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Section 1 – Introduction

1.1 Project Information and Background

1.1.1 Mission Creek Watershed Description

Mission Creek is one of the largest stream in the near vicinity of Santa Barbara, California, encompassing a watershed area of about 11.5 square miles. The stream commences at the crest of the Santa Ynez Mountains roughly 3 to 5 miles from the Pacific Ocean at elevations of up to about 4,000 feet above sea level, flowing about 8 stream miles to its terminus at a brackish lagoon along the waterfront of Santa Barbara's harbor. It is comprised of two main branches; Mission Creek, and Rattlesnake Creek. The two tributaries join at roughly stream mile 4, above the historical alluvial fan upon which the City of Santa Barbara is located.

Mission Creek flows through several clearly distinguishable and seismically highly active geologic strata (Gurrola, 2001). Typical channel slopes are quite steep in the upper reaches, ranging up to 1000 feet per mile and more. Channel slopes in the middle foothills portion of the stream, from the confluence with Rattlesnake Creek to the upper end of the alluvial fan, range from about 150 to 750 feet per mile. The lower reach of Mission Creek on the alluvial fan has channel slopes ranging up to about 150 feet per mile. Historical geologic activity has greatly modified the stream course of Mission Creek, with several rising anticlines having moved the active channel as much as several miles across the historical floodplain and alluvial fan over the more recent geologic past (Keller, 2000). The upper reaches of the stream comprise the most important areas of steelhead rearing habitat, while the lower reaches serve primarily as the migration corridor during periods of higher flows. The basin is highly affected hydrologically by periodic wildfire activity, which results in temporally very high sediment loads extending through several winter flood seasons until revegetation of the watershed occurs. The steep slopes of the watershed and the high gradient of the stream channel result in significant transport of sediment of relatively large size gradation throughout the entire stream channel length during flood events. The paved channel reaches provide high transport capacity for these materials, essentially acting as 100% sediment throughput reaches.

The characteristic dry/wet cycle of the Southern California coast plays a significant role in the hydrology of the Mission Creek watershed, with the result that the native steelhead population is highly adapted to the uncertain availability of streamflows for migration. Large, deep pools in the upper bedrock reaches of the stream provide holding habitat for long periods of drought, while limited gravel beds throughout the watershed provide suitable spawning and incubation areas generally only during relatively wet periods. This cycle typically extends over multi-year periods. Wet periods are often characterized by very heavy rainfall events occurring several times through the winter months, with sustained dry periods during the summer and fall months. Dry periods are characterized by the pronounced lack of large rainfall events during consecutive winter periods, followed by very dry spring, summer, and fall months extending over perhaps several years. As a consequence of the unique hydrologic conditions and evolutionary adaptation of the native steelhead stock, migration corridor passage availability is a critical requirement for the continued existence of the anadromous and resident life histories of these fish in the Mission Creek watershed.

An added area of significant concern for recovery of native anadromous steelhead stocks in Mission Creek includes the particularly damaging effect of the drought/wildfire/flood cycle characteristic of this and other Southern California watersheds. Severe flood events following wildfires in the watershed may result in temporary catastrophic loss of entire populations of resident rainbow trout, which are understood to be ancestral remnant stocks of formerly anadromous steelhead populations (NOAA, 2003). Such loss of resident fish, together with the subsequent inability to recolonize damaged areas as a result of total upstream passage barriers such as the concrete paved channel sections of Mission Creek, may lead to complete extirpation of the steelhead and rainbow populations in the affected watershed. Until the present, this particular combination of events has not occurred, and thus has not resulted in the total loss of the rainbow/steelhead population in the Mission Creek watershed, simply because catastrophic fires of the necessary magnitude and areal extent have not affected the entire Mission Creek watershed in total as yet. However, the very real threat of such a combination of events, and the rather ominous consequences, makes re-establishment of passage through such total barriers to upstream migration as the concrete paved reaches of the Mission Creek channel, an imperative recovery requirement.

1.1.2 CALTRANS Channels Description

The project reach consists of two sections of trapezoidal concrete paved channel, the downstream section about 0.77 miles in length and the upstream section about 0.27 miles in length, separated by a relatively natural bed reach. Most of both the concrete paved channel sections were constructed as part of the CALTRANS Highway 101 construction during the early 1960's, and a small portion of the upstream section was constructed during the 1930's. The downstream paved reach is bounded by Canon Perdido Street downstream and Arrelaga Street upstream, and the upstream paved reach is bounded by Pedregosa Street downstream and Los Olivos Street upstream. These channel modifications straightened and paved the former Mission Creek channel to provide more efficient flood flow and sediment conveyance. The paved channel invert slope in the downstream section is 0.0067, 0.0133, and 0.0112 from downstream to upstream, respectively, and in the upstream section it is 0.0178, 0.0128, and 0.0150 from downstream to upstream, respectively. The paved reaches are designed to flow supercritical during flood events. Throughout the downstream paved channel section, the base channel width is a uniform 26 feet, with 10 foot high sideslopes at 1V:1H, and unpaved shallower slopes of natural embankment above. The upstream paved reach also averages 26 feet in base width downstream of Mission Street, but only 20 feet upstream of Mission Street. Several bridges cross the paved channel sections, with transitions upstream and downstream from the 26 foot base width of the trapezoidal channel to 30 feet wide directly under the bridges.

1.1.3 Project Background & Previous Studies

This study is intended to assist in defining potential project alternatives for restoration of fish passage through the lower reaches of the Mission Creek stream corridor. In 2000, the City initiated the development of fish passage planning actions for Mission Creek. Following that commitment, the Coastal Conservancy commissioned an inventory of fish passage barriers to steelhead passage along the Southern California Coast (Stoecker, 2002). In that inventory study, the paved portions of Mission Creek were identified as a total barrier to upstream migration.

The City of Santa Barbara commissioned a preliminary investigation of potential alternatives for modification of the concrete channel sections of Mission Creek to permit fish passage upstream (Penfield and Smith, 2002). In that assessment, three alternatives were evaluated. Two were relatively low cost concepts which retained the major portion of the concrete paved channels for flood flow passage, while the third alternative comprised an extensive widening of the channel. The low cost alternatives consisted of a 1) narrow, rock-filled chute with intermittent resting pools cut into the existing concrete apron, and 2) longitudinal and lateral curbs cast on the existing concrete apron to form a series of shallow pools at very low flows. The third alternative consisted of removal and replacement of the entire concrete channel with a much wider natural bottom channel, with left and right banks retained with low walls and footings. This alternative would require purchase of significant real estate holdings to provide space for construction, and was estimated to cost more than $50 million.

In 2002, the U.S. Army Corps of Engineers, at the request of the City of Santa Barbara and based on prior discussions with the Environmental Defense Center, initiated a Section 206 project to restore fish passage through the concrete channel reaches of the Mission Creek channel. The resulting Project Restoration Plan (PRP) (US Army Engineer District, Los Angeles, 2002) established the initial phase of the Corps' Section 206 project. This PRP identified the objectives of the Section 206 study and outlined future engineering efforts necessary for completion of the passage restoration project for the concrete channel reaches of Mission Creek.

In 2004, the U.S. Army Corps of Engineers published the baseline (i.e., without-project conditions) hydraulics and hydrology report appendices for the Section 206 study (U.S. Army Engineer District, Los Angeles, 2004). Funding for continued effort on the part of the Corps' was significantly reduced following this report, and the Corps was forced to put the continuing work on hold indefinitely until funding could be restored to continue the engineering effort identified in the previous PRP report. The hydraulic baseline report includes the results of initial steady-state water surface profile modeling of the existing Mission Creek channel, and the results of initial sediment transport modeling of the existing Mission Creek channel. The hydrology baseline report includes the results of a hydrologic analysis of the Mission Creek watershed to determine design discharge ranges and anticipated event hydrographs for various flood events.

In order to continue the engineering studies identified by the Corps in the PRP report, the Environmental Defense Center commissioned this study to develop a suite of intermediate restoration alternatives for the concrete channel reaches of Mission Creek. These intermediate alternatives were intended to fill the void between the low cost alternatives and the high cost alternative identified previously by the City (Penfield and Smith, 2002), and acknowledged by the Corps in the Section 206 report. The three alternatives explored in this study investigate passage restoration by means of removal of a portion of, or all of, the existing concrete channel apron and replacement with a structural, roughened channel with natural substrate.

1.2 Scope and Authorization

1.2.1 Scope

The scope or work for this study consists of the following tasks:

Task #1. Sediment Transport Analysis.

Reconstitute Corps of Engineers' HEC6T sediment transport model. Input geometry for Alternatives 1, 2, 3, and existing conditions into model input deck and execute using previously assumed sediment delivery, bed sediment sample data, and sample flood hydrographs as with previous Corps of Engineers analysis. Determine adjustments to Alternative 1, 2, and 3 geometry necessary to minimize excessive sedimentation or degradation within project reach for long term maintenance period (10 years?).

Task #2. Bridge Modifications to Maintain Flood Capacity.

Within the context of the steady state water surface profile model, identify up to three preferred potential modifications to each of the bridges within project reach to improve flood capacity, working with the Santa Barbara County and City flood control staff to determine a feasible alternative.

Task #3. Channel Transition Zone Treatment Development.

In the steady state water surface profile model, determine up to three feasible treatment/modifications to upstream and downstream channel transition areas from concrete paved channel to natural or semi-natural sections necessary to minimize erosion or stability concerns.

Task #4. Construction Access and Staging Areas.

(THIS TASK POSTPONED UNTIL FUNDING IS AVAILABLE) Using previously provided information from CALTRANS and new information provided by the City and County, determine approximate potential location, size, and configuration of possible construction staging areas for purposes of constructing the proposed Alternatives 1, 2, and 3. Also, determine construction access locations to the channel invert for purposes of construction of Alternatives 1, 2, or 3, and determine improvements/modifications necessary to these access locations to enable equipment of the size necessary to construct proposed channel modifications to reach channel invert and move materials as necessary.

Task #5. Refine Steady State Water Surface Profile Model.

Using the identified improvements or modifications to channel geometry developed in Tasks 1 through 3 above, revise steady state water surface profile model to reflect the refined Alternatives 1, 2, and 3.

Task #6. Conceptual Level Construction Cost Estimates.

Refine conceptual construction cost estimates for Alternatives 1, 2, and 3 to reflect prescribed modifications determined in Tasks 1 through 4 above. Construction costs estimates will include anticipated construction and engineering cost estimates to the 30% level, with a 50% cost contingency applied. These cost estimates will NOT cover anticipated costs of permitting, public outreach, or governmental costs associated with development and completion of Alternatives 1, 2, or 3. The level of detail of the conceptual alternatives in this study will be to approximately the 30% feasibility level, with major civil feature dimensions and configurations shown, hydraulic profiles developed, and construction methods and access discussed. The goal is to facilitate completion of the Corps' Section 206 feasibility report, and provide additional information to local sponsor and interested non-governmental organizations for the purpose of securing funds to continue through the study phase and eventually obtain permits for implementation. This effort will be limited to preliminary feasibility level only.

Task #7. Coordination and Meetings.

Maintain close coordination with Santa Barbara County Flood Control District (Tom Fayram, Jon Frye) and Santa Barbara City Public Works Department (Pat Kelly) through conference calls, e-mails, and sharing of concepts and draft plans. Attend one meeting in Santa Barbara to present results of this work order to City and County staff, as well as interested parties from the US Army Corps of Engineers, NOAA Fisheries, USFWS, NGO's, and others. In addition, one site visit will be necessary to meet with City and County flood control staff and possibly CALTRANS to review existing bridge structures and develop modification alternatives, and review potential staging and construction access points.

Task #8. Report.

Provide an appropriately detailed narrative report describing the existing condition of the constructed channel for fish passage and how the proposed feasibility level Alternatives 1, 2, or 3 would improve it. Describe the technical feasibility of the proposed conceptual fish passage alternatives and explain what characteristics of the proposed alternatives provide for the desired fish passage to upstream reaches of Mission Creek, if applicable. Describe what types of adverse environmental effects would be expected to result and how those may be minimized (e.g., noise, water quality, traffic). Describe any secondary project benefits (e.g., cooler water temperatures, riparian habitat, landscaping and aesthetics, etc.).

1.2.2 Authorization

This study was originally authorized by the Environmental Defense Center on 24 June, 2005.

1.3 References

AASHTO, American Association of State Highway and Transportation Officials.

ACI 318, American Concrete Institute, Building Code Requirements for Reinforce Concrete.

AISC, American Institute of Steel Construction, Manual of Steel Construction and Allowable Stress Design, Ninth Edition, 1989.

Bathurst, J.C. (1982). "Flow resistance in Boulder-Bed Streams," *Gravel Bed Rivers*, R.D. Hey, J.C. Bathurst, and C.R. Thorne, eds., John Wiley and Sons, New York, pp. 443-465.

Behlke, Charles E., Douglas L. Kane, Robert F. McLean, and Michael D. Travis. 1991. *Fundamentals of culvert design for passage of weak-swimming fish*. State of Alaska, Department of Transportation and Public Facilities, State wide Research M/S 2554, 2301 Pegar Road, Fairbanks, AK 99709-5316.

Bell, M.C. 1991. *Fisheries handbook of engineering requirements and biological criteria*. U.S. Army Corp of Engineers, North Pacific Division, Portland, Oregon.

Bjorn, T.C. and C.A. Peery. 1992. *A review of literature related to movements of adult salmon and steelhead past dams and through reservoirs in the lower Snake River*. U.S. Fish and Wildlife Service, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, Moscow, ID, 83843.

California Department of Transportation (CALTRANS). 1961. "Plans for Construction on State Highway in Santa Barbara County in Santa Barbara, between 0.2 mile east of Bath Street and 0.6 mile west of Los Olivos Street," Project No. U-007-2(1).

City of Santa Barbara, 2002. Stormwater Treatment Options for Reducing Bacteria in Arroyo Burro and Mission Creek Watersheds. URS Corporation, October, 2002.

Chow, V. T. 1959. "Open Channel Hydraulics," McGraw-Hill, New York.

Clay, C.H. 1961. *Design of fishways and other facilities*. Department of Fisheries of Canada, Ottawa, Ontario.

Copeland, R. R., D.C. McVan, and S.E. Stonestreet. 2000. "Sedimentation Study and Flume Investigation, Mission Creek, Santa Barbara, California; Corte Madera Creek, Marin County, California," U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi.

Gurrola, L.D., et. al. 2001. Neotechtonics of the Santa Barbara fold belt, California, with a section on Investigation of the Mission debris flow deposit, Santa Barbara, California. Geologic excursions in southwestern California: Society of Economic Paleontologists and Mineralogists, Pacific Section. Book 89.

Henderson, F. M., 1961. "Open Channel Flow," Prentice Hall, New York.

Hydrologic Engineering Center. 1990. "HEC-2, Water Surface Profiles" User's Manual, U.S. Army Corps of Engineers, Davis, California.

Hydrologic Engineering Center. 2002. "HEC-RAS, River Analysis System" User's Manual, Version 3.1. U.S. Army Corps of Engineers, Davis, California.

Hydrologic Engineering Center. 1993. "HEC-6, Scour and Deposition in Rivers and Reservoirs," User's Manual, U.S. Army Corps of Engineers, Davis, California.

Keller, E. A. and L.D. Gurrola. 2000. Final Report, Earthquake hazard of the Santa Barbara fold belt, California: NEHRP Report Final.

Newbury, R.W. (1995). "Rivers and the art of stream restoration," *Natural and anthropogenic influences in fluvial geomorphology*, J.E. Costa, A.J. Miller, K.W. Potter, and P.R. Wilcock, eds., American Geophysical Union, Washington, D.C., pp. 137-149.

NOAA, 1995. *Juvenile Fish Criteria*, National Marine Fisheries Service, Environmental & Technical Services Division, Portland, Oregon, Revised February 16, 1995.

NOAA, 2000. *DRAFT Anadromous Salmonid Passage Facility Guidelines and Criteria*, National Marine Fisheries Service, Technical Services Division, Portland, Oregon, 2000. (Not formally issued yet).

NOAA, 2003. Updated Status of Federally Listed ESU's of West Coast Salmon and Steelhead. West Coast Salmon Biological Review Team. NOAA Northwest Fisheries Science Center & Southwest Fisheries Science Center. July, 2003.

Orsborn, John F. 1985. *New concepts in fish ladder design*. Washington State University, Department of Civil and Environmental Engineering prepared for Bonneville Power Administration Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208-362.

Penfield and Smith. 2002. "Mission Creek Fish Passage Alternatives," Santa Barbara, California.

Powers, Patrick D., John F Orsborn, Thomas W. Bumstead, Sharon Klinger-Kingsley, and Walter C. Mih. 1985. *Fishways-an assessment of their development and design*. Washington State University. Prepared for Bonneville Power Administration Division of Fish and Wildlife, P.O. Box 3621, Portland, OR 97208-362.

RSMeans. Heavy Construction Cost Data. 18th Annual Edition, 2006.

Stoecker, M., and Conception Coast Project. 2002. "Steelhead Assessment and Recovery Opportunities in South Santa Barbara County, California."

Thomas, W. T. 1997. "Sedimentation in Stream Networks (HEC-6T)," User's Manual, Clinton, Mississippi.

U.S. Army Engineer District, Los Angeles. "Mission Creek Section 206 Study, Santa Barbara, California, Project Restoration Plan," 2002.

U.S. Army Engineer District, Los Angeles. "Mission Creek Section 206 Study, Santa Barbara, California, Hydraulic Documentation Without-Project Conditions Report & Draft Hydrology Appendix F3 Phase/Baseline Condition " February, 2004.

U.S. Army Corps of Engineers. Engineer Manual EM 1110-2-1418 Channel Stability Assessment for Flood Control Projects, October, 1994.

U.S. Army Corps of Engineers. Engineer Manual EM 1110-2-1601 Design of Flood Control Channels, October, 1994.

U.S. Army Corps of Engineers, Engineer Manual EM 1110-2-2502 Retaining and Flood Walls, September, 1989.

U.S. Army Corps of Engineers. Engineer Manual EM 1110-2-4000 Sedimentation Investigations of Rivers and Reservoirs, October, 1995.

United States Geological Survey. *Water Supply Papers, 2005*. 2005.

United States Geological Survey. (1967). *Roughness Characteristics of Natural Channels – USGS Water-Supply Paper 1849.* United States Government Printing Office.

United States Geological Survey. (1992). *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains – USGS Water-Supply Paper 2339.* United States Government Printing Office.

Walker, D.R., R.G. Millar, and R.W. Newbury (2004). "Energy Profiles Across Constructed Riffles," *Proc. Am. Soc. Civil Engineers, J. Hydraulic Engineering*, **130**(3), pp. 199-207.

Washington Department of Fish and Wildlife. *Fishway Guidelines for Washington State.* Draft Guidelines, April 25, 2000.

Weaver, C.R. 1963. *Influence of water velocity upon orientation and performance of adult migrating salmonids*. U.S. Fish and Wildlife Service Fishery Bulletin 63:97-121.

Whittaker, J.G. (1987). "Sediment Transport in Step-Pool Streams," *Sediment Transport in Gravel-Bed Rivers*, C.R. Thorne, J.C. Bathurst, and R.D. Hey, eds., John Wiley and Sons, New York, pp. 545-579.

Section 2 – Channel Modification Alternatives

2.1 Alternative 1 and Variations

Alternative 1 consists of removal of approximately half the width of the concrete channel apron and replacement with a deepened channel section. Embedded integral natural and artificial boulder elements cast into the concrete invert of the deepened thalweg would provide hydraulic roughness, some substrate retention, and velocity cover for migrating steelhead. The proposed natural boulder features could be composed of granitic material if more durability were desirable. The current channel base apron width throughout the downstream 0.77 mile length of paved channel is approximately 26 feet, with a cold joint in the slab running roughly down the centerline of the channel. The current apron width of the upstream 0.27mile paved channel is also approximately 26 feet in the section downstream of Mission Street, transitioning to approximately 20 feet throughout the section upstream of Mission Street. A similar cold joint in the center of the slab is present in the 26 foot wide portion of the upstream reach; however, the slab is continuous in the 20 foot wide section.

Within the existing bridge sections, which currently consist of vertical sidewalls and approximately 30 foot wide apron, the right (south) half of the slab would be removed to within about 4 feet of the vertical abutment wall. Drawings from the 1961 CALTRANS construction work indicate that the bridge crossing abutments and support structures are founded on spread mat footings roughly 4 feet wide, with the footing base about 6 feet below the current slab elevation. The proposed channel excavation work would entail deepening (by three to five feet) only outside of the footing and footing support prism footprint. Excavation work would proceed cautiously, with temporary shoring as necessary to protect the bridge abutment footing from settling or failure during construction. Additional structural support may be required to ensure long-term stability of the affected bridge abutments. A review of the 1961 CALTRANS plans for the concrete channel did not reveal evidence of buried infrastructure below the existing channel pavement. However, additional research will be required to confirm the apparent lack of interference of the proposed channel deepening work with any buried conduits, ducts, pipe, wire, fiber optic lines, power lines, or other features.

Construction of the Alternative 1 channel modification would commence at the downstream ends of each of the two paved sections, with sawcutting of the invert slab where necessary along roughly the centerline and along the right descending toe of the channel sidewall. If needed to retain the vertical position of the existing sideslope paving, soil anchors could be installed through the slope paving as necessary. Equipment access is likely available to the downstream section through an existing access ramp downstream of Valerio Street, and a second ramp could be constructed downstream of Canon Perdido Street, if necessary. Equipment access to the upstream section may be available at or near Mission Street.

Several variations of the Alternative 1 concept were investigated in this study (Alternatives 1A through 1E). **Alternative 1A** consisted of a uniformly deepened right half of the channel to 2 feet depth (net after reconstruction of roughened bed) below the existing concrete apron (Figures 2.1 and 2.2). **Alternative 1B** consisted of the same configuration as Alternative 1A, but with an additional 3 feet of net depth below existing grade under bridges for a total of 5 feet net depth, and adverse grade up to the 2 foot net depth upstream and downstream of the bridges within the downstream paved reach (Figures 2.3 and 2.4). Within the upstream paved reach, net depth under the Mission Street bridge was increased to 8 feet, with the commensurate adverse grade upstream and downstream to meet the uniform 2 foot net depth of the remainder of the channel. **Alternative 1C** consisted of the same configuration as Alternative 1B, but with the over-excavation extended with flat gradient downstream of Canon Perdido Street to meet the existing natural thalweg elevation (Figures 2.5 and 2.6). **Alternative 1D** consisted of a uniform deepening of the right half of the channel to a net depth of 4 feet below existing concrete apron elevation, and no additional deepening under bridges (Figures 2.7 and 2.8). **Alternative 1E** consisted of a uniform deepening of the right half of the channel to a net depth of 8 feet below existing concrete apron elevation (Figures 2.9 and 2.10).

Bridge modifications investigated in Alternatives 1B and 1C were intended to improve hydraulic capacity and reduce adverse impacts on sediment transport resulting from the hydraulic energy losses created by the bridge transitions. The additional extension of the over-deepened channel in Alternative 1C was intended to encourage more efficient sediment transport through the Canon Perdido bridge and downstream into the natural reach. The present condition permits deposition of bedload in the natural channel section immediately downstream of the Canon Perdido bridge, which in turn causes ponding of stagnant water under the bridge.

Demolished slab materials, including steel reinforcement, would be crushed and recycled to the greatest extent possible, with debris hauled to an offsite storage and/or disposal site yet to be identified. Using the remaining slab width as the staging area, the underlying materials would be over-excavated to a maximum depth of about 5 to 8 feet, taking care not to destabilize or fail the remaining slab section by overloading the sawcut edge. All demolition and excavation work would likely proceed toward the access ramps, although the contractor may choose to perform the structural concrete channel replacement work immediately behind the excavation work or at any point in between. In this case, additional access ramps, though likely temporary, will be required at the downstream ends and/or at intermediate points along the paved reaches. Since construction will be performed during summer, rainfall runoff should not be present and the channel should be relatively dry. Any groundwater or surface runoff from side drains will be captured and pumped through temporary diversion lines into a mobile siltation tank and then released downstream of the construction area back into Mission Creek.

Maintenance of the Alternative 1 channel would be accomplished with excavators and highway duty trucks, driving along the left side slab of the channel bottom. Maximum reach from the center of the left channel slab would be approximately 20 to 24 feet, roughly within the capacity of a 160 (20 ton) to 200 (25 ton) class excavator. Vegetation and sediment would be removed with excavators from the channel bed as needed and hauled off site.

2.2 Alternative 2

Alternative 2 consists of removal of the entire horizontal apron slab of the concrete channel and replacement with a deepened channel section with integrated natural and artificial boulder elements to provide hydraulic roughness, some substrate retention, and velocity cover for migrating steelhead (Figures 2.11 and 2.12). As for Alternative 1 described above, Alternative 2 would include over-excavation of the channel invert below the existing slab, to a depth of perhaps 5 or 6 feet below the existing slab elevation. The sidewalls and invert of the excavation would be reconstructed in structural concrete, with natural and artificial boulder roughness elements cast and anchored into the concrete surface as described for Alternative 1 above, leaving a channel on average about 3 feet lower than the original slab. Again, boulder features could be composed of granitic material if more durability were desirable.

As for Alternative 1, construction of the Alternative 2 channel modification would likely commence at the downstream ends of each of the two paved sections, with sawcutting of the invert slab along the right and left toe of the paved slopes. If necessary to retain the stability of the existing sideslope paving, soil anchors could be installed through the slope paving as necessary. As discussed above, equipment access is likely available to the downstream section through an existing access ramp downstream of Valerio Street. Equipment access to the upstream section may be available at or near Mission Street.

As described for Alternative 1 above, demolished slab materials, including steel reinforcement, would be crushed and recycled to the greatest extent possible, with debris hauled to an offsite storage and/or disposal site yet to be identified. Using the remaining slab upstream of the actual excavation and demolition work, the underlying materials would be over-excavated to a maximum depth of about 5 to 6 feet. All demolition and excavation work would likely proceed toward the access ramp, although the contractor may choose to perform the structural concrete channel replacement work right behind the excavation work or at any point in between. In this case, additional access ramps, though likely temporary, will be required at the downstream ends and/or at intermediate points along the paved reaches.

Since construction will be performed during summer, rainfall runoff should not be present and the channel should be relatively dry. Any groundwater or surface runoff from side drains will be captured and pumped through temporary diversion lines into a mobile siltation tank and then released downstream of the construction area back into Mission Creek.

Maintenance of the channel with Alternative 2 would be accomplished by temporarily placing granular base materials with low silt content in a shallow lift as necessary to provide a suitable temporary access roadway driving surface along the channel bed. Vegetation and sediment would be removed with excavators from the channel bed and hauled off site, using the temporary access roadway. When maintenance work was completed, most of the temporary access road materials would be removed and hauled off site, with the remaining materials retained in the channel to be swept away and/or redistributed during future natural flood event processes.

2.3 Alternative 3

Alternative 3 is similar to Alternative 2 as described above, with the additional removal of the left bank slope paving, excavation of the embankment down to the current apron elevation, and construction of a vertical retaining wall and horizontal apron in place of the existing paved slope (Figures 2.13 and 2.14). As for Alternatives 1 and 2 described above, Alternative 3 would include over-excavation of the channel invert below the existing slab, to a depth of perhaps 5 to 6 feet below the existing slab elevation. Also as for Alternatives 1 and 2 described above, the deepened channel section would include integrated natural and artificial boulder elements to provide hydraulic roughness, some substrate retention, and velocity cover for migrating steelhead. The sidewalls and invert of the excavation would be reconstructed in structural concrete, with the natural and artificial boulder roughness elements cast and anchored into the concrete surface as described for Alternatives 1 and 2 above, leaving a channel on average about 3 feet lower than the original slab.

Construction of Alternative 3 would require either temporary vertical excavation support to prevent damage to the adjacent structures, or that the excavation be performed in increments, with the exposed soil face supported progressively with drilled soil anchors and reinforced shotcrete or cast-in-place retaining wall elements. As for Alternatives 1 and 2, construction would likely commence at the downstream ends of each of the two paved sections, with sawcutting of the invert slab along the right toe of the paved slope. The left half of the channel slab and sidewall would be removed entirely as described. If necessary to retain stability of the existing right sideslope paving during construction, soil anchors could be installed through the slope paving as necessary. As discussed above, equipment access is likely available to the downstream section through an existing access ramp downstream of Valerio Street. Equipment access to the upstream section may be available at or near Mission Street.

Since construction will be performed during summer, rainfall runoff should not be present and the channel should be relatively dry. Any groundwater or surface runoff from side drains will be captured and pumped through temporary diversion lines into a mobile siltation tank and then released downstream of the construction area back into Mission Creek.

Maintenance of the channel with Alternative 3 would be accomplished throughout the channel reach except at bridges from the left bank horizontal apron, likely with excavators and trucks as described above. However, since the entire width of the channel would be comprised of natural, structurally anchored boulder elements, the maximum required reach of any excavation equipment would be approximately 32 feet. Maintenance under bridges, if required, would entail placement of temporary granular material over the roughened channel invert to form an access roadway suitable for travel by maintenance equipment without damaging the structurally anchored roughness elements. Vegetation and sediment would be removed with excavators from the channel bed on an as-needed basis and hauled off site, using the temporary access roadway. When maintenance work was completed, most of the temporary access road materials would be removed and hauled off site, with the remaining material left in place to be removed or redistributed by future flood events.

Section 3 – Numerical Hydraulic Modeling

3.1 Introduction and Methodology

Evaluation of the alternative fish passage modifications developed in this study was focused on two specific computer modeling methods. The first utilized a one-dimensional, steady-state water surface step-profile model developed by the U.S. Army Corps of Engineers; HEC-RAS (Hydrologic Engineering Center, 2002). The second utilized a one-dimensional, steady-state, stepped hydrograph water surface profile and sediment transport step-profile model also developed by the U.S. Army Corps of Engineers; HEC-6 (Hydrologic Engineering Center, 1993). The HEC-RAS model was used to determine the hydraulic characteristics of flow through the existing and modified channel configurations, absent any effects of sediment which will move through the channel reach during moderate to high discharge flood events. We will restrict our attention in this section to the results of the HEC-RAS modeling only, with the following section 4.0 devoted to the sediment transport issues and HEC-6 modeling effort.

The HEC-RAS modeling, in particular, illustrated the varied effects of the smooth concrete existing channel, bridge sections, and natural channel sections on the average water surface profile for various discharges. Discharges evaluated in the HEC-RAS modeling ranged from low flows typical of the receding limb of flood hydrographs, to high flows typical of flood events. In addition, the HEC-RAS modeling provides expected average flow velocities at each cross section throughout the study reach. Model output can be directed to include bed shear stress, conveyance, flow Froude number (a dimensionless parameter measuring the relative gravity forces acting on the body of fluid), and a variety of other hydraulic parameters. The resulting water surface profiles, flow velocities, and hydraulic characteristics resulting from channel modifications specific to each alternative were evaluated to compare relative effects of each alternative on flood conveyance, low flow characteristics, and sediment transport.

3.2 Hydraulic Model Basis

Following after the previous Section 206 work conducted by the U.S. Army Corps of Engineers, the hydraulic modeling analysis was developed after guidance provided in the Corps' Engineer Manual EM 1110-2-1601 (US Army Corps of Engineers, 1994). Fish passage evaluation of the proposed modification alternatives followed after guidance provided in Milo Bell's seminal compendium of fisheries engineering data (Bell, 1991), experience with various anadromous fish passage projects throughout the Pacific Northwest, and new work related to naturalized fish ladders currently being studied in depth in both Western North America and Europe.

3.3 Hydrology

The previously developed hydrologic analysis by the U.S. Army Corps of Engineers in the Section 206 work completed to date was used as the primary basis of typical flood event hydrology. As discussed above, the hydrologic analysis conducted by the Corps included both a flood frequency analysis based on the systematic record and historical data, and a rainfall-runoff calculation for several large frequency flood events. In addition, routing of calculated flood discharges was accomplished with the computer routing model HEC-1, and the calculated flood discharge hydrographs were calibrated using the observed gage data from the USGS Mission Creek gage. Runoff characteristics were adjusted until both the peak estimated discharge and the flood runoff volume compared well with the observed data. Although there is uncertainty expected within the estimated discharges calculated, the median value represents a fair starting point for hydraulic modeling analysis. The uncertainty increases with less frequent, larger flood events, with anticipated range as much as $\pm$ 10% or more expected at the 100-year event and larger. Results of the Corps' hydrologic analysis are presented in the table below, showing approximate discharge values for several flood frequency events. For the hydraulic modeling exercise, we are primarily concerned with the value calculated at the USGS gage site at the Mission Street bridge.

Table 3.1
Mission Creek Median Probability Peak Discharges – Existing Conditions
(from COE Section 206 Hydrology Appendix, 2004)

Concentration Point	Drainage Area (mi^2)	Peak Discharge (cfs)					
		5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
6	7.87	1400	2200	3500	5100	6900	12500
USGS Gage @ Mission St	8.38	1450	2300	3750	5200	7050	12900
7	8.74	1450	2300	3750	5200	7050	12900
8	10.93	1500	2400	3800	5500	7500	13600
9	11.28	1500	2350	3700	5300	7300	13200

The Corps' Section 206 hydraulic modeling appendix (Corps, 2004) provides more precise discharge values for these flood events at locations within the study reach (Cross Section 13621 to Cross Section 6223).

Table 3.2
Mission Creek Peak Discharges – Existing Conditions
(from COE Section 206 Hydraulic Appendix, 2004)

Location in Feet Above Pacific Ocean	Peak Discharge (cfs)					
	5-Year	10-Year	25-Year	50-Year	100-Year	500-Year
(Los Olivos) Cross Section 13621	1400	2200	3500	5100	6900	12500

USGS Gage Cross Section 12610	1450	2300	3550	5200	7050	12900
(Micheltorena) Cross Section 9535	1450	2300	3550	5200	7050	12900
(Canon Perdido) Cross Section 6223	1500	2400	3800	5500	7500	13600
(Pacific Ocean)	1500	2350	3700	5300	7300	13200

3.4 Hydraulic Model Development Criteria

3.4.1 Hydrology of Flood Events

For the hydraulic modeling of the various alternatives evaluated in this study, we have used the estimated flood discharge values calculated by the U.S. Army Corps of Engineers, as discussed above. There has been considerable discussion regarding the accuracy of the Corps' discharge figures, especially for the larger flood events. Past and current analyses have yielded different values for the regulatory flood event (i.e., 100-year), with no conclusive recommendation for adoption of any particular value. However, since this study was intended to evaluate mainly fish passage provisions through the concrete channel reach, and not to exhaustively evaluate regulatory flood events, we have intentionally restricted our flood event analysis to the discharges estimated by the Corps in their Section 206 report, within the following conditional limits:

- Channel modifications shall not increase water surface profile above the existing condition at any location for all flood events of frequency equal to or greater than the 10-year event, or the actual channel capacity, whichever is less.
- Channel modifications shall not result in adverse hydraulic conditions in the vicinity of channel transitions or bridges.

If particular alternatives developed in this study did not meet these conditional limits, further consideration of that alternative for additional design effort was not recommended, unless there were some overriding interest in continuing the investigation in that direction following completion of this study.

3.4.2 Fish Passage Flows

The primary purpose of this study was to develop and evaluate alternatives for channel modification that would enable (theoretically) upstream migration of adult steelhead through the concrete paved channel reach. To meet this goal, there are at least three separate criteria that must be met: 1) Flow velocity must not exceed the burst swimming speed of adult steelhead at any location, 2) Flow depth must be sufficient to enable adult steelhead to remain fully submerged, 3) Passable flow conditions must persist continuously for at least enough time for adult steelhead to navigate the entire length of the concrete paved reaches.

The following criteria were selected, based on the general guidelines noted above.

(1) Flow Velocity

a. Flow velocity during passage time period must not exceed 8 fps at any location (Bell, 1991)

b. Average flow velocity (averaged over entire reach) during passage time period must not exceed maximum sustained swimming speed of smallest fish attempting passage (Bell, 1991), and shall preferably be at least 2 feet per second less

c. Resting area flow velocity shall not exceed 1 fps, or 0.1 x normal swimming speed (Bell, 1991)

d. Assume adult steelhead size range 12 inches minimum and 30 inches maximum, with corresponding estimated maximum burst swimming speed 10 body lengths per second, or 10 fps and 25 fps, respectively (Bell, 1991)

e. Assume adult steelhead maximum sustained swimming speed 5 body lengths per second, or 6 fps and 15 fps, respectively (Bell, 1991)

f. Assume adult steelhead maximum cruising swimming speed 2.5 body lengths per second, or 3 fps and 7.5 fps, respectively (Bell, 1991)

g. Resting pool volume shall be sufficiently large to provide at least 4 ft-lbs/second/ft^3 of water energy dissipation

(2) Flow Depth and Passage Channel Width

a. Minimum average channel flow depth 12 inches

b. Minimum flow depth over any weir-type obstruction 6 inches

c. Minimum channel constriction width 4 feet

d. Maximum head drop over in-stream obstruction 1.5 feet

Passage time is calculated as the total length of channel to be passed (1.04 miles), divided by the difference between average flow velocity and maximum sustained swimming speed. For example, 4 fps average flow velocity and 6 fps maximum sustained swimming speed yields a passage time of 53 minutes.

(3) Passage Time vs. Flow Availability

a. Minimum passage time 1 hour from Canon Perdido Street to Los Olivos Street

b. Discharge range throughout passage time period of hydrograph shall not fall below that sufficient to maintain minimum flow depth as noted above.

Overall, the successful fish passage modification alternative must, as a minimum, provide sufficient passage time during the correct portion of the flow hydrograph to permit all adult steelhead of the minimum expected size range to fully transit the concrete paved reaches of the channel. It has been anecdotally noted that most southern steelhead tend to attempt passage upstream immediately following the peak of higher flow events, after water clarity has increased and total suspended sediment concentrations fall below about 1500 - 2000 ppm (pers. comm. with M. Stoecker, 2005). This information compares favorably with other studies where documented passage movement ceases at turbidities above 4,000 ppm (Bell, 1991). The most successful passage modification alternative will be found in the configuration that provides good passage conditions for the longest period of time over the widest ranges of discharges. Section 4 below provides additional discussion of suspended sediment concentration during flood events.

3.4.3 General Hydraulic Design Criteria

The following general hydraulic design criteria apply to structural features of the proposed fish passage channel modification alternatives. Generally they are intended to define hydraulic loads driving structural design requirements, project longevity, debris and sediment transport, stagnant water issues, maintenance issues, and hydraulic performance.

(1) Hydraulic Loads and Pore Pressure Drainage

a. All slabs and other horizontal concrete structural features should be designed to withstand the full unbalanced downward loads applied by the estimated 500-year water surface profile

b. All slabs and other horizontal concrete structural features should be provided with pore pressure relief at intervals of not less than 10 feet in any direction, or less as underlying soil and subbase gradation requires

c. All slabs and other horizontal concrete structural features should be designed to withstand underlying unbalanced pore pressure equivalent to at least 5 feet of hydraulic head, or as required by underlying soil or subbase materials

d. All vertical and sloping concrete structural features should be designed to resist the full unbalanced horizontal and lateral loads applied by the estimated 500-year water surface profile

e. All vertical and sloping concrete structural features should be provided with pore pressure relief at intervals of not less than 10 feet, in any direction, or less as underlying soil and subbase requires

f. All vertical and sloping concrete structural features should be designed to withstand underlying unbalanced pore pressure equivalent to at least 5 feet of hydraulic head, or as required by underlying soil or subbase materials

(2) Materials, Wear Resistance, and Construction Tolerances

a. All concrete materials shall be designed to resist wear and abrasion by moving sediment for a service life of at least 50 years

b. All concrete materials should have minimum design strength of 4,000psi (28 day)

c. All new concrete structural features should be designed with porous base material to provide rapid relief of high unbalanced pore pressures

d. Maximum permissible deviation from uniform surface profile of all new structural concrete surfaces should not exceed 1/4" per 10 ft of length in any direction. No abrupt joint deviation in excess of 1/8" should be allowed in any uniform concrete surface exposed to flowing water.

(3) Debris and Sediment Transport

a. Channel modifications should permit the free passage of the majority of sediment bed load entirely through the paved concrete reaches of the channel, with minor deposition of fine material only within the roughened channel perimeter

b. Channel modifications should permit the free passage of all woody vegetation and debris

(4) Ponding and Stagnant Water

a. Channel modifications should be designed to prevent or minimize ponding of stagnant water for longer periods than 2 weeks

b. Roughened channel bed pore pressure relief system should be designed to permit drainage of standing water into groundwater table following flood events

(5) Maintenance Requirements

a. Channel modifications should be designed to accommodate the passage of heavy equipment and trucks throughout the entire length of modified channel

b. Equipment access may be permitted over temporary access roadway surfaces if necessary

c. Channel modifications should be designed to permit emergency repair or debris removal activities from all locations where existing condition permits such activities to occur

3.4.4 Hydraulic Model Sensitivity

To evaluate the sensitivity of the predicted water surface profiles generated by the hydraulic model, a range of hydraulic roughness parameter values was utilized, based on various sources of guidance. Sensitivity analysis is normally conducted to determine the maximum and minimum possible deviation of the predicted performance from the mean. The mean value is commonly determined by calibration of model roughness parameters using observed high water marks at various locations throughout the length of the study reach.

The previous Corps of Engineers hydraulic modeling determined the mean roughness parameters values using a number of observed high water marks for at least one flood event. Consequently, this study assumed similar mean roughness values to those used in the previous Corps modeling effort to ensure consistency with the Corps Section 206 project evaluation.

Of particular concern for this project is the hydraulic capacity of the paved channel sections during flood events, especially when sediment bed load transport rates are high. Similar paved channels elsewhere in California have experienced some unanticipated hydraulic capacity limitations as a result of high concentrations of bed load movement and the corresponding establishment of bedforms on the channel invert. Corte Madera Creek, a similar sized stream to Mission Creek, located in the San Francisco Bay area, experienced overflows above the top of bank during a flood event of less than the design magnitude during the 1990's. Subsequent investigation of this channel in the laboratory revealed that sediment bed load in high concentrations raised the effective hydraulic roughness factor above that which was used for the original design, which reduced the actual hydraulic capacity of the channel (Copeland, et. at., 2000). The Corte Madera example showed that bed roughness could be as much as 25% higher than the typical design value for concrete.

In addition to sediment transport effects, the condition of the concrete paving material can vary over the length of the channel. Accordingly, actual bed roughness can be as much as 10 to 15% higher or lower than the design value. Previous evaluation and calibration of the model-predicted water surface profiles for the existing condition channel by the Corps in the earlier Section 206 work confirmed that the study reach was not "… overly affected by the 'n' values that were used within the concrete reaches." (Corps Section 206 Hydraulic Appendix Report, 2004).

In this study, Manning's 'n' values of 0.015 in the smooth concrete portions of the channel, 0.030 to 0.040 for natural portions of the channel bed, and 0.060 to 0.171 for natural vegetated overbank portions of the channel were used in the hydraulic model. For sensitivity testing, a Manning's 'n' value of 0.019 was used for the smooth concrete portions of the channel to reflect effects of high sediment bed load transport rates during large flood events. Within the deepened channel sections for all fish passage modification alternatives, a Manning's 'n' value of 0.035 at higher flood flow discharge events was used to reflect the hydraulic roughness of the embedded boulder elements. For evaluating velocity and depth relationships at lower fish passage flows, a Manning's 'n' value of 0.060 was used for the deepened channel sections to reflect the increased effective roughness in relation to decreasing roughness elements submergence, as recommended in previous studies on boulder-stepped type streams (Bathurst, 1982; Walker, 2004; and Newbury, 1995).

Starting water surface elevations used in the HEC-RAS hydraulic model were taken as normal depth downstream at the natural channel section, and critical depth upstream at the beginning of the concrete paved channel reach. The starting energy grade line slope of 0.044 at the downstream end of the modeling reach (cross section 4370) was determined from the hydraulic water surface profile generated by the HEC-RAS model, and represents the calculated average energy slope for the range of discharges input into the model. Sensitivity analysis of the model to the starting energy grade line slope showed that changes in the input energy grade line slope at the downstream end of the modeled channel reach did not affect the calculated water surface elevation at the downstream end of the portion of the model reach affected by potential fish passage modifications (cross section 5115). Initial sensitivity testing input energy grade line slopes ranged from 0.030 (well below the natural average channel slope) to 0.055 (well above the natural average channel slope). Starting water surface elevations at the upstream end of the model reach were based on calculated critical depth, since the flow regime in the upstream end of the smooth concrete channel is supercritical.

3.5 Alternative 1 Hydraulic Modeling Results

Results of the numerical steady state water surface profile modeling work for each variation of Alternative 1 analyzed were compared to both the existing condition and the original Alternative 1 configuration with the 2 foot deepened channel section. The table below summarizes the major differences between each variation of the Alternative 1 configuration.

Table 3.3
Fish Passage Modification Alternatives – Summary Descriptions

	Channel Depth	Bridge Crossing Channel Depth	Downstream Transition
Alternative 1A	2 ft	2 ft at all bridges – same as channel	None
Alternative 1B	2 ft	5 ft at all bridges except 8 ft at Mission Street	None
Alternative 1C	2 ft	5 ft at all bridges except 8 ft at Mission Street	Extend deepening d/s of Canon Perdido
Alternative 1D	4 ft	4 ft at all bridges – same as channel	None
Alternative 1E	8 ft	8 ft at all bridges – same as channel	None

3.5.1 Alternative 1A

A typical cross section for the Alternative 1A channel modification is shown in Figure 3.1, and a typical bridge section modification is shown in Figure 3.2. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.3 through 3.6, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.7. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 1A configuration are shown in Figures 3.8 and 3.9, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.10 and 3.11, respectively. Note that the average flow velocity and depth meet the fish passage design criteria as discussed in Section 3.4.2 above over a much larger range of discharges than the existing channel.

3.5.2 Alternative 1B

A typical cross section for the Alternative 1B channel modification is shown in Figure 3.12, and a typical bridge section modification is shown in Figure 3.13. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.14 through 3.17, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.18. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 1B configuration are shown in Figures 3.19 and 3.20, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.21 and 3.22, respectively. Note that the average flow velocity and depth meet the fish passage design criteria as discussed in Section 3.4.2 above over a much larger range of discharges than the existing channel.

3.5.3 Alternative 1C

A typical cross section for the Alternative 1C channel modification is shown in Figure 3.23, and a typical bridge section modification is shown in Figure 3.24. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.25 through 3.28, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.29. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 1C configuration are shown in Figures 3.30 and 3.31, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.32 and 3.33, respectively. Note again that the average flow velocity and depth meet the fish passage design criteria as discussed in Section 3.4.2 above over a much larger range of discharges than the existing channel.

3.5.4 Alternative 1D

A typical cross section for the Alternative 1D channel modification is shown in Figure 3.34, and a typical bridge section modification is shown in Figure 3.35. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.36 through 3.39, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.40. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 1D configuration are shown in Figures 3.41 and 3.42, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.43 and 3.44, respectively. Note again that the average flow velocity and depth throughout all fish passage flows shown meet the fish passage design criteria at nearly every location as discussed in Section 3.4.2 above. Refinement of this alternative during the physical scale modeling phase of future study will determine minor modifications necessary to fully meet fish passage criteria throughout the entire study reach, especially in the upstream transition sections to the concrete paved channel reaches.

3.5.5 Alternative 1E

A typical cross section for the Alternative 1E channel modification is shown in Figure 3.45, and a typical bridge section modification is shown in Figure 3.46. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.47 through 3.50, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.51. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 1E configuration are shown in Figures 3.52 and 3.53, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.54 and 3.55, respectively. Note again that the average flow velocity and depth throughout all fish passage flows shown meet the fish passage design criteria at nearly every location as discussed in Section 3.4.2 above. Refinement of this alternative during the physical scale modeling phase of future study will determine minor modifications necessary to fully meet fish passage criteria throughout the entire study reach, especially in the upstream transition sections to the concrete paved channel reaches.

3.6 Alternative 2 Hydraulic Modeling Results

A typical cross section for the Alternative 2 channel modification is shown in Figure 3.56, and a typical bridge section modification is shown in Figure 3.57. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.58 through 3.61, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.62. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 2 configuration are shown in Figures 3.63 and 3.64, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.65 and 3.66, respectively. Note again that the average flow velocity and depth throughout all fish passage flows shown meet the fish passage design criteria at nearly every location as discussed in Section 3.4.2 above. Refinement of this alternative during the physical scale modeling phase of future study will determine minor modifications necessary to fully meet fish passage criteria throughout the entire study reach, especially in the upstream transition sections to the concrete paved channel reaches.

3.7 Alternative 3 Hydraulic Modeling Results

A typical cross section for the Alternative 3 channel modification is shown in Figure 3.67, and a typical bridge section modification is shown in Figure 3.68. HEC-RAS model computed water surface profiles showing the comparison of the 2-year, 10-year, 25-year, and 100-year (FEMA) flood event water surface elevations against the existing condition are shown in Figures 3.69 through 3.72, respectively. A typical HEC-RAS model cross section showing the comparison of the low fish passage flow (4 cfs), medium fish passage flow (20 cfs), higher fish passage flow (38 cfs), and maximum anticipated fish passage flow (180 cfs) water surface elevations is shown in Figure 3.73. A comparison of average channel thalweg velocity for the high and maximum fish passage flows through the existing channel and the proposed Alternative 3 configuration are shown in Figures 3.74 and 3.75, and a comparison of water depth at the high and maximum fish passage flows is shown in Figures 3.76 and 3.77, respectively. Note again that the average flow velocity and depth throughout all fish passage flows shown meet the fish passage design criteria at nearly every location as discussed in Section 3.4.2 above. Refinement of this alternative during the physical scale modeling phase of future study will determine minor modifications necessary to fully meet fish passage criteria throughout the entire study reach, especially in the upstream transition sections to the concrete paved channel reaches.

3.8 Bridge Modification Hydraulic Modeling Results

As discussed in Section 3.5 above, Alternatives 1B and 1C investigated the effects of modifications to bridge crossings to improve hydraulic capacity. In general for supercritical regime channels, various channel modifications can result in significantly different hydraulic characteristics than the same modifications made in subcritical regime channels (Henderson, 1961). The existing paved reaches of the Mission Creek channel are designed to flow under supercritical regime conditions, while the natural reaches flow under subcritical regime conditions. Widening of the channel under bridges with supercritical flow normally will result in a lowering of the water surface profile, provided the transition upstream to the width expansion is smooth and uniform. Conversely, narrowing of the channel under supercritical flow normally will result in a rise in the water surface profile.

Deepening of a supercritical channel with no widening will result in a lowering of the water surface profile, unless (and this point is highly important) there is a following rise in the channel invert downstream. If the rise is greater than a critical amount, the supercritical flow profile will be ‘drowned’ out and a hydraulic jump will occur within the deepened channel section. If no rise occurs, then the water surface profile will reestablish a uniform supercritical regime in the downstream channel. Conversely, deepening of a subcritical channel will normally result in a rise in the water surface profile. When the subcritical channel regains its previous slope in the following rise in the invert, the water surface will fall slightly as the flow regains its velocity head.

In this study, bridge modifications were intentionally limited only to deepening, with and without a continued deepened section downstream of the bridge. In Alternative 1C, additional deepening was analyzed at the Mission Street Bridge, since it appeared that this bridge was a significant cause of elevated water surface elevations. Widening was not considered within the scale of the median cost alternatives evaluated in this analysis. Widening of the bridges within the Mission Creek channel is expected to be quite costly, likely pushing any widening alternative well beyond the $7.5 million cost limit of a typical US Army Corps of Engineers Section 206 project.

3.9 Channel Transition Hydraulic Modeling Results

Several channel transition configurations were evaluated in this study, as discussed in Section 3.5 above. In particular, an extension of the channel thalweg deepening downstream of Canon Perdido to the point where the new thalweg would meet the existing channel thalweg was analyzed in Alternative 1C. Refer to the cross sections and profiles illustrated in Section 3.5 above for detailed results of the sediment transport characteristics in transition areas.

Section 4 – Sediment Transport Modeling

4.1 Introduction & Methodology

A number of past researchers have documented sediment transport processes in steep mountain streams with average slopes similar to that which we find in the Mission Creek channel, especially in the reaches above the concrete paved channels. The upper reaches generate the majority of large size gradation materials during flood events, and the steep channel slopes enable the stream to carry much of the material as bed load or wash load nearly continuously to the estuary at the Pacific Ocean. Past studies have effectively characterized the typical morphology in case studies. In general, steep streams fall into four classes, all of which can be defined by a combination of average bed slope, roughness element size, and relative submergence of bed features (Bathhurst, 1982). Three of these classifications have been defined in terms of hydraulic roughness, with the fourth defined as "boulder stepped-pool." Small scale roughness occurs in channel with slopes greater than about 0.1 percent, and relative submergence of roughness elements of greater than 15. Relative submergence is measured as the ratio of depth to mean sediment element height. Intermediate scale roughness occurs in streams with slopes generally greater than about 0.4 percent, and relative submergence of roughness elements between 4 and 15. Large scale roughness occurs in stream with slopes generally greater than 0.4 percent but less than about 5 to 10 percent, and relative submergence of roughness elements of less than 4. Stepped-pool streams generally occur with relative submergence of roughness elements of 1 or less (i.e., boulder height is roughly the same as depth, or even exposed during large flows), and slope greater than 5 to 10 percent. Certainly, some examples within each classification do not adhere strictly to these limits on slope and relative roughness, but these are considered to be anomalies.

When relative roughness within the wetted perimeter is reduced significantly in steep streams, such as would be the case within the paved concrete channel sections, the energy dissipation occurring in pools and riffles is decreased proportionally or entirely eliminated. As a result, average flow velocity is increased, and the channel bed may degrade in response to increased boundary shear at the bed. In the case of Mission Creek, degradation within the concrete sections is prevented by the concrete apron structure. In most natural steep streams, the additional factor of imbrication or structural matrix development of large bed elements (Whittaker, 1987), may influence the stability of the bed. Large elements such as boulders in these types of streams may develop a structural matrix in response to their relative placement to one another. Their inherent stability is enhanced by this matrix, and enables them to remain stable over a wider range of discharges. The proposed channel deepening and thalweg roughening measures for the paved Mission Creek channel includes structural placement and anchorage of such large roughness elements as part of project construction. Additionally, degradation of the proposed constructed channel will be prevented by the structural design of the underlying boulder matrix and structural concrete base materials. Natural response of the sediment transport processes to such large scale roughness elements may include reduction in bed shear as discussed above, with resulting deposition of bed load materials. A key element in the design of the proposed fish passage modifications will be to ensure that average sediment transport will be maintained at the current sediment bedload inflow rates over the life of the project, without excessive areas of deposition within the concrete channel reach.

To enable effective fish passage through the concrete channel reach as proposed, the effective hydraulic roughness will be increased as discussed above. The embedded large boulder matrix will be selected and placed such that relative submergence at the maximum desired fish passage discharge will fall within the range of 1 and 3 (i.e., average depth of flow between 1 and 3 times the exposed height of boulder elements). This submergence ratio is equivalent to “large scale” roughness, as described in Bathurst (1982). In addition, the size range of the embedded large boulders will be selected such that they are not likely to be entrained in typical sediment transport processes (Whittaker, 1987), and thus would be expected to remain resistant to movement should they become dislodged from the structural anchorage system. Over time, some wear on the embedded roughness boulders would be expected, roughly commensurate with natural wear one might observe on the grouted riprap features currently in place at transition sections of the existing channel. Replacement or reconstruction of some of these elements over time would be expected. A specific wear rate to be expected was not identified in this study, but would be evaluated in future engineering investigation.

The principles described above have been put into effective use in a number of stream channels, especially within the Pacific Northwest US and Canada, to restore the riffle-pool structure characteristic of streams which have been modified, some by anthropogenic disturbances (Walker, 2004). Good examples of successful application of roughness increase to effect reconstruction of riffle-pool structure exist, as discussed in Walker (2004) and in Newbury (1995). The proposed design of the channel deepening and long-term stabilization measures within this report follows after these theoretical and practical examples.

4.2 Sediment Transport Model Basis

The US Army Corps of Engineers’ sediment transport computer model HEC-6 was utilized to evaluate transport of bed load gradations through the project reach. The Los Angeles District of the US Army Corps of Engineers previously developed a HEC-6T sediment transport model to simulate the base line condition. HEC-6T is the same basic modeling code as HEC-6, with added graphics interface and output modules. The Corps model cross sections and sediment input data provided the basis for the HEC-6 model used in this study to evaluate the various channel modification alternatives.

HEC-6 is a one-dimensional, steady state water surface profile model similar to HEC-RAS, except that it also calculates the sediment transport capacity available at each cross section throughout the study reach, in addition to providing the calculated water surface profile and flow velocity. For each cross section in the model, HEC-6 first calculates the hydraulic characteristics, based on the steady state discharge at a specified time step. From that data, the model calculates the potential transport capacity for all specified sediment gradations incoming to that cross section from the section immediately upstream adjacent to it. The model determines whether deposition or scour will occur at that particular cross section, and adjusts the channel bed elevation, within the lateral limits specified by the modeler, upward or downward as necessary to prepare the model geometry for the next time step and adjusted steady state discharge value. In this stepwise fashion, HEC-6 calculates a resultant bed elevation and gradation for every cross section in the model at each time step the user specifies. Transport functions and various coefficients can be varied by the user to adjust the model's predicted results to best approximate observed or estimated bed changes in response to recorded storm events or annual flow records.

Since HEC-6 was originally developed to evaluate an average annual deposition or scour, it must be carefully implemented when evaluating single storm events. As described above, the time step must be carefully selected to avoid computational instabilities. In addition, the HEC-6 model is incapable of calculating the effects of any overbank or in-channel hydraulic storage capacity that might attenuate flood discharges or change the basic one-dimensional routing assumed in the stepwise calculation. Within these operational limits and in the hands of a competent user, HEC-6 can be a very useful tool for evaluating channel modification proposals such as the Mission Creek channel analyzed in this study.

In this study, the previous Corps model was used primarily to establish inflowing sediment load and cross section geometry for the base condition. To these data the Corps model added the desired single storm event hydrology, in this case a flood event very near the flow rate that would fill the existing natural soft-bottom channel reach to capacity, roughly equivalent to an observed calibration event which occurred in March 2001. The estimated peak discharge of about 1100 cfs for this March 2001 event is near the 2.5 to 3 year flood event. Larger flood events were not modeled with the HEC-6 computer model, as flow would have left the natural channel reach and gone out of banks, yielding inaccurate transport calculations and poor sediment deposition and scour estimates. The effects of larger flood events on sediment transport characteristics would likely be best evaluated in a physical scale hydraulic model, as discussed in the Recommendations section below (Section 7.2).

4.3 Sediment Transport Model Development Criteria

4.3.1 Sediment Size Gradations

Bed sediment size gradations were selected directly from the Corps' previous HEC-6T model, based on bed sediment samples taken by the Corps in the previous study from the natural reaches upstream and downstream of the paved sections. Sediment size ranges varied from very fine sand (VFS) ranging from 0.0625 mm to 0.125 mm in diameter to small boulders (SB) ranging from 256 mm to 512 mm in diameter. Silt and clay transport were not considered, as discussed below. Medium boulders and larger particles greater than 512 mm in diameter also were not considered, as the proportion of total transport volume comprised of these largest particles is several orders of magnitude smaller than that of small boulders. For the sake of simplicity, the bed gradation for each cross section is not provided here, rather only several representative samples at several cross sections through the study reach. These sediment size gradation curves (Figures 4.2 through 4.4) are copied directly from the previous Corps modeling report, and are representative of bed samples collected at the locations identified Figure 4.1 (COE, 2004).

4.3.2 Bedload Sediment Transport Function

For this modeling exercise, we selected the same combination of the Toffaleti and Meyer-Peter Mueller transport functions as the previous Corps study, for it has proved most appropriate for streams in which the bedload composition is primarily gravel sizes and larger, with sand sizes comprising a relatively small, but noticeable, percentage of the total bed composition. Most other transport functions were originally developed and empirically verified for sand bed streams, which is not appropriate for the Mission Creek Channel. In steep streams such as Mission Creek, most small sediment size particles are swept entirely through the reach and do not contribute significantly to bed load deposition or scour. Although these size ranges and their propensity to deposit or scour at each cross section are calculated by the HEC-6 model, the resultant calculations support the fact that the smaller sizes are primarily 'wash load' and remain fully suspended in the water column entirely through the reach for modeling purposes.

4.3.3 Bedload Sediment Transport Inflow

Actual measurements of bedload sediment inflow discharge have not been collected for Mission Creek. In this study, we assumed, as the Corps' previous study also assumed, that sediment transport equilibrium occurs within the sediment supply reach upstream of the paved channel sections. We assumed, as did the previous Corps modelers, that observed bed sediment size gradations reasonably reflected the relative proportions of bed sediment discharge for various size ranges. The sediment inflow discharge rating curve shown in Figure 4.5 is copied from the previous Corps modeling effort for reference.

4.3.4 Sediment Transport Model Sensitivity

The previous Corps study analyzed the sensitivity of the sediment transport model to variations in sediment inflow, using factors of 25% greater or less than assumed inflow, and 50% greater or less inflow. The Corps concluded that the model was relatively insensitive to variations in sediment inflow through the paved reaches, and only moderately sensitive to sediment inflow variations through the natural reaches. No further sensitivity evaluation was conducted in this study. Comparison of the bed elevations in the Mission Creek channel following several flood events in 2001 indicated this sensitivity analysis conclusion was appropriate.

4.4 Existing Channel Sediment Transport Modeling Results

Expected sediment deposition in the existing channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.6. Net bed change is represented in Figure 4.7. Note the lack of significant deposition in the vicinity of all bridges except just downstream of, and under Canon Perdido. The hydraulic cause of the calculated deposition at Canon Perdido is discussed more thoroughly above in Section 3. To summarize, the downstream hydraulic control created by the natural channel causes a regime transition in the vicinity of the Canon Perdido Street bridge from supercritical flow to subcritical flow. When the flood hydrograph begins to decline, the hydraulic jump created within this transition moves progressively upstream through the bridge. As the flood hydrograph falls further, materials still in transport from upstream reaches of the concrete channel begin to drop out of the flow and deposit near Canon Perdido. Because the capacity for sediment throughput of the paved channel is so much greater than the natural channel, sediment inflow from the upstream natural reach decreases, while any material within the concrete reach continues downstream to Canon Perdido. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach for the existing channel is shown in Figure 4.8 in Appendix D.

4.5 Alternative 1A Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 1A channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.9. Net bed change is represented in Figure 4.10. Note the lack of significant deposition in the vicinity of all bridges except Canon Perdido. The hydraulic cause of the calculated deposition at Canon Perdido is discussed above in Section 3, and can be summarized as the slowing of flow velocity at the exit section of the bridge and transition through to the subcritical regime of the downstream natural channel. This effectively results in bed sediments dropping out of transport just downstream of, and under the bridge in Alternative 1A. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 1A is shown in Figure 4.11 in Appendix D.

4.6 Alternative 1B Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 1B channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.12. Net bed change is represented in Figure 4.13. In contrast to Alternative 1A, note that there is significantly more deposition in the vicinity of the bridges, resulting from the over-deepening implemented at each bridge crossing. The hydraulic cause of the calculated deposition at each of the bridges is discussed more fully on Section 3 above. In supercritical flow channel, such as would be the case in the paved reaches, deepening of the channel causes a decrease in flow velocity and an increase in water surface elevation. This reduces the capacity of the flow to carry large size bed materials, causing such particles to drop out in these areas. Confirmation of this phenomenon should be made in the physical scale model of the channel modifications. In practical terms, the proposed deepening may or may not result in the typical supercritical flow characteristics described above. It may be the case that the flow through the bridges actually is subcritical over the roughened channel portion and supercritical (or nearly so) over the paved concrete apron. Such complicated flow regimes can only be accurately simulated in a physical scale model. Similar deposition in the vicinity of the Canon Perdido bridge as discussed above for Alternative 1A was noted as well. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 1B is shown in Figure 4.14 in Appendix D.

4.7 Alternative 1C Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 1C channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.15. Net bed change is represented in Figure 4.16. In contrast to Alternative 1A and in agreement with Alternative 1B, note that there is significantly more deposition in the vicinity of the bridges, resulting from the over-deepening implemented at each bridge crossing. The hydraulic cause of the calculated deposition at each of the bridges is discussed above, and need not be repeated here. Similar, but less, deposition in the vicinity of the Canon Perdido bridge as discussed above for Alternatives 1A and 1B was noted as well. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 1C is shown in Figure 4.17 in Appendix D.

4.8 Alternative 1D Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 1D channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.18. Net bed change is represented in Figure 4.19. In contrast to Alternative 1B and 1C, and in agreement with Alternative 1A, note that there is less deposition in the vicinity of all the bridges except Canon Perdido. More deposition was predicted in the vicinity of Canon Perdido than was the case with Alternative 1A, primarily the result of the overall deeper channel section and no transition downstream through the higher thalweg elevations of the downstream natural reach. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 1D is shown in Figure 4.20 in Appendix D.

4.9 Alternative 1E Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 1E channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.21. Net bed change is represented in Figure 4.22. In contrast to Alternative 1B and 1C, and in agreement with Alternatives 1A and 1D, note that there is less deposition in the vicinity of all the bridges except Canon Perdido. More deposition was predicted in the vicinity of Canon Perdido than was the case with Alternative 1A or 1D, again primarily the result of the overall deeper channel section and no transition downstream through the higher thalweg elevations of the downstream natural reach. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 1E is shown in Figure 4.23 in Appendix D.

4.10 Alternative 2 Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 2 channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.24. Net bed change is represented in Figure 4.25. There was significantly more deposition noted throughout the length of the modified paved reaches with Alternative 2 compared to Alternative 1A, 1D, or 1E. The additional width of the roughened channel, reduced average flow velocity, and lack of smooth concrete apron to provide increased conveyance during flood events contributes to the calculated reduced efficiency of sediment transport through the Alternative 2 study reach. The hydraulic causes of the calculated deposition characteristics are better and more thoroughly described in Section 3 above. At moderate flows such as this modeled channel capacity flood event, Alternative 2 would be expected to flow within subcritical regime as a result of the higher effective channel bed roughness. The result is increased deposition at nearly all cross sections. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 2 is shown in Figure 4.26 in Appendix D.

4.11 Alternative 3 Sediment Transport Modeling Results

Expected sediment deposition in the proposed Alternative 3 channel configuration following the modeled channel capacity discharge flood event is shown on the profile in Figure 4.27. Net bed change is represented in Figure 4.28. There was significantly more deposition noted throughout the length of the modified paved reaches with Alternative 3 compared to Alternative 1A, 1D, or 1E. The additional width of the roughened channel and the reduced average flow velocity results in some deposition throughout the study reach. However, the expected nonuniform sub- and super-critical flow regime in the vicinity of the transition between the roughened channel bottom and the smooth concrete apron of the enlarge channel portion would be expected to improve flood flow conveyance through the study reach. The hydraulic causes of the calculated deposition characteristics are better and more thoroughly described in Section 3 above. At moderate flows such as this modeled channel capacity flood event, Alternative 3 would be expected to flow mostly within subcritical regime, at least over the roughened channel portion. Net deposition during this modeled channel capacity flood event in the vicinity of Canon Perdido and elsewhere throughout the project reach with Alternative 3 is shown in Figure 4.29 in Appendix D.

Section 5 – Operation & Maintenance

5.1 Disease Vector Control Issues

The City of Santa Barbara has noted that there are issues to be addressed concerning potential stagnant water pools and enhancement of mosquito populations. The presence of West Nile virus in California is a very real threat to the resident human population, and disease vector control efforts have targeted the reduction or elimination of standing water as a significant factor in the control of this disease. This concern may render those alternatives that result in standing water or long-term pooling of water less acceptable. In this study, the alternatives that appear to potentially contribute to the presence of standing water include Alternatives 1B and 1C, where over-deepened sections under bridges might permit such retention. There are several potential methods for reducing the presence of standing water in the deepened channel portion, including provision of porous media forming part of the structural invert of the channel, or drains regularly spaced on the channel bottom to permit absorption of standing water into groundwater. However, more investigation into the groundwater characteristics throughout the paved reaches must be accomplished to determine the viability of such measures. In areas where groundwater pore pressure during dry periods was positive, drains would not likely be feasible, as groundwater inflow would cause standing water to persist.

There are a variety of chemical and biological controls on mosquito populations that could be investigated. However, that approach is well beyond the scope of this study and should be evaluated as part of future engineering design development.

5.2 Water Quality Issues

Water quality impacts associated with natural bottom stream channel corridors have generally been positive (URS, 2002). Natural channels generally will support highly effective annual and semi-annual vegetation with high filtering capacity for pollutants, including organic nutrients. One of the options the City of Santa Barbara has considered for improving the water quality of inflows into the nearshore marine environment includes development of natural vegetation in stream channels to accomplish this filtering process (City of Santa Barbara, 2002). The proposed deepened channel alternatives proposed in this study will serve to support some annual vegetation growth on the natural sediments that will deposit throughout the roughened channel bottom in the modified reaches during the course of normal hydrologic cycles. Although not explicitly evaluated in this study, the effect of such vegetation on water quality may be positive. However, more definitive investigation of this potential benefit should be made during more detailed engineering evaluations in the future phases of engineering for the Mission Creek project.

5.3 Sediment Removal and Vegetation Management

As discussed above in the description of each alternative, it is possible (and even probable) that periodic maintenance efforts will require the removal of excessive sediment deposition at selected locations throughout the modified channel reach. The sediment transport model results suggest that the area in the vicinity of the Canon Perdido bridge would experience the most significant deposition. Intuitive observation of the existing channel suggests that sediment will tend to deposit here, beginning at the natural channel interface with the paved channel. The sediment transport model calculated that considerably more deposition would occur in this area with Alternatives 1B, 1C, 2, and 3 than with Alternatives 1A, 1D, and 1E. However, with the addition of the deepened channel extension downstream to DeLaGuerra Street, a considerable reduction in deposition occurs in this area, suggesting that maintenance efforts would be decreased by inclusion of this extension work. The existing channel condition transport model shows similar results, with only small amounts depositing in the natural channel reach downstream of Canon Perdido. This would suggest that the channel has achieved some form of transport stability, given its present configuration. Areas in the immediate vicinity of bridges would also likely experience some deposition, although not large volumes, and restricted primarily to that area within 50 to 100 feet of the upstream face of each bridge. More detailed examination of the expected sediment removal maintenance efforts would be best approximated in the physical scale hydraulic model of the channel, as recommended in Section 7.2 below.

Section 6 – Engineering & Construction Costs

6.1 Introduction

Feasibility-level engineering and construction costs consist primarily of rough estimates of physical scale model verification testing, final design engineering, construction plans and specifications development, engineering through construction, and costs for initial construction, contractor's overhead and profit, and escalation to the year 2010.

6.2 Conceptual Construction Cost Estimate Basis

Costs are estimated for the current year, and escalated at 3% inflation until 2010.

Construction cost contingency is estimated at +50% for feasibility engineering level costs. The cost contingency would be expected to decrease to perhaps 20% at the conclusion of the final design phase, which would be preceded by the physical scale hydraulic modeling design verification testing. As recommended by the City of Santa Barbara, construction cost estimates were increased by an additional factor of 40% applied before overhead, profit, and taxes, above those reported in Means (Means, 2006) to account for local costs in the Santa Barbara area. This "Santa Barbara factor" increases the estimated costs considerably by compounding through the contingency cost amount.

6.3 Conceptual Cost Estimates

Details of preliminary engineering costs for each proposed alternative are provided in the Tables section at the end of this text. Final design and construction plans and specifications engineering costs are estimated at 12% of total construction costs. Engineering during construction costs are estimated at 5% of total construction costs. Physical scale hydraulic modeling costs are estimated at about $275,000, assuming both a technical detailed model and a small scale demonstration model are to be constructed and tested. The rough preliminary costs (for year 2006, not including escalation to future years) are summarized below:

Alternative 1A – 2 Feet Channel Depth Right Half Only:

Construction costs (including 50% contingency and local cost factors) $8,772,420

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $1,499,400

<u>Alternative 1B – 2 Feet Channel Depth + Bridge Over-Deepening Right Half Only</u>:

Construction costs (including 50% contingency and local cost factors) $9,525,597

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $1,619,352

<u>Alternative 1C – 2 Feet Channel Depth + Bridge Over-Deepening + Canon Perdido D/S Transition Right Half Only</u>:

Construction costs (including 50% contingency and local cost factors) $9,569,521

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $1,626,778

<u>Alternative 1D – 4 Feet Channel Depth Right Half Only</u>:

Construction costs (including 50% contingency and local cost factors) $10,809,291

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $1,837,550

<u>Alternative 1E – 8 Feet Channel Depth Right Half Only</u>:

Construction costs (including 50% contingency and local cost factors) $14,942,861

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $2,540,311

<u>Alternative 2 – 3 Feet Channel Depth Entire Apron Width</u>:

Construction costs (including 50% contingency and local cost factors) $12,588,843

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $2,140,102

<u>Alternative 3 – 3 Feet Channel Depth Entire Apron Width + Left Overbank Retaining Wall & Apron</u>:

Construction costs (including 50% contingency and local cost factors) $25,620,678

Final design engineering, physical modeling, plans and specifications development, and construction engineering costs $4,355,400

Section 7 – Conclusions & Recommendations

7.1 General Conclusions

Based on the water surface profile and sediment transport modeling accomplished in this study, modification of the concrete paved channel sections of Mission Creek can meet the specified fish passage criteria. Although the relative effectiveness of the channel modification alternatives evaluated in this study in meeting the passage and flood control objectives varies between the different proposed treatments, it is apparent that a feasible design is possible. The range in construction and engineering costs associated with each alternative evaluated in this study is not large, compared to the difference between these and the full channel restoration alternative previously evaluated in the Penfield and Smith, and Corps of Engineers studies. None of the alternatives presented in this study will provide fully natural channel conditions through the paved reaches of Mission Creek. However, for the purposes of meeting the immediate fish passage objectives, all will achieve passage through this reach to upper watershed areas. The choice of alternatives to carry forward is ultimately up to the local project sponsors such as the City of Santa Barbara and the Santa Barbara County Flood Control District. The information presented in this report attempts to fill in the missing data and carry the typical US Army Corps of Engineers-funded study forward to the final design engineering level.

Of the seven channel modification alternatives evaluated in this study, two stand out as relatively attractive from a passage effectiveness, operation and maintenance, and construction cost perspective. Those two would be Alternatives 1D and 1E. Both alternatives fall into the mid range of construction costs, both maintain the channel's effectiveness as a flood control facility, both can be maintained relatively easily using the remaining concrete apron portion as an access roadway, and both meet the fish passage objectives without significant adverse sediment deposition. The next phase of engineering analysis should examine closely the feasibility of over-excavation under the bridges in particular. Alternative 1E proposes to excavate as much as 10 feet below the existing apron elevation, while Alternative 1D proposes only about 6 feet below the existing concrete apron elevation. The depth to which the underlying material may be safely excavated is dependent on the stability of the existing bridge abutment structures. Structural engineering for support during construction will be more critical for Alternative 1E than for 1D, and should be accomplished in the next phase on engineering analysis.

7.2 Recommendations for Continuing Engineering Studies

We recommend that the future phases of engineering design include the following steps:

Physical Scale Modeling – Future study should include a physical scale hydraulic and sediment model of the preferred channel modification alternative selected from the list proposed and evaluated in this study. We recommend that the physical scale model be constructed in such a fashion as to permit simple replacement of one alternative configuration readily with another. For example, the model test bed should be designed such that any configuration between Alternative 1A and 3, and the existing channel conditions can be installed and tested. The model should include the capability of inclusion of moveable bed sediments, with associated scour and/or deposition at selected locations. In addition, the model test bed should be of sufficient length to include channel deepening extension downstream of Canon Perdido at least as far downstream as DeLaGuerra Street, since Alternatives 1C and 1E showed significant channel maintenance benefits from that feature. The physical model may be tested with and without the assumption that the US Army Corps of Engineers' Lower Mission Creek Flood Control Project will be built, and with and without the assumption that the Cabrillo Boulevard pedestrian and bicycle bridge will be raised. Such assumptions may impact the surface water elevation within the fish passage modification project reach. The model may be constructed in one or more segments, to reflect the specific locations of interest. In addition, the model could be constructed in such a manner as to enable shipment of the entire model test bed to Santa Barbara for demonstration purposes. The modeling work should result in recommendation of a final preferred modification configuration to meet the fish passage, sediment transport, operation and maintenance, and flood control objectives of the City and County.

60% Design Level Engineering Analysis – Future study following the physical modeling should include an approximately 60% design level analysis of the preferred channel modification selected during the physical scale modeling effort recommended above. The analysis should include structural design of the proposed channel modifications, structural design of the bridge transition sections, and structural design of temporary construction support of the existing bridge structures. In addition, further evaluation of the water quality enhancement design criteria should be made, similarly for the disease vector control issues.

90% Design Level Engineering Analysis – This phase of engineering should bring the preferred channel modification alternative to the 90% level. All features of the proposed modification design should be fully defined at this level, construction access, time schedule, debris disposal, and permit issues should be fully resolved at the conclusion of this phase of engineering.

Construction Plans and Specifications – This phase of engineering should develop the final engineering designs into biddable construction documents, suitable for open bid by construction contractors. The products should include all necessary permits, construction plans for all features of the proposed channel modifications, and detailed specifications.