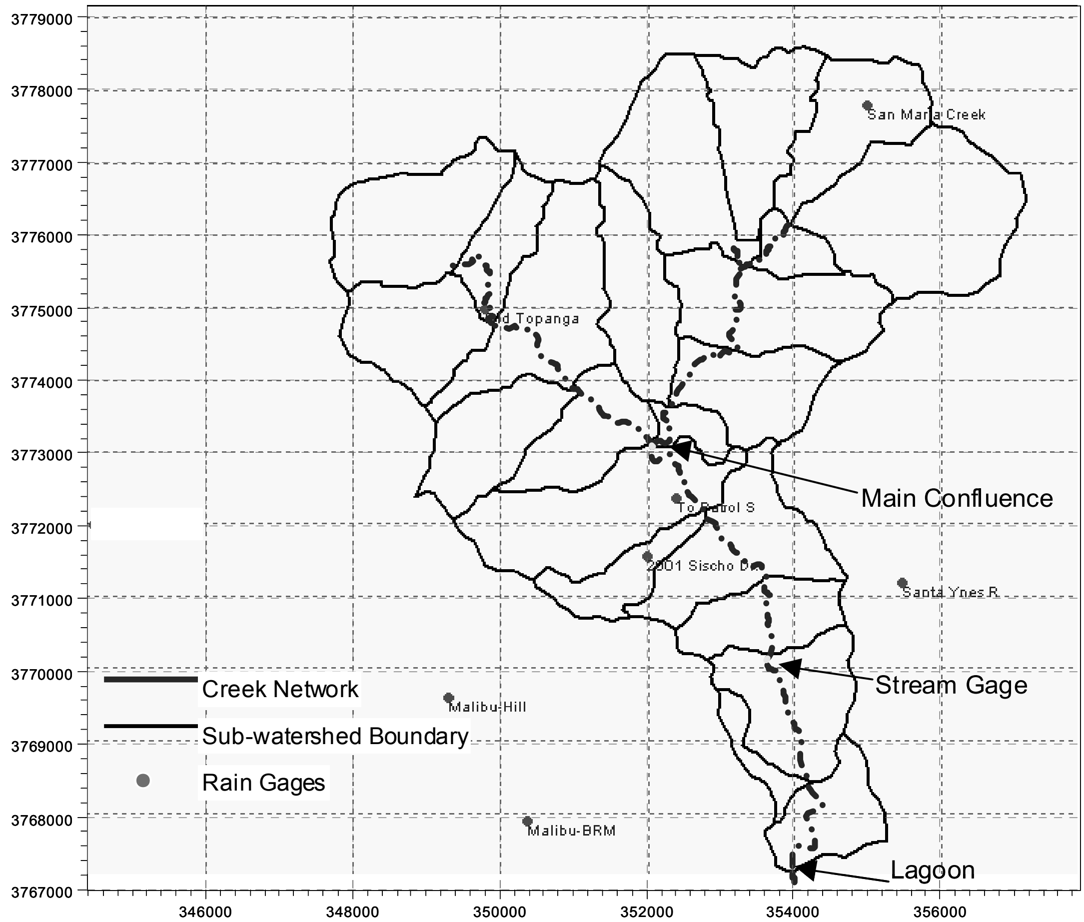

Fig. 3 Hydrology and hydraulic model setup

4. MODELING BOUNDARY CONDITIONS

HYDROLOGY AND HYDRAULICS

The main model input data are precipitation, potential evapotranspiration rates of the watershed, and water levels in the downstream lagoon. There are three functional rain gages in the watershed and three functional rain gages in its vicinity as shown in Figure 3. The Santa Maria Creek gage was removed in 1988. The Thiessen method was used in calculating the mean precipitation for each sub-watershed. Therefore, the mean precipitation mainly depends on the gages within the watershed. The time of concentration is very short for this small and steep watershed, therefore, short time interval precipitation data are critical to accurately predict the peak runoff. However, the short interval data are only recorded by the automatic gage at one site mid-way up the watershed (Topanga Patrol Station).

The monthly mean potential evapotranspiration rate in the watershed was downloaded from the web site of the California Irrigation Management Information System (CIMIS, 2001) at Santa Monica Station (#99), which is the closest station to the watershed.

The water levels at the ocean boundary were downloaded from the web site of the Center for Operational Oceanographic Products and Services (CO-OPS, 2001) of the National Ocean Service at Santa Monica prediction station (#9410840).

Stream flows recorded in the Topanga stream gage by the Los Angeles County Department of Public Works (LACDPW) were used as model upstream boundary input in simulating the lagoon alternatives and the performance of improvements between lagoon and the gage. The stream flows recorded at the stream gage and the water depths measured at various locations by the RCD were used as the model calibration data.

SEDIMENTATION

The sedimentation modeling requires sediment transport rate input at all open boundaries where there is inflow. Sediment erosion from the lower watershed between the lagoon and the main confluence is not considered since sediment is mainly contributed to the creek from erosion in the upper watershed (Orme, et al. 2002). No measured sediment transport rate or sediment delivery rate at the main confluence is available. The total suspended solids (TSS) measured by the RCD during their water quality study were used in estimating the sediment transport rate. The estimated sediment transport rate was then verified by the hillside erosion data collected by the Topanga Creek Erosion and Sediment Transport Study (Orme, et al. 2002).

5. MODEL INITIAL CONDITIONS

HYDROLOGY AND HYDRAULICS

Initial conditions for hydrologic modeling include the maximum water content in storage in the surface and root zone, runoff coefficients and time constants for routing the interflow, overland flow and base flow. These data were initially determined from the soil type and its infiltration rate, vegetation coverage, impervious development, watershed slopes and sizes, and base flow data. They were then adjusted during the model calibration to match the measured flow rates recorded in the stream gage.

The Manning's roughness coefficients, n, in the hydraulic modeling were first selected based on the site inspection, literature review (Chow 1959 & USGS 2001) and past working experiences. It was then refined during the model calibration process. Roughness coefficients ranging from 0.06 to 0.07 were used in this study, which is very typical for mountain streams with cobbles and large boulders at the bed.

SEDIMENTATION

In addition to the initial data required for RR and HD modeling, the bed material grain size data are required for sedimentation modeling. The bed material grain size data in the lagoon and creek were provided by the RCD. The sediment grain size varies from silt/clay to boulders. Therefore, the MIKE11- GST (Graded Sediment Transport) model was used and five fractions with mean grain sizes of 0.00001, 0.0004, 0.033, 0.16, and 0.5m were modeled. The Smart-Jaeggi's sediment transport model was selected as it calculates the transport of coarse sediments in steep creeks. Parameters in the transport model were adjusted during the model calibration processes.

6. MODEL CALIBRATION AND VERIFICATION

HYDROLOGY AND HYDRAULICS

For the hydrological model, the calibration goal was to match the recorded flow rate in the stream gage. Calibration was done for a four and one-half-year continuous simulation. The first six months is the model "warm-up" period, and the remaining four years modeling period was for the model calibration and verification. The predicted and measured flow rates are compared at the stream gage and show relatively good agreement as shown in Fig. 4.

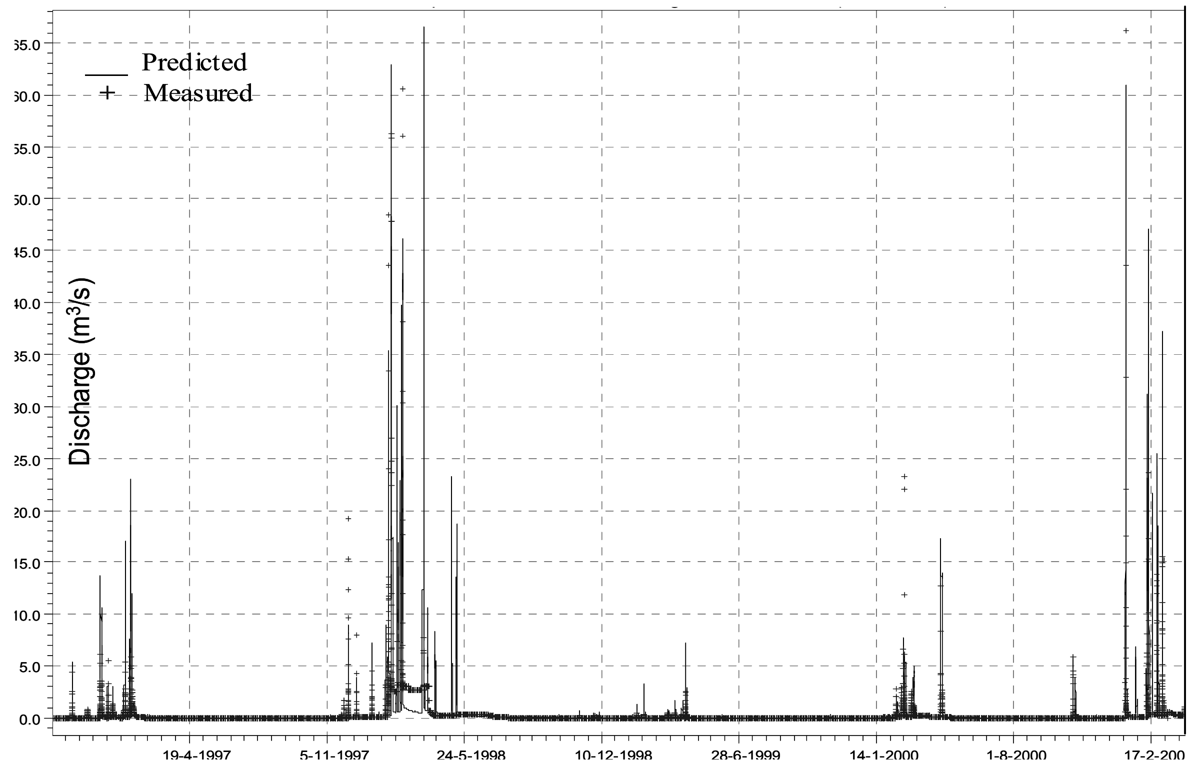

Fig. 4 Calibration of hydrological model MIKE11-RR

For hydraulic calibration and verification, water depths predicted and measured at various locations were compared. Fig. 5 shows an example of the comparisons. The results showed relatively good agreement. These visual correlations were considered sufficient to conclude that the hydrology and hydraulic model can be used with confidence to model alternatives and make relative comparisons of their performance.

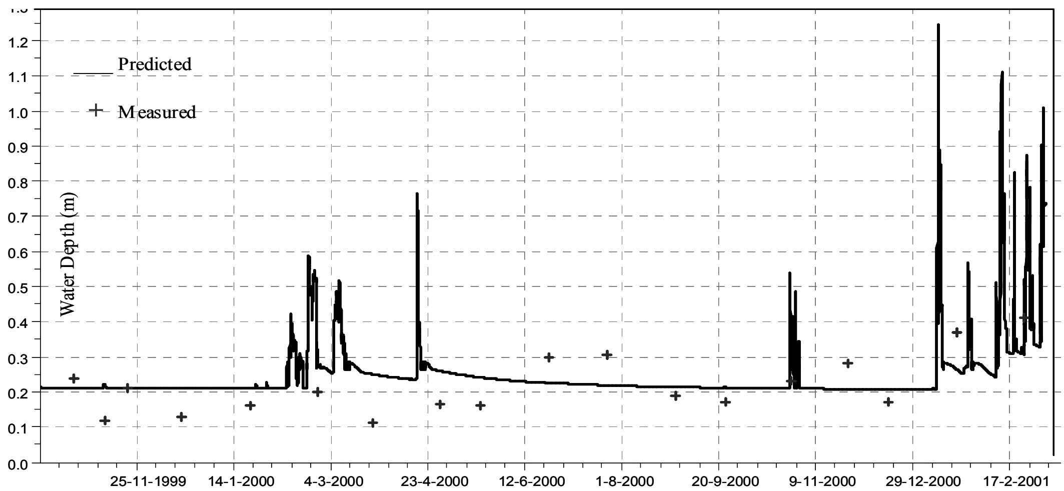

Fig. 5 Calibration of hydraulic model MIKE11-HD

SEDIMENTATION

The calibration goal was to match the estimated sediment transport rate and the total sediment transport volume over the calibration period at the stream gage. The calibration was done for a four and one-half-year continuous simulation. The calibration parameters were the critical shear stress and coefficients in the Smart-Jaeggi's sediment transport equation. Fig. 6 shows the predicted sediment transport rate at the stream gage versus the sediment transport rates estimated from the measured TSS data at the stream gage. As shown in the Figure, the model predicted the sediment transport pattern very well, but slightly underestimated the peak and overestimated the low flow sediment transport rates. The predicted total sediment transport volume at the stream gage over the four and one-half-year period by the model is 5,330 cubic meters (m^3) and that estimated from the TSS sampling data is 3,950 m^3. These results were sufficient to conclude that the sediment transport model can be used with confidence to model alternatives and make relative comparisons of their performance.

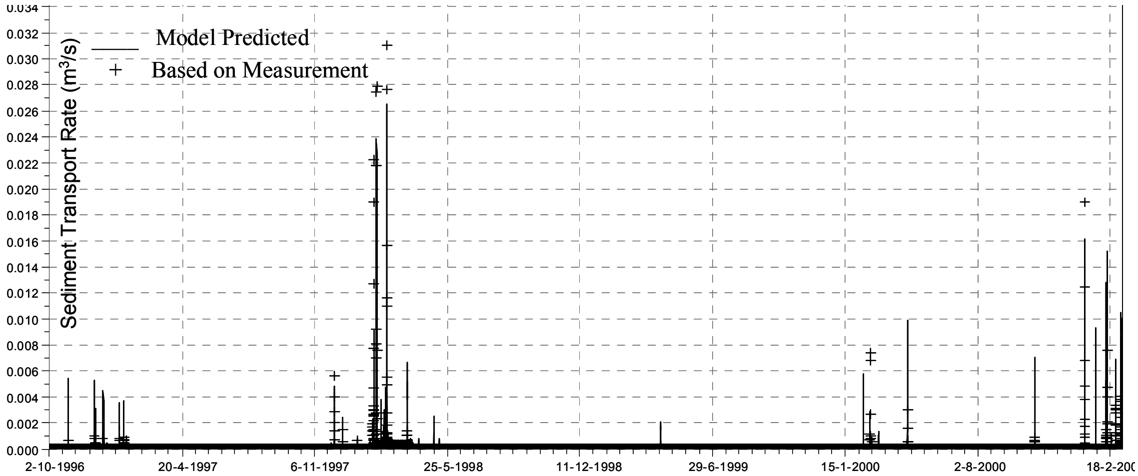

Fig. 6 Calibration of MIKE11-GST model

7. ALTERNATIVE MODELING AND RESULTS

Modeling periods for alternative comparison and upstream improvement evaluation included:

water year 1997 to 2001 and two extreme storm events (a 20-year flood in Jan. 1983 and an 83-year flood in Feb. 1980). The modeling area for lagoon alternative comparison as well as improvements downstream from the stream gage only extends from (and includes) the lagoon to the stream gage such that the recorded flow rate at the stream gage can be used as the model upstream boundary input. Improvements upstream of the stream gage were modeled using the discharge predicted by MIKE11-RR for the specified periods. The performance of an alternative relates to its ability to pass the flood and convey sediment to the sea under storms, and to remain environmentally suitable habitat during prolonged low flow conditions. Conditions conducive to fish passage and migration, such as an open lagoon mouth and flow velocities within a certain range, are dictated by storm flows. Also, flooding, sedimentation and damage to habitat and infrastructure of alternatives can occur during storm events.

HYDROLOGY AND HYDRAULICS

Results of hydrologic and hydraulic modeling indicate that lagoon alternatives perform vastly different during storms. Alternative 4 performs the best for flood control purposes, fish passage and habitat. Water levels and flow velocities near the downstream bridge are lowest for this scenario, suggesting that sediment transport to the sea will be maintained rather than sediment deposition occurring upstream of the bridge constriction at the backwater area. This is desirable for habitat and restoration purposes, and benefits the coastline by maintaining the sediment supply to the beach. Alternative 3 also performs better than either Alternatives 1 or 2, as it also conveys flows effectively owing to the large mouth section. Alternatives 1 and 2 would basically continue to support existing conditions of poor flood conveyance and resulting adverse effects of flooding to infrastructure, habitat and fish migration.

SEDIMENTATION

The modeling period for alternatives is from the beginning of water year 1997 to March 2001. The results were summarized from the beginning of water year 1998 to March 2001. Table 2 summarizes the total sediment accretion and erosion volumes in the lagoon and different stream reaches over the four years of the modeling period for all four alternatives.

Table 2 Total Sediment Accretion And Erosion Volumes From a Four-Year Simulation (Cubic Yards)

Alternative	Upstream Inflow	Confluence to Upstream End of Habitat Survey	Upstream End of Habitat Survey - Stream Gage	Stream Gage - Upstream End of Lagoon	Lagoon
Existing Condition	3,765[1]	-1,836[2]	-1,369	4,823	434
Alternative concept 2	3,765	-5,419	-2,299	5,308	4,915
Alternative concept 3	3,765	-5,419	-2,368	7,309	1,711
Alternative concept 4	3,765	-5,419	-2,912	7,697	3,086

Note: 1. A positive number indicates the sediment accretion. 2. A negative number indicates the sediment erosion.

Overall, creek reaches upstream of the stream gage are under a scour mode and river reaches between the stream gage and the lagoon are under a depositional mode. With upstream improvements, sediment moves through the creek and reaches the downstream locations. Alternative 2 has the largest sediment deposition volume in the lagoon area, and the sediment is mostly deposited in the area immediately upstream of the PCH Bridge and forms a bar. This is due to the backwater effect caused by the existing PCH Bridge. For Alternative 4, the volume of sediment deposited in the lagoon is smaller. Contrary to existing conditions, any sediment deposited in the lagoon after restoration may be flushed out to the ocean under a larger storm event due to the larger cross-section under PCH, and thus is expected to reside only temporarily.

Concept design of upstream improvements and the preferred Alternative 4 were completed for quantifying quantities and costs. These data will be used for permits and to provide basis for environmental review. Currently, preparation of project study report for lengthening of PCH bridge and "Narrows" improvement are underway.

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