PT 46

The San Clemente Dam Removal Option
A Review of Benefits to Steelhead Fisheries
and
Approaches to Sediment Management

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1.0 Introduction

The San Clemente Dam (SCD) is located on the Carmel River, in Monterey County, California, approximately 18 river miles upstream from the Pacific Ocean (Figure 1). Nearly filled with sediment, SCD is an 85 foot high thin arch concrete dam that has been determined to be a seismic hazard by the California Dept. of Water Resources (DWR), Division of Dam Safety. The evaluation of alternative measures for eliminating that hazard is the subject of an ongoing environmental review by regulatory agencies, including DWR, California Department of Fish & Game (CDFG), Monterey Peninsula Water Management District (MPWMD), Monterey County Water Resources Agency, and the National Marine Fisheries Service (NMFS). The preferred alternative of California-American Water Company (Cal-Am), the dam owner, is to retrofit and strengthen the aging dam with steel and concrete. Decisions to appreciably modify the existing project will require a Clean Water Act, Section 404 permit from the Army Corps of Engineers (ACOE) and formal section 7 consultation by the NMFS. Modifications to the project may also require permits from the State Water Resources Control Board (SWRCB).

Completed in 1921, the 85 foot high SCD originally impounded about 2100 acre-feet (AF) of water with flashboards in place. Today that impoundment is nearly full of sediment. Current storage capacity of the project is less than 150 AF. The San Clemente Reservoir provides no flood storage, no hydroelectric generation, and no significant water supply. Other than serving to hold back roughly 2000 AF (~of stored sediment, the dam functions only as a water diversion point for Cal-Am. The SCD is a principal site where water is diverted during high flow periods from the Carmel River to Cal-Am's Carmel Valley Filter Plant.

In addition to serving as the principal water source for the Carmel Valley, the Carmel River currently supports the largest run of steelhead trout within the South-Central California Coast Evolutionarily Significant Unit (ESU), a biological unit of steelhead that was listed as threatened under the Endangered Species Act (62 FR 43937) in August 1997. In February 2000, the Carmel River was listed as Critical Habitat for steelhead (65 FR 7764). The annual run of steelhead in the Carmel River historically sustained a popular fishery that supported over 10,000 angling hours per year, the second largest steelhead fishery south of San Francisco (Snider 1983). Steelhead returns to the Carmel River are now greatly reduced from historic levels – recent adult returns to the SCD are estimated to be in the hundreds, whereas, historic returns to the river have been estimated to be as high as 12,000 to 20,000 adult fish (Snider 1983; CACSS 1988). Given this decline and the need to recover steelhead populations, potential opportunities for achieving significant enhancements to steelhead populations must be evaluated carefully. The evaluation of alternatives for addressing the seismic hazard of SCD provides an important opportunity for achieving potential long-term enhancements and recovery of steelhead in the Carmel River.

Like most dams, the SCD is a significant obstacle to migratory fishes such as steelhead. The dam and its impoundment also significantly affect riverine habitats for steelhead and other aquatic species. It is generally agreed that steelhead would be appreciably benefitted if the SCD and all of its impounded sediment were somehow immediately removed from the river. However, sediment management is a costly, complex problem, and unless handled carefully dam removal incurs substantial risk from the downstream movement of sediment and the associated potential for increased flooding.

This paper concerns the importance of carefully evaluating the option of removing the SCD. The current, preferred alternative of Cal-Am is to fortify the old dam with substantial additional steel and concrete. Under that scenario, the SCD would continue to have little purpose other than to hold back nearly 2000 AF of sediment for another 50+ years while serving as one of the many water diversion points along the river. By retaining the dam, the restoration and enhancement of many miles of stream habitat would be unrealized, passage for migratory steelhead would continue to be adversely affected, and the effects of sediment releases from the sediment filled impoundment will continue to be an unresolved problem. Section 2 of this paper provides additional discussion about the fisheries related benefits of removing the SCD. Section 3 discusses conceptual approaches to managing the impounded sediment and removing the dam, while limiting the risk to downstream property owners. Section 4 explores the issue of costs associated with dam retention and dam removal. Section 5 provides a summary and recommendations for addressing information needs for evaluating the dam removal alternative for the SCD Seismic Retrofit Project.

2.0 Benefits of Dam Removal to Steelhead and Other Natural Resources

The removal of the San Clemente Dam and its reservoir offers an historic opportunity to take a major step in the restoration of the Carmel River's ecosystem and its steelhead fishery. Dams and reservoirs are recognized to cause many detrimental effects to river ecosystems and their fisheries. Those effects include curtailing transport of the natural range of sediment sizes, elevating downstream temperatures, blocking downstream drift of aquatic insects, impeding or delaying the migration of fish both upstream and downstream, and replacing natural streams with lacustrine habitats or inundating them with accumulated sediments.

The retrofit and notching alternatives for the SCD would keep the dam in place, thereby allowing the reservoir to act as a sediment sorting mechanism, with only sand and finer particles passing through the system. The lower river will continue to be starved for coarser sediments such as gravels and cobble. The trapping of coarse sediments by the dam will continue to adversely affect steelhead spawning and rearing habitat in reaches below the dam. The remaining habitat will be further degraded by the releases of sand and finer sediments flushing over the sediment-filled dam. Elevated levels of sand and fines have been known to be a factor contributing to the decline or loss of salmon and steelhead populations (Cordone and Kelley,1961). Increased levels of fine sediments have been shown to have direct impacts on salmonid behavior, physiology, growth, reproductive success, and the availability of food (Bjornn et al. 1974, 1977; Sigler 1984, 1988; Waters 1972).

The modern, ecologically-oriented approach to environmental management is away from single species and single impact mechanism analysis in solving complex environmental problems (Bisson et al. 1997). Increasingly scientists and environmental managers are coming to the conclusion that the most effective means of protecting and recovering species is by restoring ecosystems to conditions that most closely mimic the natural physical processes that create the dynamic conditions that maintain diverse and healthy habitats. A sufficiently natural episodic throughput of bed material is crucial for the maintenance of diverse and healthy habitats for river biota and the food web supporting fish species.

2.1 Current Impacts to Steelhead Habitat Downstream from the San Clemente Dam

The lack of sediment transport has caused channel incision, bed armoring, a decrease in channel complexity, overly steep banks, diminished riparian vegetation, and a lack of spawning gravels in the river section between SCD and Tularcitos Creek. The impacts to the fishery from these conditions include the loss of edge-water habitats for rearing fry, reductions in velocity refuges for rearing fish, decreased vegetative cover, less riffle and pool habitat for rearing steelhead juveniles, and a less diverse insect prey population. In addition, the increased solar radiation of the reservoir and delta deposits have increased downstream temperatures. Summer water temperatures greater than 75° F (MPWMD 1997, 1998, 1999) in the Carmel River below SCD are near the upper tolerance levels for steelhead. At these elevated levels, steelhead growth is reduced (Myrick 1999), and fish are more susceptible to disease (Inglis et al. 1993).

Incision of the channel contributes to lowering of the water table below the root zone of riparian vegetation. Lack of sediment deposition in the riparian areas affects soil composition, fertility and riparian flora successional patterns, essentially restricting vegetation to colonizing species and preventing mature seral stage trees from establishing. This, in turn, limits the recruitment of large woody debris to the channel, the amount of shade and insulation from ambient temperatures, the amount of overhead cover, and sources of prey items from riparian vegetation.

Stable channels containing stored sediments and large organic debris are more productive at every tropic level than either degraded channels devoid of sediments or channels that are aggraded and unstable (Everest et al. 1987). Sediment input, transport and storage affect channel shape, sinuosity, and the formation of riffles and pools (Knighton 1984). The diversity of habitat created by the mosaic of channel forms and substrates is partly a result of the sorting of sediment sizes, substrate scour, and sediment deposition. These channel forming processes occur at high flows when the channel features, such as bars, are maintained by the effective discharge, *i.e.*, the flow range that transports the greatest quantity of sediment (Knighton 1984).

Changes in sediment load affect the bed material size (Lisle 1982), and this can alter both the quality and quantity of habitat for both fish and benthic macroinvertebrates. Lack of sediment supply, as occurs below dams, results in a coarsening of the bed. The armored channel becomes narrower, straighter and deeper, thereby limiting the creation of diverse aquatic environments necessary for rearing fish. Because gravels preferred by salmonids are transported downstream without being replaced, fewer riffles and pools are formed. The result is decreased spawning habitat and decreased rearing habitat preferred by juvenile steelhead (Everest 1969; Bugert et al. 1991). Changes in sediment load can also reduce the diversity of habitat for benthic invertebrates. Without the scouring that occurs with mobilization of the bedload, there is a shift in the macroinvertebrate fauna to predator resistant forms such as case-building caddisfly larvae that are less available as prey items for rearing fish (Power et al. 1995). When bedload is naturally mobilized, caddisfly larvae and other predator-resistant grazing invertebrates tend to get ground up. This allows smaller more rapidly developing grazers such as larval midges and mayflies to increase in abundance, thereby enhancing food production for juvenile steelhead. In the absence of scouring, the food web supporting fish populations can collapse (Wooton et al. 1996).

Although elevated sediment levels can have a major impact on stream productivity, the effects may be short-lived, and fish populations may recover rapidly, if favorable stream conditions are restored (Winter 1990). The Carmel River below Tularcitos Creek demonstrates this point. Tularcitos Creek, the largest tributary of the Carmel River delivered over 100 AF of sediment to the Carmel River in the flood of 1995. That load was believed to have negatively impacted the fisheries of the Carmel River. However, by 2000, the 4.4 mile reach beginning 1.5 miles downstream from Tularcitos Creek had recovered and produced the highest densities and numbers of rearing juvenile fish ever sampled anywhere in the basin (MPWMD 1990-2000). Based on MPWMD sampling from 1995-1999, this 4.4- mile reach, produced 28 to 42 percent of fish rearing in the mainstem (Duffy 2000).

HEC-6 modeling results show that with removal of SCD, the amount of coarse sediment would increase, significantly changing the characteristics of the habitat downstream (Mussetter Engineering Inc.). The resulting accumulation of gravels would be beneficial to spawning and rearing fish and aquatic insect assemblages (Waters 1995).

2.2 Distribution of Steelhead Habitat in the Carmel River

Duffy (2000) identifies summer rearing habitat as the most critical limiting factor for the production of juvenile steelhead in the Carmel River. Three-quarters of the potential rearing habitat within the watershed occurs above SCD. Two-thirds of the potential spawning habitat occurs above the dam. Duffy (2000) states that "This data clearly presents the fact that steelhead must pass over San Clemente Dam for access to the majority of spawning habitat." Of the 37 miles of tributary spawning habitat available in the basin, 28.3 miles are above SCD. Of the 29.1 miles of potential tributary rearing habitat available in the basin, 23.9 miles occur above SCD. Mainstem rearing has 12.2 miles available above the dam and 7.8 miles below. These figures show that it is critical to promote and enhance steelhead passage to the majority of habitat that is located in the upper basin above SCD. Yet it is anticipated that there will be a worsening of passage problems at the dam and in the reservoir delta, with the accumulation of sediment in the reservoir and the anticipated need for sediment flushing that could affect fish ladder operations.

2.3 Passage of Steelhead over the San Clemente Dam

Dams, even those with fish passage facilities, are a primary cause of fish mortality. The series of dams on the Columbia-Snake River system kill an estimated 85 to 95% of migrating smolts on their way to sea, and between 34 to 57% of adults returning to spawn (Sims 1994). Individual dams are estimated to cause mortality rates of 5 to 10% of upstream migrating adults (Kaczynski and Palmissano 1993). Injuries that result from ladder passage are bruising and skin abrasions. Delay at dams is also an important factor in the survival and success of spawning adult steelhead. Delays can alter the migration timing and deplete limited energy reserves, thereby diminishing spawning success and contributing to mortality on the spawning grounds or soon after. Factors contributing to delay include: 1) the time fishes spend locating the ladder entrance, 2) the relative proportion of spill over the dam, 3) the amount of attraction flow to the ladder entrance, 4) the overall effectiveness of the fish passage facility, and 5) water quality. Fall back of fish having ascended passage facilities is documented to be another source of mortality and delay.

Passage over the San Clemente Dam is currently afforded by an antiquated fish ladder that at 68-feet is one of the highest in California. The ladder is estimated to pass 55% of the adult steelhead population of the Carmel River (Duffy 2000). This is a rough estimate based on a mechanical counter in the ladder, creel surveys and redd counts conducted by MPWMD. The accuracy of this estimate is unknown. This is a significantly lower number than what might be expected given the distribution of spawning and rearing habitat in the basin. The ladder has numerous structural and operational problems. The existing ladder is only passable at a narrow range of river flows. The ladder as it is currently built does not conform to modern fish passage facility specifications.

Modern fish ladder designs specify consistent 1 foot drops between pools and consistent pool sizes that effectively dissipate flow energy which in turn minimizes fish energy expenditures. In the existing ladder, 70% of the jumps between pools are 2.5 feet or greater with one jump over 3.5 feet. Existing pool sizes are effective at dissipating flow energy up to 3.5 cfs. This represents the maximum recommended ladder flow which in turn limits the attraction flow at the ladder entrance to 3.5 cfs. This attraction flow is inadequate considering the wide range of streamflows occurring during steelhead migration, the location of the ladder entrance relative to the base of the dam and the hydraulics created from flow over the dam. Exit conditions at the top of the ladder are poor because velocities are high and flow openings are small due to the structural configuration of the dam abutment. Ladder flow control is also limited for this reason creating inadequate conditions for fish passage.

With sediment soon to be passing over the dam, the ladder will become clogged with sediment at high flows and become impassable (Duffy 2000), requiring continual and difficult maintenance that will require shutting the ladder down after high flows, which is the same time fish would be attempting to use the ladder. Maintenance of the ladder in the future after high flows will cause additional delays for upstream migrating steelhead adults. Upstream migration of juvenile steelhead during summer has been shown to be an important component of the movements of rearing fish (Kahler et al. 2001). The ladder at San Clemente Dam has no potential for passing juvenile fish upstream.

2.3-1 Passage of Downstream Migrating Smolts and Kelts

The San Clemente Dam adversely affects smolts and kelts (post-spawning adults) that migrate downstream over the dam spillway. From the information presented in Ruggles and Murray (1983) there is the potential for increased injury or mortality from abrasion with the bottom of the plunge pool or from the mechanical forces of shearing effects within the turbulence caused by spill. The proposal to retrofit the dam with one main spillway and two auxiliary spillways will concentrate flows and require a deeper and larger plunge pool to dissipate the increased turbulence and shearing effects. Shearing effects, resulting from differences in velocity planes causing rapid deceleration or acceleration, may cause similar injuries as in free-fall conditions.. Sheering effects that occur in turbulence have received little study and are not well quantified, but high speed cameras have shown injuries can occur in a millisecond when juvenile salmon are subjected to a jet of water with velocities in excess of 9 m/s (Groves 1972). Sweeney and Rutherford (1981) reported delayed mortality of Atlantic salmon kelts subjected to drops of 18-meters.

Passage over dams also increases the potential for the predation of smolts because of delayed migration and disorientation from turbulence and back-rolls at the base of the spill column. Such locations often have concentrations of predators. Studies on the Snake River (Long et al. 1968) showed a mortality of 32% for juvenile coho salmon released into back-rolls. Steelhead smolts subjected to sheer stress at levels below that which caused injuries, suffered significantly higher rates of predation than control fish (Nietzal et al. 2000).

Fish that pass over spillways often suffer abrasions to the skin. These injuries can result from striking the base or face of the dam or from abrasions received on the floor of plunge pools with insufficient depth. Death may result from injury to the skin because of abnormal accumulations of fluid in tissues, loss of vital salts and plasma proteins, or penetration of pathogenic organisms.

2.3-2 Passage of Adult Steelhead Over the Accumulated Reservoir Deposits

With the dam remaining in place, sediment deposition will continue to aggrade the approximately one mile of stream above the dam, resulting in an unstable and increasingly braided channel after large flow events. Flows below 200 cfs create passage barriers in that delta. Maintenance of a channel for passage through the increasingly convex shaped reservoir delta deposits will be difficult. Steelhead generally migrate on the declining limb of these large flow events, precluding any time for mechanical reworking of the channel. The channel above the reservoir has had to be reopened mechanically in the past, and the location and number of impassable sites will only become more frequent and numerous in the future as the deposits continue to aggrade.

2.3-3 Passage of Smolts and Kelts Through the Reservoir

The downstream migration of smolts in the spring is a critical life history stage for steelhead. This out-migration generally occurs at the same time that kelts are returning to the ocean. In the Carmel River, the timing of these out-migrations are critical, given that the flow in the lower river ceases in late spring or early summer as a result of groundwater pumping in the river's alluvial aquifer. The artificially reduced spring flows cause the lagoon at the river mouth to close earlier than it would naturally. The delay in smolt and kelt out-migration caused by the reservoir, in concert with the drying of the lower river and early closing of the lagoon cuts short the run timing of the Carmel River steelhead population. Some individuals may become stranded in areas of the river that will subsequently dry up; others may become trapped in the lagoon during the summer and fall when temperatures can exceed lethal levels (MPWMD 1998). Studies on the Columbia River show out-migrating smolts mill about, cross the reservoirs and journey upstream as a result of encountering dams (Johnson and Moursand 1999; Venditi et al. 2000). Also, if stratification occurs in the reservoir before the steelhead out-migration is complete, fish can become trapped below the warm surface layer and subjected to predation for an additional year before migrating the next spring. Delayed migration can cause steelhead to residualize (Raymond 1979). Residualized fish in stratified reservoirs can have poor survival due to the marginal habitat conditions available in the strata between the warm epilimnion and the oxygen deficient hypolimnion.

2.4 Long-Term Detrimental Effects of the Dam Retrofit and Notching Alternatives

Alternatives to keep the dam in place with releases of sediments through sluice gates or notching will perpetuate indefinitely detrimental effects to the river's ecosystem and fisheries resources. The ability to manage sediment through the use of sluice gates is limited. Ten years of the average annual 17 AF of sediment could be built up and added to a small episodic event of 150 AF, resulting in a 300+ AF release of fine sediment. The dam retrofit plan anticipates managing stored sediments by releasing them only in wet years during early and mid-season storms, and using later season storms as flushing flows to remove the released sediments from the system (Duffy 2000). Unfortunately, there is no way of predicting whether subsequent flushing flows will be available.

The ladder would be impassable during sluicing events because of the lowered reservoir levels, thereby delaying the passage of adult fish. With the dam notching alternative and a reconfigured ladder, the ladder may also become chronically filled with fine sediments. The flushing of sediments through sluice gates may also directly impact downstream migrating adults and juveniles passing through the sluice gates. Fallback of adults migrating upstream may also be increased during sluicing events. The fines and sand in turbulent suspension in the plunge pool would cause further delays in the ability of fish to locate the ladder entrance.

High flows in wet years would be the principal events when the sluice gates would be releasing large amounts of sediment. Unfortunately, this would also be the same years when the river has the best ability to rear large numbers of juveniles. Thus, the best years of production would be negatively impacted throughout the life of the project by delaying and impairing adult migrations and by introducing high levels of fine sediment that adversely affect downstream spawning and rearing habitats.

With retention of the dam, the downstream channel morphology, riparian zone, and resulting fishery habitat would continue to be negatively impacted by continued channel incision. With bank hardening of over 50% of the lower river and rising, and the continued retention of gravel behind the dam, the supply of gravel would remain limited. The stream channel would become increasingly bimodal in distribution, with sand in the lower reaches and rubble in the armored channel of the upper reaches.

2.5 Use of San Clemente Reservoir for Water Storage

Retrofitting the dam and dredging the reservoir to restore a portion of the project's water storage capacity would not only maintain the adverse impacts to the downstream ecosystem, it would also prevent migration over the dam until the reservoir was refilled each year. The period of reservoir filling would vary from year to year; in dry years it could be for an extended period. The refilling period would also delay continuous river flow to the lagoon and the opening of the lagoon to the ocean. The entrance of steelhead into the river could be significantly delayed and could cause the loss of the early part of the steelhead run, thus further limiting the run timing and possible genetic diversity of the population. Additionally, the increased reservoir size could further delay smolts and kelts on their out-migration journey, subject the smolts to greater predation in the reservoir and cause some smolts to residualize to non-migratory stages.

2.6 The Value of Restored Habitat in the Reservoir and Delta

A dam removal alternative would restore productive spawning and rearing habitat in the reaches currently occupied by the sediment filled reservoir and its alluvial delta. This approximately one mile stretch of river has the potential to effectively increase available mainstem summer rearing habitat by about five percent. Based on an estimated production of one juvenile per lineal foot of stream and an adult return rate of one to six percent, this added rearing habitat has the potential to increase the population of returning adult steelhead by an additional 50 to 300 fish per year, which would increase the run size by roughly 10 to 50%.

2.7 Conservation of Steelhead Populations During the Dam Removal Process

If the dam is removed, the release of fine grained sediments would adversely affect downstream habitats for about 5 to15 years. The actual duration would depend on the river's hydrology and the rate at which the dam is incrementally removed. To preserve the steelhead run during this process and expedite recovery, a number of measures could be implemented. Most importantly, a trap and haul operation would need to be established. Steelhead could be trapped at a facility sited at the Old Carmel River Dam. Trapped adults could then be transported and released in unaffected reaches above San Clemente Reservoir where most of the rearing habitat and spawning habitat is located. A second measure might include repeating operations undertaken during the drought of the early 1990's when the lagoon mouth did not open to the ocean for several years and rearing habitat was limited. Captive broodstock were maintained at offsite facilities; adults were artificially spawned; and close to 200,000 juveniles were released into the Carmel River between 1991 and 1994. Additional rearing could also take place at the MPWMD rearing facility at Sleepy Hollow.

Although increased sedimentation could adversely affect steelhead habitat in downstream reaches in years immediately after dam removal, the long-term benefits of removing the SCD to Carmel River fisheries outweigh the short-term impacts. Short-term sedimentation associated with dam removal would not be catastrophic to Carmel River steelhead, because most steelhead spawning and rearing habitat is upstream from SCD. Furthermore, steelhead spawning downstream from the dam would have some capacity to cope with such impacts. Females will often perform test digging in several locations before selecting the site in which the egg nests are finally excavated. When excavating nest sites, salmonid species typically clean gravel substrates used for spawning. In Evans Creek, Oregon, a stream with a heavy load of granitic sands similar to the Carmel River, spawning activity by Chinook slamon decreased average fines smaller than 1 mm from 30% to 7% (Everest et al. 1987). Chum salmon of the Susitna River of Alaska, which has a high load of glacial till, select spawning sites in sloughs where the surface layer consists of 100% fine sediment. The salmon clean the surface until the fine sediment has been removed and the underlying gravel exposed (Vining et al. 1985). The ability of salmonid species to clean gravels was quantified by Kondolf et al. (1993), who found that regardless of the hydraulic slope, velocity, depth or shear stress, the amount of fines remaining in spawning gravels averaged 63% of pre-spawning concentrations.

Where conditions are generally unfavorable for redd construction another behavioral adaptation has been noted. In the Toutle River, coho salmon spawn on the apex of large mounds of volcanic sediments (Allen et al., unpublished manuscript). Similar mounds or dunes have been observed in chinook spawning areas of Oregon, Washington, and Idaho (Huntington 1985). Another adaptation used by steelhead on the Rogue River in Oregon was noted by Everest et al.(1987). Steelhead spawning in two different tributaries having similar size, flow characteristics, and spawner densities, but differing in sedimentation levels, dug redds 48% larger and 25% shallower in the more heavily sedimented stream. Females spawning in the more heavily sedimented stream spent more time and effort excavating redds to create favorable incubation conditions and buried their eggs less deeply.

3.0 Conceptual Approach to Removing San Clemente Dam

The removal of on-stream dams has been an important tool in the restoration of many stream ecosystems (Bednarek 2001). Since 1912 more than 465 dams have been intentionally removed nationwide; the vast majority of these cases occurred since 1980 (American Rivers et al. 1999). Most dam removal projects have been conducted for reasons of safety, economic consideration, or ecological restoration. Of the 465 cases reviewed by American Rivers et al., the average height of removed dams was about 21 feet. However, there were more than 40 dams that were 40 feet or taller, including 4 dams that were at least 120 feet tall.

The American Society of Civil Engineers (ASCE 1997) provides case studies and engineering guidelines for the retirement and removal of dams and hydroelectric facilities. ASCE (1997) reviews steps for conducting environmental review, sediment management, and conceptual plans for removing onstream dams. This publication states that experience and review of case studies show that the costs of sediment management and environmental review are the principal costs of dam retirement and removal. Case studies demonstrate several approaches to handling stored sediment. Some projects use conventional excavation and trucking; others rely on natural river erosion; still others are approached with bank and stream stabilization programs that leave as much sediment in place as possible. Geology, topography, and project design influence the approaches used to remove the onstream structures and sediment.

3.1 Incremental Dam Removal

Any responsible plan to remove the SCD would likely propose to reduce the dam incrementally and at a rate consistent with the river's capacity to (1) remove sediment from the project area, and (2) transport it downstream at dependable rates. Staged removal is a common approach to dam removal when sediment management is largely accomplished through stream erosion (ASCE 1997). When a combination of sediment management methods are used, staged removal is still an appropriate approach to dam removal because it provides a high level of safety at the damsite during removal when floods may inundate the dam and control sediment release rates.

Concrete dams have been removed in lifts from top to bottom using diamond wire saw cutters. One method for providing safe working conditions and control over sediment release rates is to first cut a weir in the dam, and then remove a lift from the entire dam width. A well developed plan for removing a similarly constructed dam on the Elwha River in Washington has been developed. The Glines Canyon Dam, on the Elwha River is a 210-foot high gravity arch reinforced concrete dam built in 1927 that is very similar to SCD. The plan for Glines Canyon Dam removal calls for setting up a project crane and then cutting a 15-foot deep notch near the left abutment, with width designed for projected stream flow. This step would be followed by cutting and removing 7.5-foot high blocks across the entire width of the dam. The last notch in that lift, near the right abutment, would be cut 15-feet deep to accommodate stream flow. The process of removing 7.5-foot deep notches would then reverse until the left abutment was reached. Removing each 7.5-foot lift will require less than 2 weeks time, and construction delays are anticipated only during extreme flood conditions that overtop the 7.5-foot lift. The incremental notching procedure maintains the dam's structural integrity during the removal process.

Incremental notching by diamond wire saw would continue until sediment is encountered at the dam face. The Glines Canyon plan calls for blasting for staged excavation below sediment level (because sawcutting is no longer practical), but maintains the 7.5-foot lifts and 15-foot deep notches every two weeks as for the upper portions of the dam above the sediment. However, the sediment at the notch location would be exposed to immediate release as each notch is blasted in stages. More control over sediment release rates would be possible with sediment dredging at the dam face prior to removal, or through hydraulic dredging using a construction crane during removal. The buildup of woody debris could also be controlled by removing it with the crane.

At the Glines Canyon Dam, the rate of notch cutting and the notch dimensions will be modified depending on flow conditions and flood stages downstream. Also, construction will be interrupted during critical fish migration windows to allow reduced suspended sediment loads downstream. The notch width controlling the sediment transport rate, could be adjusted based on adaptive management and monitoring downstream. It is also technically feasible to "prepare" a wider notch but not remove it unless favorable hydrologic conditions allowed for greater than normal sediment release rates. Sediment release rates and notch dimensions would have to be carefully determined to develop a responsive dam removal plan.

3.2 Sediment Management

At this time, the most feasible method of removing the SCD is unknown. However, it is known that, like most other dam removal projects, the management of impounded sediment would probably be the most significant cost of removing the SCD. The release of large percentages of the 2000 AF of stored sediment behind the SCD has the potential to impact both downstream habitats and existing properties constructed in the river flood plain for one or two decades. By removing the dam, stored sediments would slowly move downstream towards the river's mouth. The presently incised channel with its armored cobble substrate would be overlain with a gravel-sand mix. Each section of the river would initially aggrade and then gradually degrade as it passed the bulk of the released sediment. Winter flows would eventually carry much of the finer materials (*i.e.*, sand and silt) through the lower reaches and out to the ocean. After several years, the stream channel would have a more natural balance of cobble, gravel and sand.

The greatest challenge in removing the SCD is to develop a cost-effective plan that successfully limits the extent of stream channel aggradation during and after dam removal. The build-up of sediments must be limited, especially at key hydraulic controls, in order to limit the risk of flooding to downstream property owners.

The Sediment Subcommittee of the SCD Technical Team, under the leadership of the California Department of Water Resources, has produced a numerical model to estimate timing, magnitude and duration of various downstream sedimentation effects given a range of sediment evacuation volumes. The modeling exercise, using the widely accepted HEC-6 sediment transport hydraulic model, is contracted with Mussetter Engineering Inc. To date, the model has examined sediment evacuation volumes from SCD of 1500 AF, 750 AF, 300 AF, and the resumption of the natural incoming load. In addition to modeling the evacuation volumes, the model accounts for continued natural sediment load from the upstream watershed. The model is based on new channel topography mapped in Spring 2001 and the estimates of reservoir sediment quality and quantity reported by Moffat and Nicol (1996).

Output from the model includes changes in water surface elevation, changes in river bed elevation, changes in bed material size gradation, sediment concentration, critical flow depth for fish migration, and all these parameters at multiple time steps for a 41-year period of record from 1958-1998. Two different start dates were used to identify the differences in sedimentation processes for project initiation beginning in either a wet or dry period. Consequently, two 10-year average periods of dry (1985 start date) and wet (1978 start date) hydrologic conditions were modeled. The hydrologic record was then wrapped around to the beginning of the period of record (1958) to provide 41 years of simulation for both starting date scenarios.

Model results show different effects of the various evacuation volumes and both starting hydrologic conditions (refer to Figures 2 and 3). The greatest modeled increase in water surface elevation occurs when 1500 AF of sediment is released under wet starting conditions (1978). (The dry starting condition 1500 AF scenario was not run). At River Mile (RM) 8.2, the maximum water surface change is approximately 5.9 feet during the simulation period. The 750 AF dry start scenario gives a change in water surface elevation of 4.9 feet at the same location. The 5-point running average difference between 1500 AF wet and 750 AF dry is approximately 1 foot over the majority of the river, with 2 feet being the greatest difference near RM 10.8. The water surface differences between the 750 AF wet model scenario and the 750 AF dry scenario exceed 3 feet for the entire distance from RM 4 to RM 10.

Similarly, the difference in maximum water surface elevation between 300 AF wet and 300 AF dry are greater than between 750 AF wet and 300 AF dry. These striking results of the modeling effort, to date, lead to the conclusion that the starting hydrology and sequence of floods have a greater influence on increased flooding potential than does the volume of sediment evacuated from the reservoir. The modeled change in maximum water surface elevation along the Carmel Valley is a complex response between antecedent channel conditions, and the location and shape of the sediment wedge as it moves downstream. Flood risk is the joint probability of (1) the timing and location of the sediment wedge at a critical point combined with (2) the probability of occurrence of the largest flood in the record.

The recent sediment transport modeling indicates that without active measures to either limit the sediment evacuation from the reservoir, or reduce the build up of sediments in channel locations, the stream channel may aggrade by as much as 4 feet along RM 8 to 10 for an approximately 12-year period after dam removal, and it would aggrade by about 2 feet in the lower river (RM 1-5) for as much as three decades following dam removal (Mussetter Engineering Inc., in prep.). However, with adequate sediment management, it is unlikely that dam removal would affect stream stage by more than one to two feet. Yet, even with that potential increase, it may be necessary to apply additional measures to reduce flood risk, such as the placement of temporary retaining walls (e.g., "ecology blocks") along lowlands most likely to be flooded.

The possible development of a cost-effective plan to remove the SCD will require a focused effort to resolve the potential problems of sediment transport to the lower river. Existing sediment transport model runs can be interpreted to integrate efforts to reduce sediment loading by dredging or slurrying impounded sediments to offstream sites. The modeling effort has not addressed possible mitigative steps such as annual monitoring of the bed elevation of the stream channel and active channel maintenance by mechanical removal or aggregate mining.

3.3 Flood Risks

Property damage due to floods has occurred along the Carmel River in the past decade during flood flows with approximately 25-year recurrence intervals. The current FEMA flood insurance study, completed in 1984, was based on 1980 channel geometry and the hydrologic record from the period 1958-1980. The period following 1980 includes several significant peak flows as well as the flood of record (peak instantaneous flow was ~14,000 cfs in March 1995; peak mean daily flow was 9050 cfs on February 3, 1998). In addition to a longer hydrologic record that includes larger peak flows, the channel may have less conveyance capacity in today's condition due to growth of riparian vegetation and post-1980 human encroachment. Technically, the FEMA flood map is obsolete and inaccurate because (1) the boundary conditions of the flow model have changed substantially and (2) the hydrologic record has doubled.

Currently, 1400 properties with improvements (homes or other structures) are identified within the legal 100 Year Floodplain. Homes and golf courses were flooded during peak flows in 1995 and 1998. The County of Monterey recognizes the low level of flood protection along the Carmel River and the inadequacy of the 100-Year Flood Map. There is a new 'repetitive loss program' to financially assist property owners undertaking preventative measures against future flood damages to those properties where more than one claim has been filed in the past 10 years. However, an effort to remap the FEMA 100-Year Flood Plain is several years away.

With its accumulated sediment, the SCD increases the risk of flooding. Water storage capacity of the present-day reservoir is approximately 150 AF, less than 10% of the original capacity. A fairly simple and inexpensive analysis could demonstrate that sediment has already passed through the reservoir and over the dam during recent flood events because the reservoir is no longer an 100% efficient sediment trap. Trap efficiency will dramatically diminish toward zero in the next few years when the SCD reservoir completely fills with sediment. Flood risk, or the perception of risk, will increase when the reservoir fills, trap efficiency diminishes, and the Carmel River begins to deliver substantial percentages of the incoming sediment load and entrain portions of the reservoir deposit surface.

Three areas where floods occur repeatedly have been identified by the Monterey County Water Resources Agency. The areas are near Highway 1 (RM 0.75-1.75), near Valley Greens and Via Mallorca (RM 3.0-5.5), and near Rosie's Bridge (RM 14.5-15.5). The model results illustrate that, for all sediment volumes and hydrologic scenarios, increases in flood level will occur at four locations: (1) a 1 to 3 foot increase between RM 1.3 and 2.1, (2) a 2 to 4 foot increase between RM 3.8 and 4.3, (3) a 2.0 to 3.5 foot increase at RM 14.2, and (4) a 1.5 to 3.0 foot increase at RM 17.4. The first three areas overlap with those areas identified as flood prone by Monterey County. It can be argued that flood improvements are currently needed in these areas, and the improvements necessary for managing sediment transport may not be substantially different.

As noted above, sediment transport modeling for the Carmel River indicates that dam removal without first reducing the total quantity of sediment stored behind SCD has the potential to temporarily increase the channel bed elevation between 3.0 and 4.5 feet for 10 to 15 years between RM 4.8 and 10.2. The stream channel in those sections would then erode and stabilize about 1 to 2 feet higher than current conditions after approximately two decades from dam removal. However, additional modeling also shows that if the total release of sediment is limited to approximately one-half or one-third of the stored volume, the river channel would not aggrade more than about 3 feet in any section for more than one year and aggradation greater than about 2 feet would last for only 3 years. After two decades, all but one reach of the river would stabilize at about 0.25 feet aggradation. These results suggest that reducing the volume of stored sediment, allowing the release of a smaller volume for river transport, would reduce the extent of flooding caused by channel aggradation. Thus, by first mechanically removing about 750 AF of sediment, the potential for a scenario with four feet of channel aggradation would be removed.

Channel aggradation and increased flood stage height are related but not directly proportional because stage height is a function of bed roughness. When a cobble bed river receives a sand layer, the stage height is reduced for a given discharge. In fact, bed aggradation of a few feet can occur without increasing flood stage height because of the effect of reduced roughness. ASCE (1997) describes the relationship between stream channel aggradation and flooding:

> *The frequency at which certain property is flooded may increase because of the river erosion and aggradation that results from dam removal. Flood stages for a given river flow would increase from river bed aggradation. For steep rivers, increases in river stage may be less than the amount of river bed aggradation because river stage at a given location depends on river stage at the next riffle downstream. Riffles are high velocity areas of the river and are least likely to aggrade. As long as river bed aggradation does not occur at a downstream control, only small increases in river stage would occur upstream from aggradation of river pools. Flood stage increases would be more sensitive to aggradation in rivers with more mild slopes.*

Given this relationship between stream gradient and aggradation, flooding risk associated with removal of the SCD could be effectively limited if the total volume of sediment is circumscribed, hydraulic controls are monitored and maintained in the upper and middle segments of the river (*e.g.*, between SCD and RM 5 or 6), and the channel is effectively maintained in the lower segment. A combination of temporary flood walls, permanent channel improvements, channel maintenance for sediment accumulation, and controlled sediment release from SCD could be included in a coordinated multifaceted dam removal program for preventing or substantially reducing flood risk in the flood prone areas. The program could be designed for cost effectiveness and flexibility as well as ecological and aesthetic sensitivity. For example, the appropriate locations for temporary flood walls are indicated by the modeling results. But the length and height of temporary flood walls would be a function of the sediment release rate, and vice versa. Appropriate sedimentation basins or channel maintenance areas are also indicated by the model results, but the volumes and frequency of sediment removal are determined by the release rate and hydrology. Therefore, it is vitally important to provide for control over the sediment release rate during planning for dam removal. Permanent channel capacity improvements are also reasonable to safely convey frequent flood flows. Many of the currently needed permanent channel capacity improvements are probably not substantially different than those required to contain flooding due to sediment releases.

In summary, to limit the risk of flooding, a dam removal alternative could require a multifaceted approach involving:

1) mechanical removal of a portion of the sediment behind the dam,
2) a flexible, staged removal plan allowing some control over the volume of sediment released during a given year,
3) monitoring of streambed elevation changes or stage changes in downstream reaches,
4) mechanical removal of channel sediment at certain downstream sites during the removal period, and
5) placement of temporary, modular retaining walls ("ecology blocks") at sites where stage changes are predicted or where flood protection is currently low.

Cal-Am would suggest that the SCD retrofit plan would not cause flooding downstream. The dam retrofit plan includes periodic sediment releases of up to approximately 300 AF in "wet years". This is to maintain a small storage capacity and a sediment free area around the water intake structure. Natural incoming sediment load to the reservoir averages 17 AF annually, and historical sediment delivery events such as forest fires and landslides have delivered 100-200 AF to the reservoir. The Carmel River watershed is strongly influenced by the cyclic El Nino weather patterns that have 1-3 wetter than normal years followed by a decade of normal to drier than normal years. Consequently, the build up of approximately 170 AF of sediment would be a normal condition in the watershed during the period of time between wet years. Sediment delivery events are coupled with wet winters and high flows that would mobilize the sediment accumulated in the reservoir as well as that accumulated in the watershed. The sediment model shows that over 100 AF of sediment is transported during wet years from the watershed upstream from SCD. Therefore, for planning purposes, it is appropriate to examine the downstream impacts of multiple pulses of sediment evacuation resulting from the storage of sediment during dry and normal years and its evacuation during wet years. It is NMFS understanding that volume would be approximately 300 AF.

The HEC-6 model has examined a single 300 AF release in 41 years. According to Entrix (2000) and Duffy (2000), a more realistic scenario would include multiple releases of 200-300 AF every 10-13 years to periodically maintain a 300 AF pool behind the dam. The sediment model results for the single 300 AF release show that substantial increases in water surface elevation will occur in the flood prone areas. To the extent that this model scenario conservatively represents the retrofit sediment management plan described in Entrix (2000) and Duffy (2000), it appears that the management plan does not significantly reduce flood stage in the flood prone areas, when compared to the evacuation of 750 AF. The ecological impacts of storing accumulated sediment behind SCD and then releasing the accumulation during every wet period are probably more detrimental than the impacts of a much larger release on a one-time basis.

4.0 Costs Associated with Dam Removal and Retention

The plan for managing sediment during the removal of the SCD will require careful analysis comparing the costs of immediately dredging and storing sediments at off-stream sites and the costs of channel maintenance and/or aggregate mining in downstream reaches. Reviewing the dredge and storage options for the SCD project, Moffat and Nichol (1996) reported that Cal-Am could store about 550-620 AF of sediment at its Carmel Valley Filter Plant (CVFP) in less than one year. They estimated that the one-time costs of that effort would range from $7 to $9 million depending on transportation by slurry or truck, respectively. Moffat and Nichol also reported that Tularcitos Creek was an additional potential sediment storage site with capacity reaching 740 AF.

Recently, the DWR has conducted a reconnaissance level review of potential sediment storage sites. Three or four sites are closely located to SCD and the reservoir deposits, and have potential storage capacity to dispose of the entire 2000 AF of sediment. Their proximity would allow the use of heavier equipment providing transportation reductions and would require less handling. Both advantages would reduce total costs.

It is generally believed, and suggested by Moffat and Nichol, that there is potential economic value in the reservoir sediments, in spite of potentially high transportation costs between the source and the market. The parent rock of the watershed is granitic, which produces high quality aggregate materials that are rare in coastal California. Landscaping and construction rock and sand are valued at $10 to $20 per cubic yard in 1995 dollars. This suggests that a large portion of the costs of mechanical removal of sediments could be offset by sorting and selling the marketable materials.

Critical sedimentation zones in the Carmel River channel may also be managed. Accumulations of sediment could be mechanically removed from the channel during dry seasons, in preparation for winter floods. These materials would also have potential economic value and would require less transportation costs to reach nearby markets. With such economic partnerships, costs for dredging the reservoir or maintaining the river channel in the middle and lower river could be less than that for impoundment dredging and sediment storage at upper valley sites. The potential savings for such collaboration between Cal-Am and aggregate suppliers must be fully explored.

4.1 Long Term Costs

The preferred project has a 50-year project life. What then? Managing the sediment accumulation will probably become more difficult in the future as the population continues to grow, land becomes more expensive, and more restrictive permitting requirements are implemented. During this period the sediment accumulation will increase fish passage difficulties that will require periodic attention, and the fish passage limitations will not be solved by installing a new fish ladder. American Rivers (2000) found that in many cases, dam removal saves significant taxpayer dollars compared to repair or environmental mitigation costs. On average, removal costs were only 37% of the estimated dam repair costs for 10 dams profiled in the report, *Dam Removal Success Stories: Restoring Rivers Through Selective Removal of Dams that Don't Make Sense*. It is highly recommended that Cal-Am determine its maintenance and operational costs of the retrofitted SCD for at least 50 years into the future when comparing the economics of the alternatives for SCD retrofit. Dam removal and restoring unregulated sediment transport is the only alternative that accrues long term benefits to the ecosystem and to the fish of the Carmel River.

5.0 Summary and Recommendations

A proper and thorough assessment of the option of removing the San Clemente Dam provides an historic opportunity to take a major step in the restoration of the Carmel River's ecosystem and its associated steelhead fishery. The San Clemente Dam is an obstacle to migratory steelhead, a federally listed threatened species. Three-quarters of the potential rearing habitat and two-thirds of the potential spawning habitat within the Carmel River watershed occur above San Clemente Dam. The dam and its impoundment adversely affect several miles of habitat for steelhead and other aquatic species. In addition to being an impediment to fish movements, the dam curtails the transport of gravels important for salmonid spawning; it contributes to elevating downstream temperatures; it adversely affects aquatic insect drift and habitat; and it causes channel incision with associated impacts to riparian vegetation.

The removal of on-stream dams has been an important tool in the restoration of many stream ecosystems. Since 1912 more than 465 dams have been intentionally removed nationwide. At least 40 of these dams were 40 feet or taller, including four that were at least 120 feet high. Review of case studies show that the costs of sediment management and environmental review are the principal costs of dam retirement and removal. Stored sediments can be removed using one of several approaches Some projects use conventional excavation and trucking; others rely on natural river erosion; still others are approached with bank and stream stabilization programs. Geology, topography, and project design influence the approaches used to remove the onstream structure and sediment.

At this time, the most feasible method of removing the SCD is unknown. However, it is known that, like most other dam removal projects, the management of impounded sediment would probably be the most significant cost of removing the SCD. The release of large percentages of the 2000 AF of stored sediment behind the SCD has the potential to impact both downstream habitats and existing properties constructed in the river flood plain for one or two decades. The greatest challenge in removing the SCD is to develop a cost-effective plan that successfully limits the extent of stream channel aggradation during and after dam removal. Removal of the dam structure would likely be done incrementally and at a rate consistent with the river's capacity to transport sediment downstream.

The Sediment Subcommittee of the interagency SCD Technical Team has produced a numerical model to estimate the timing, magnitude and duration of various downstream sedimentation effects given a range of sediment evacuation volumes. Model results show different effects of the various evacuation volumes and hydrologic conditions during the years immediately after dam removal. The results indicate that starting hydrology and the sequence of floods have a greater influence on increased flooding potential than does the volume of sediment released from the reservoir. Anticipated changes in maximum water surface elevation along the Carmel Valley is a complex response between antecedent channel conditions, and the location and shape of the sediment wedge as it moves downstream. Flood risk is the joint probability of (1) the timing and location of the sediment wedge at a critical point combined with (2) the probability of occurrence of the largest flood in the record.

The possible development of a cost-effective plan to remove the SCD will require a focused effort to resolve the potential problems of sediment transport to the lower river. Existing sediment transport model runs can be interpreted to integrate efforts to reduce sediment loading by dredging or slurrying impounded sediments to offstream sites. The modeling effort has not addressed possible mitigative steps such as annual monitoring of the bed elevation of the stream channel and active channel maintenance by mechanical removal or aggregate mining.

Property damage due to floods has occurred along the Carmel River in the past decade during flood flows with approximately 25-year recurrence intervals. Technically, the FEMA flood map is obsolete and inaccurate because the boundary conditions of the flow model have changed substantially and the hydrologic record has doubled. Currently, 1400 properties with improvements (homes or other structures) are identified within the legal 100 Year Floodplain. Analysis could demonstrate that sediment has already passed through the reservoir and over the dam during recent flood events, because the reservoir is no longer an 100% efficient sediment trap. Trap efficiency will dramatically diminish toward zero in the next few years when the SCD reservoir completely fills with sediment. Flood risk, and the perception of sediment releases causing increased flooding, will both increase substantially when the reservoir fills, trap efficiency diminishes, and the Carmel River begins to deliver substantial percentages of the incoming sediment load together with portions of the reservoir deposit surface.

Flooding risk associated with removal of the SCD could be effectively limited if the total volume of released sediment is reduced through initial dredging of a portion of the stored sediments, annual monitoring and maintenance of hydraulic controls in the upper and middle segments of the river (*e.g.*, between SCD and RM 5 or 6), and channel monitoring and maintenance along the lower segment. A combination of temporary flood walls, channel maintenance for sediment accumulation, and controlled sediment release from SCD could be included in a coordinated multifaceted dam removal program for preventing or substantially reducing flood risk in the flood prone areas. Recent modeling indicates that areas most likely to be flooded are those already identified as flood prone by Monterey County. Flood improvements would be helpful in several areas already with flood risks. Improvements necessary for managing sediment transport associated with a dam removal scenario may not be substantially greater than current needs. A dam removal program could be designed for cost effectiveness and flexibility as well as ecological and aesthetic sensitivity. For example, the appropriate locations for temporary flood walls can be indicated by the modeling results. But the length and height of temporary flood walls would be a function of the sediment release rate.

To limit the risk of flooding, a dam removal alternative could require a stepped approach involving:

1) mechanical removal of a portion of the sediment behind the dam,
2) a flexible, staged removal plan allowing some control over the volume of sediment released during a given year,
3) monitoring of streambed elevation changes or stage changes in downstream reaches,
4) mechanical removal of channel sediment at certain downstream sites during the removal period,
5) placement of temporary, modular retaining walls ("ecology blocks") at sites where stage changes are predicted or where flood protection is currently low.

To fully examine the potential feasibility of removing the SCD, additional analysis is needed. We recommend that the following evaluations be performed:

1) The initial reservoir dredging feasibility study of Moffat and Nichol (1996) should be updated in order to explore currently available sediment disposal sites and costs.

2) Estimates of sediment quality and quantity in the entire reservoir storage basin should be further refined through additional field sampling and analysis.

3) The HEC-6 model results should be used to identify critical channel maintenance locations downstream from SCD.

4) Additional model scenarios should incorporate mechanical removal of channel sediment accumulations in order to evaluate their downstream effects on flood elevations.

5) The model results should be evaluated to identify critical flooding areas in downstream segments. The effectiveness of temporary flood walls ("ecology blocks") or the enlargement of levees should be evaluated with additional modeling.

6) The HEC-6 model should be extended to include the reservoir, thereby allowing the development of detailed dam removal schedules and the design for incremental notching.

7) Additional HEC-6 model scenarios should be developed to accurately examine the downstream flooding effects and long-term ecological effects of the sediment

management plan as described in Duffy (2000) for the retrofit alternative. Because of the inaccuracy of hydrologic forecasts for coastal watersheds, those model runs should examine the effects of sediment releases for each of the El Nino cycles in the hydrologic record.

A plan for managing sediment during the removal of the SCD will require careful analysis comparing the costs of immediately dredging and storing sediments at off-stream sites and the costs of channel maintenance and/or aggregate mining in downstream reaches.

The reservoir sediments are known to have potential economic value, in spite of potentially high transportation costs between the source and the market. The parent rock of the watershed is granitic, which produces high quality aggregate materials that are rare in coastal California. Landscaping and construction rock and sand are valued at $10 to $20 per cubic yard in 1995 dollars. This suggests that a substantial portion of the costs of mechanical removal of the sediments could be offset by sorting and selling the marketable materials. The potential savings for collaboration between Cal-Am and aggregate suppliers should be fully explored.

Finally, it is recommended that Cal-Am evaluate its maintenance and operational costs of a retrofitted SCD for at least 50 years into the future when comparing the economics of alternatives to the SCD retrofit. That analysis should also include costs for constructing, testing, and maintaining new upstream and downstream fish passage facilities. Dam removal may prove to be the most cost-effective alternative for addressing the issues confronting the SCD and the only alternative accruing long-term benefits to the ecosystem and to the fish of the Carmel River.

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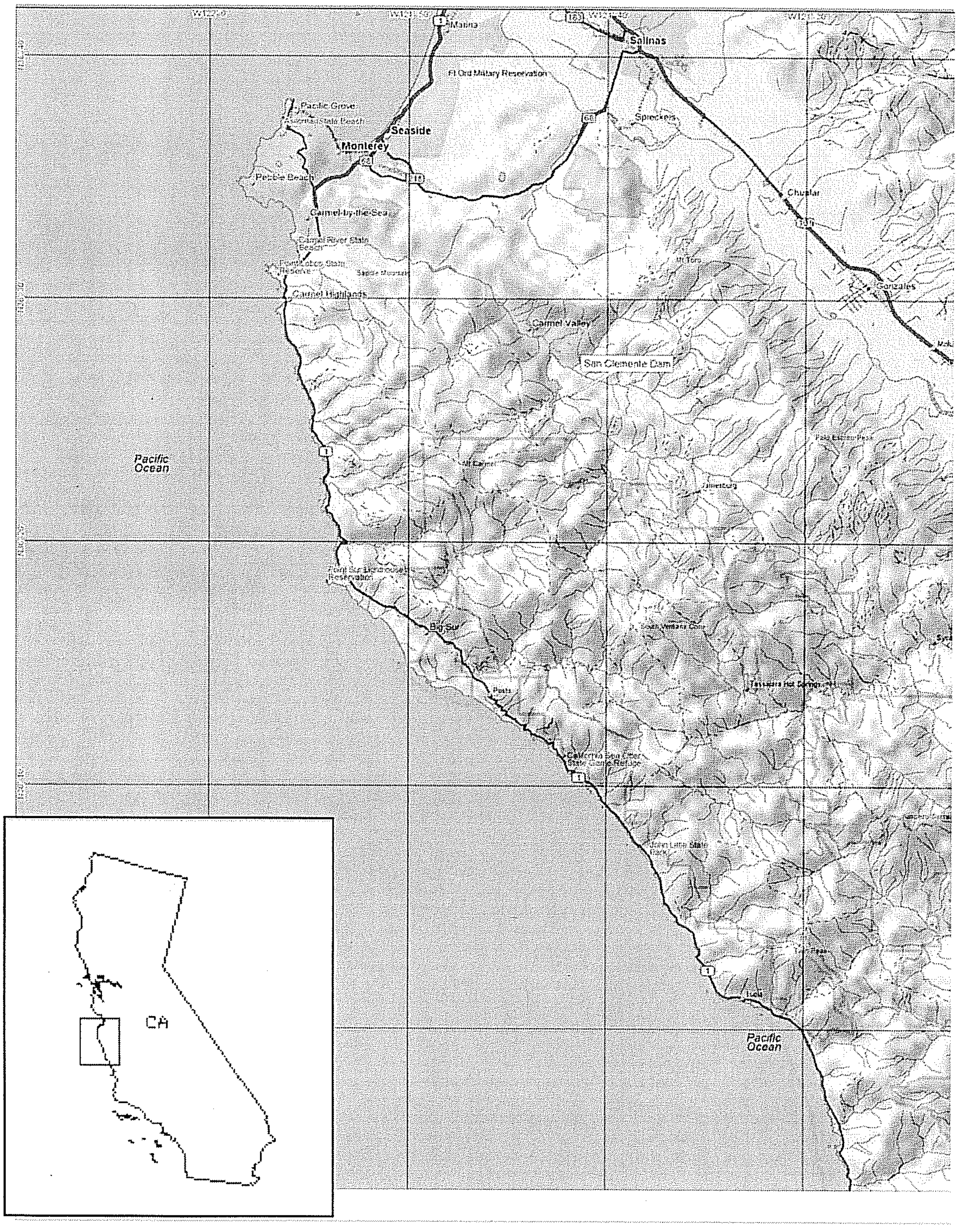

Figure 1. Location map of the Carmel River watershed and vicinity of San Clemente Dam.

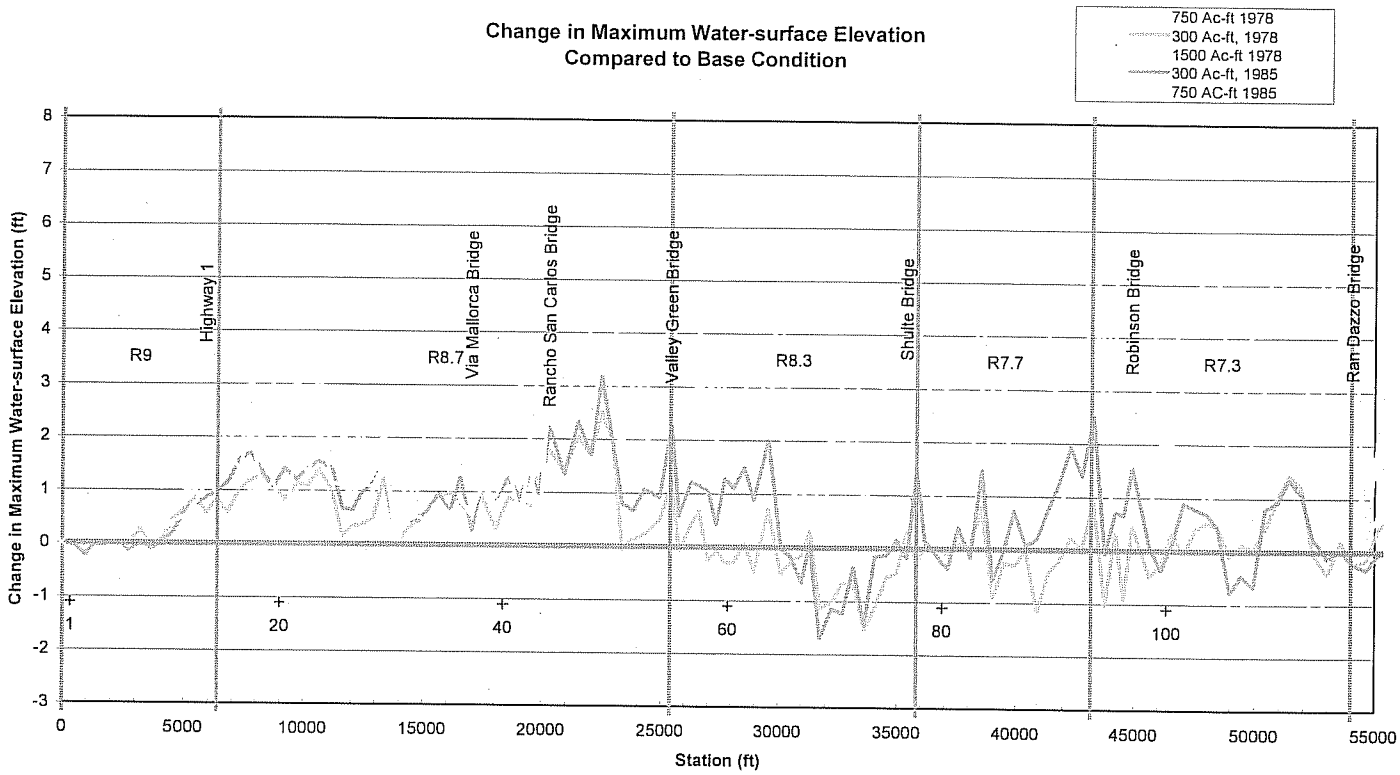

Figure 2. RM 0-10.5. Maximum water surface elevation changes, compared to background sediment loading from the watershed, for three volumes of sediment evacuated from SCD. The maximum is calculated for all cross sections and the entire 41-year period of record. The probability of these conditions occurring is discussed in section 4.1. Data from Mussetter Engineering Inc., November 2001.

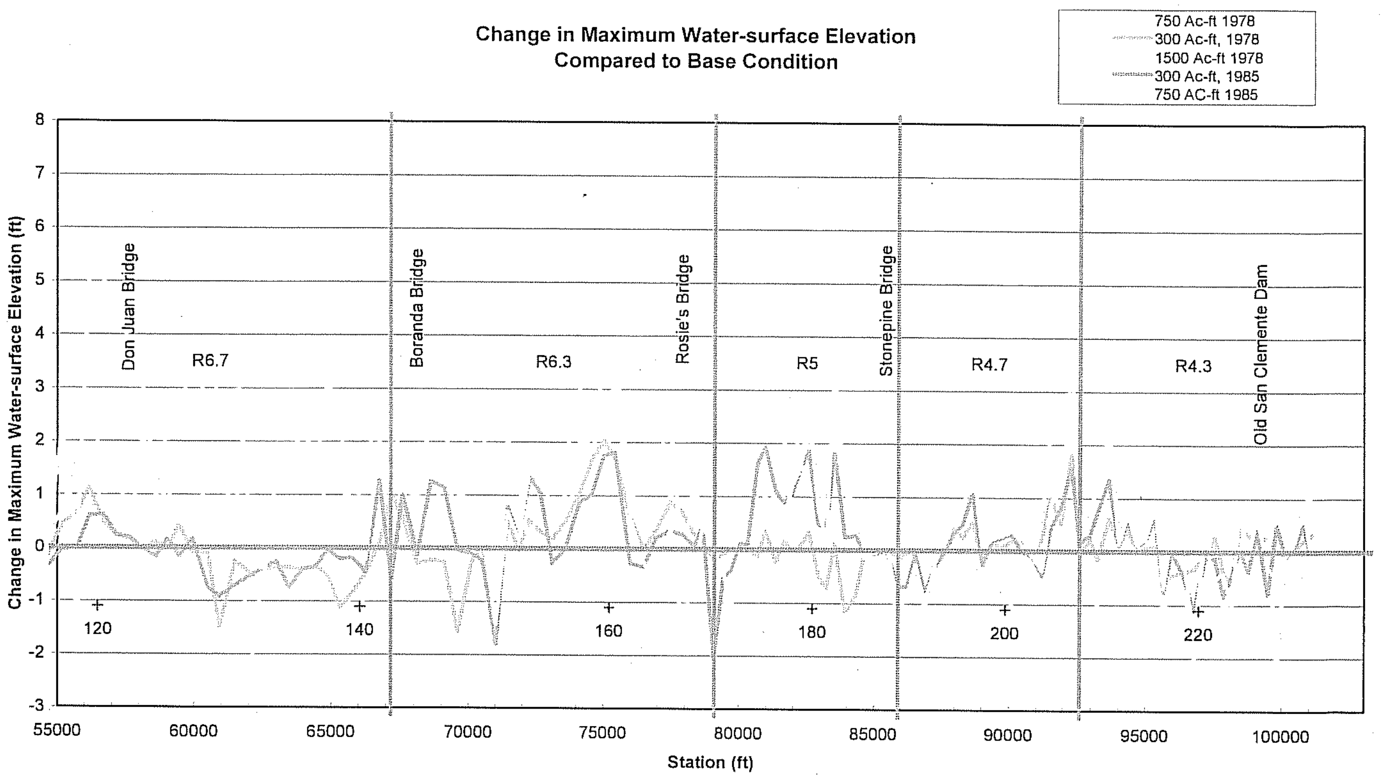

Figure 3. RM 10.5-18 (SCD). Maximum water surface elevation changes, compared to background sediment loading from the watershed, for three volumes of sediment evacuated from SCD. The maximum is calculated for all cross sections and the entire 41-year period of record. The probability of these conditions occurring is discussed in section 4.1. Data from Mussetter Engineering Inc., November 2001.

Table 1. Volume conversion from acre-feet to million cubic yards.

Acre Feet (AF)	Million Cubic Yards (MCY)
2000	3.23
1500	2.42
750	1.21
300	0.48
150	0.24
100	0.16
17	0.03