Modelling Studies to Design and Assess Decommissioning Actions for a Seismically Unsafe, Concrete Arch Dam

Krey Price [1], Mike Harvey [2], Bob Mussetter [3]

[1]*Director, Water and Environment, Tetra Tech Australia, Melbourne, VIC*
[2] *Principal Geomorphologist, Tetra Tech Inc., Fort Collins, CO*
[3]*Program Manager, Tetra Tech, Inc., Fort Collins, CO*

The California Department of Water Resources, Division of Dam Safety (DWR-DSD), has determined that San Clemente Dam on the Carmel River in Monterey County, California, does not meet seismic safety standards. Several alternatives have been considered to decommission the dam and eliminate the hazard, including thickening of the 25-m-high, concrete arch structure, lowering the dam, and complete removal. At the present time, the upstream reservoir that had an original storage capacity of about 1.8 GL, is essentially filled with sediment. The 29-km reach of the Carmel River between the dam and the Pacific Ocean passes through urbanised areas within the upscale Carmel Valley; flooding and channel stability in these areas are significant concerns. The Carmel River also contains habitat for the endangered steelhead and red-legged frog that could be positively or negatively affected by the decommissioning.

After an extensive series of hydraulic and sediment transport modelling studies, two actions remain under consideration: (1) dam thickening, which will require reconstruction of the existing fish ladder and construction of an adjacent, 3-metre diameter sluice gate to prevent sediment build-up from blocking the ladder outlet, and (2) removal of the dam and rerouting the river into a tributary branch of the reservoir, which would isolate approximately 65 percent of the existing sediment deposits from future river flows and eliminate a significant fish-passage problem. Both options were modelled extensively in hydrologic, hydraulic, and sediment transport applications. Since available models do not adequately represent sediment dynamics at the sluice gate, a special sediment routing model was formulated to evaluate this aspect of Option 1. Option 2 is currently preferred by the resource agencies, since it would optimise endangered species habitat; however, this option would be 3 to 4 times more expensive than Option 1. Evaluation efforts are ongoing, along with approaches to address liability issues associated with the decommissioning actions for the privately owned facility, while optimising the benefits and costs of the selected action.

Keywords: *Decommissioning, seismic, safety, sedimentation, siltation, modification, removal, fish passage, diversion*

Introduction

The California Department of Water Resources (DWR), Division of Safety of Dams (DSOD) determined in the early 1990s that San Clemente Dam, located on the Carmel River in Monterey County, California is seismically unsafe. DSOD found that either the maximum credible earthquake or the probable maximum flood could potentially result in a structural failure.

Corrective measures necessary to address this situation are being evaluated; the proposed measures include dam stabilisation (buttressing), reconstruction, and removal. The existing reservoir contains approximately 1.8 million cubic metres of sediment that has accumulated behind the dam.

Any option that lowers or eliminates the dam would introduce sediment currently trapped behind the San Clemente Dam into the Carmel River. Sediment that accumulates along the downstream river segments could increase flood damages and adversely affect riparian habitat.

To address the issue of sediment impacts to the Carmel River and improve on previous analyses, detailed data collection and a series of modelling scenarios were undertaken to more accurately represent the reservoir and channel response to various actions designed to increase dam safety.

During the alternatives assessment phase, a number of alternatives that had previously been considered have now been dismissed from consideration. This paper describes the initial options under consideration, the assessment process, and the issues that led to refinement of the array of alternatives, narrowing the alternatives to those currently under consideration.

In addition to capital costs, the environmental and social impacts of each alternative were assessed. DWR released a Draft Environmental Impact Report / Environmental Impact Statement (EIR/EIS) in 2006, evaluating the relative impacts of each alternative.

Various stakeholders, including the owner, the California State Coastal Conservancy, NOAA Fisheries, and the Planning and Conservation League, signed an agreement in 2008 supporting the bypass alternative and outlining an approach for implementation, including project management, planning, design, construction, and monitoring. The current cost estimate for the alternative preferred by the stakeholders is approximately USD $100 million.

Background

Carmel River Catchment Hydrology

The Carmel River drains a catchment area of approximately 660 square kilometres, flowing from the Santa Lucia Mountains to California's central coast. The project location is shown in Figure 1.

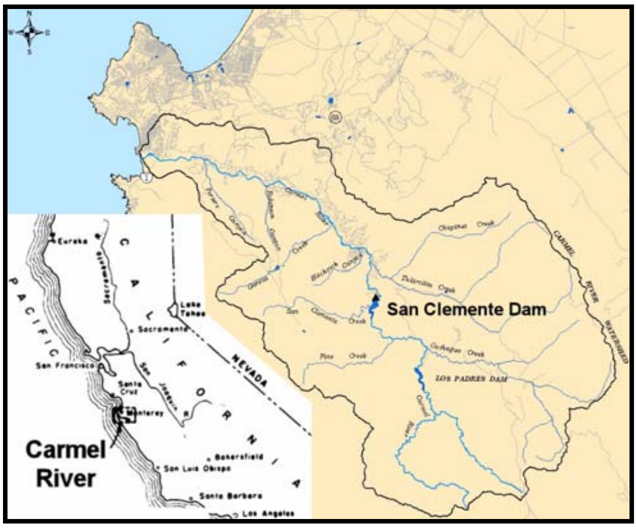

Figure 1. Vicinity map and Carmel River catchment

The mainstem river has a length of approximately 50 kilometres. The upper catchment consists of steep canyons and is generally undeveloped. The lower catchment is an alluvial valley floor with a moderate level of development. In the lower catchment, the Carmel River has 20 bridge crossings, and a number of parcels fall inside the 100-year floodplain. The river was straightened and narrowed significantly for agricultural development around the turn of the twentieth century. Near the coast, the Carmel River feeds coastal lagoons and wetlands. Breaching is required at times at the beach to establish an ocean connection.

Rainfall within the basin is highly variable, ranging from an average annual depth of 1,000 mm at the headwaters to 350 mm at the coast. 24-hour peak flow events of up to 250 mm were recorded in 1995 and 1998. Fires in the catchment – most recently a 2008 that burned 20% of the catchment – contribute to a high sediment yield due to mass wasting. Drought conditions at times contribute toward stranding and fish kills from high water temperatures.

Carmel River Habitat

The Carmel River historically provided riparian corridors for terrestrial species as well as both spawning and rearing habitat for fish. The river basin includes essential habitat for the steelhead trout and the red-legged frog, both of which are considered threatened on the U.S. Federal Endangered Species List.

San Clemente Dam

Dam Construction

San Clemente Dam was constructed in 1921 at the junction of San Clemente Creek and the mainstem Carmel River. The variable-radius, concrete arch dam is 32 metres high and drains approximately half the Carmel River catchment. Figure 2 shows the location of the dam relative to the Carmel River and the San Clemente Creek tributary.

Figure 2. Aerial photograph of project area

Appurtenances

A fish ladder was installed and operated effectively for many years until sedimentation rendered the fishway ineffective. The spillway is flashboard-regulated and the outlet works are concrete-lined steel. Figure 3 shows the spillway operating during flood conditions in 1995.

Figure 3. San Clemente Dam during flooding

Sedimentation

Sedimentation has gradually reduced the capacity of the reservoir since the dam was constructed. Under current conditions, the reservoir has effectively filled with accumulated sediment, rendering the dam ineffective in providing flood storage or water storage. The current functionality of the dam has been reduced to providing a diversion.

Seismic Concerns

In the early 1990s, geotechnical and structural investigations determined that the maximum credible earthquake would threaten the integrity of the dam, posing a potential risk to the downstream population. The extreme sediment release that would accompany a dam failure would also pose a significant environmental catastrophe. Due to these findings, DOSD issued a safety order instructing the dam owner to address the problem.

Figure 4. San Clemente Dam and Reservoir

Alternatives Development

A range of alternatives has been investigated in recent years to address the safety and environmental concerns surrounding San Clemente Dam. Various approaches have been proposed and refined during a decade of planning studies. Scenarios that progressed to the modelling phase include:

- Stabilisation (buttressing) of the existing dam with a thickened wall. In this scenario, all other project features remain unchanged from the existing condition. This alternative thus addresses public safety concerns but does not address the environmental concerns and serves as a baseline model that effectively represents the existing condition in hydrologic, hydraulic and sediment transport models;
- Stabilisation (buttressing) of the existing dam with a thickened wall, reconstruction of the existing fish ladder and construction of an adjacent, 3-metre diameter sluice gate to prevent sediment build-up from blocking the ladder outlet;
- Construction of a 6-metre deep notch (in a single construction period) that allows the existing dam to meet seismic safety standards;
- Construction of a 6-metre deep notch (staggered at either 5- or 10-year intervals) that allows the existing dam to meet seismic safety standards. Investigations into these scenarios are designed to provide a sensitivity analysis to determine the response of the reservoir and the river to either lateral planation by the eroding channel within the reservoir or mechanical removal of overbank terrace sediments as incision into the reservoir commences;
- Rerouting the river into a tributary branch of the reservoir and complete removal of the dam, isolating approximately 65 percent of the existing sediment deposits from future river flows and eliminating a significant fish-passage problem.

Alternatives Assessment

The greatest impact in terms of costs and environmental effects of each alternative involves the disposition of the sediment that has accumulated in the reservoir. The effects are dependent on a number of functions, including:

- The total amount of sediment delivered
- The timing of sediment delivery
- The magnitude and timing of flows during and after the sediment-delivery period
- The grain-size distribution of the introduced sediment

Detailed sediment characterisation was required in order to accurately assess the alternatives. Detailed ground surveys and soil samples were undertaken to estimate the volume and grain size distribution of sediment in the reservoir. From this information, a representative model of the reservoir sediment was constructed, allowing the determination of both the pattern and gradation of sediment delivered to the Carmel River downstream of the San Clemente Dam under a variety of scenarios. Figure 5 shows a photograph of the coarse material that has accumulated at the upstream end of the reservoirs. The sediment characterisation is shown in Figure 6 for the San Clemente and mainstem reservoir branches.

Figure 5. Accumulated debris in upper reservoir

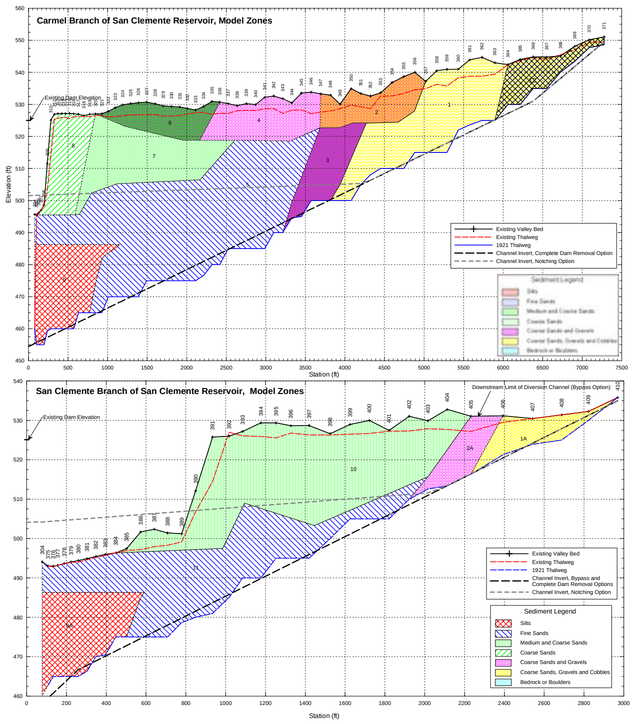

Figure 6. Sediment characterisation for mainstem reservoir (above) and San Clemente branch (below)

Tetra Tech was tasked with the sediment transport evaluation for the alternatives. The patterns of sediment erosion and transportation were evaluated over a 40-year period, both within the reservoir and downstream into the Carmel River. The results of these scenarios were compiled in terms of the pattern of sediment erosion from the reservoir; introduction of the sediment into the Carmel River; and the aggradation/degradation of the Carmel River channel due to the additional sediment load. From the results of the evaluation, the flooding response of the Carmel River was also assessed for selected scenarios. Habitat issues for selected scenarios were also addressed, in terms of suspended sediment concentrations, changes in median bed material size, and critical depth violations.

This study included an evaluation of the potential effects to the downstream river of residual sediment that would remain in the valley bottom during implementation of the baseline, notching, and bypass alternatives. A variety of analyses were performed to complete this evaluation, including the following:

- A detailed hydraulic analysis of the design elements in the existing reservoir to identify appropriate dimensions for the reconstructed reaches of the Carmel River and San Clemente Creek as a result of dam notching or complete removal.
- Sediment transport modelling to evaluate the sediment-transport characteristics through the reservoir and impacts to the downstream river for each of the three scenarios, and
- An additional hydraulic analysis to evaluate the potential effect of changes in sediment storage on flood potential in the downstream river.

Dam Reconstruction

Dam reconstruction scenarios correspond to the baseline condition in terms of hydrologic, hydraulic, and sediment transport modelling. Under baseline conditions, sediment would continue to be stored in the reservoir until the remaining pool area is completely filled and the channel across the reservoir reaches a state of equilibrium with the upstream sediment supply. As a result, the supply of sediment to the downstream river would continue for a period of time to be lower than the historic supply that existed prior to construction of the dam.

The dam-reconstruction scenario showed very little change from current conditions. The modelling predicted that it would only take a few years until the Carmel River branch of the San Clemente Reservoir filled completely from upstream sediment, while the San Clemente branch of the reservoir filled more slowly (due to a lower rate of upstream sediment introduction). Once the main (Carmel River) branch was filled, most of the sediment that was introduced from upstream followed the equilibrium channel and was released over the dam. This moderate amount of sediment had relatively little impact on the downstream reaches in terms of aggradation, flooding, and habitat change. The maximum increases in depth of channel aggradation due to sediment introduction were less than 10 cm, and these modest, transient aggradation zones were almost completely removed early in the simulations. The dam-stabilisation/thickening scenario showed very minor channel impact with varying hydrologic start dates. This minor impact was reflected in small changes to the flooding limits for the 100-year flood under baseline conditions, with insignificant changes in damage.

Dam Notching

Notching alternatives would result in the release of significant quantities of the sediment that is stored in the reservoir into the downstream river, which could potentially affect channel stability, flood-carrying capacity and instream habitat during the period of time while the elevated sediment supply is transported through the reach.

The single notching scenario allowed sediment from the reservoir to be introduced to the Carmel River in one prolonged pulse. Figure 7 shows a typical set of hourly bed profiles through the reservoir during a storm event. As expected, starting the simulation with a period of wet years created a faster rate of sediment introduction than starting with dry years, and allowed the in-reservoir channel to reach a state of equilibrium earlier. Ultimately, this means that less sediment (about 50,000 cubic metres less) was introduced in the dry start-date scenarios than in wet start-date scenarios. This is due in part to the armouring that occurs under low flows, stabilising channel sediments and making them more resistant to erosion and transportation during subsequent years of higher flow.

Downstream from the dam, aggradation under the single notching scenario resulted in a maximum of 30 cm of in-channel aggradation, with a typical aggradation depth of approximately 15 cm. While sediment derived from reservoir deposits was delivered early in the simulations, it took longer for this material to move through the Carmel River channel to the ocean. While this scenario was not analysed for changes in flood conditions, it is apparent that these modest and generally transitory changes for in-channel sediment storage would have modest flooding consequences, much closer to those of the baseline conditions than the phased-notching scenario.

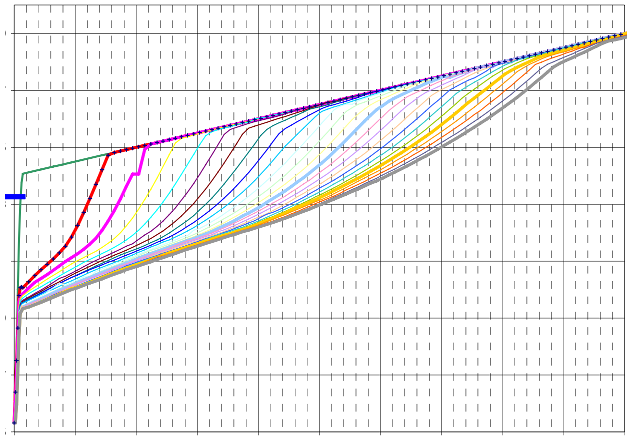

Figure 7. Hourly bed profiles for storm event

Repeating the seismic-stability notching scenario, but adding a component to the model to simulate lateral channel movement and subsequent valley widening within the reservoir introduced more sediment into the Carmel River. This lateral widening caused an additional 370,000 cubic metres of sediment to be introduced to the river over the course of the entire simulation, and prolonged the channel recovery. Not only was the amount of sediment delivered to the Carmel River increased, but also the time period over which it was introduced. While the initial pulse of sediment from the reservoir was substantially finished relatively early in the simulation, allowing the in-reservoir channel to migrate lengthened the period of elevated sediment introduction to 20 years, producing a more substantial impact on the downstream channel.

Sediment introduced from this lateral channel migration created more aggradation in some reaches, most noticeably in the downstream portions of the Carmel River. This was due in part to armouring of the channel during periods of low discharge, causing the introduced sediment to become less easily mobilised. The Carmel River did not achieve recovery from the sediment introduction for this scenario, and flooding problems are likely to be greater and more persistent than in scenarios where no in-reservoir lateral channel movement was included in the model.

The dam-removal scenarios, with subsequent notching at 5- and 10-year intervals evacuated the most sediment from the reservoir, and as a result had the greatest downstream impacts. Allowing the notching interval to be 5 years had the greatest impact, creating the least time for channel recovery from each successive notch and sediment pulse. Within the reservoir, sediment erosion was clearly tied to flow volumes. If a notch was followed by wet years, then rapid erosion cleared sediment out of the reservoir and allowed for more rapid formation of an equilibrium channel within the reservoir. This evacuated sediment then was quickly introduced to the downstream channel, where it either formed temporary aggradation zones that quickly eroded, or it accumulated for longer periods. If notching periods were followed by dry years, then erosion of reservoir sediment occurred more slowly and frequently armouring occurred. Maximum aggradation depth ranged from 15 to 80 cm. Most reaches showed successively greater aggradation depths throughout the first half of the simulation period, with pulsed increases in depth tied to each dam notching, successively delayed in a downstream direction. In the downstream-most reaches, the time-delay pulse was less distinct, due to continued supply from upstream reaches.

The large impact created by the phased notching could possibly be mitigated by excavation of overbank terrace deposits prior to each successive notch. This was investigated in the form of the addition of overbank excavation. The removal of almost 1,000,000 cubic metres of reservoir sediment created a net reduction of 320,000 cubic metres in the total amount of sediment introduced to the Carmel River over the course of the simulation. This reduced the maximum aggradation by up to 35 cm, and decreased the total of in-channel stored sediment by 40 percent.

Floodplain Assessment

An analysis of changes in flooding impacts for the 100-year event was carried out for selected scenarios by incorporating changes in bed elevations predicted by the HEC-6T sediment transport model into a more detailed floodplain model of the project reach below San Clemente Dam. In addition to the evaluation of flooding elevations and inundated areas, the relative increase in property damage was evaluated for each scenario examined. Increases in flood elevations over existing conditions for the baseline-conditions scenario are generally very small, resulting in a total increase in inundated area of only about 12 ha. Resulting increases in property damage are generally insignificant.

The phased notching scenario resulted in greater impacts to 100-year flood elevations, with an average increase over existing conditions of about 35 cm. The maximum increase occurred where large amounts of coarse sediment were deposited. The total increase in inundated area over existing conditions was about 65 ha, with scattered increases throughout the project reach. The increases in flooding depths and inundated area resulted in increased property damage at different locations along the project reach, including both residential and commercial sites.

Figure 8 shows the increase in inundated area resulting from downstream sediment accumulation. A reconnaissance-level identification of feasible alternatives for mitigating the potential increases in flood damage was performed for those areas with significant increases in estimated damages. Mitigation measures included the construction of levees or floodwalls, floodproofing individual structures, and the use of sandbags to protect areas from shallow flooding. Specific screening criteria that were used to determine which damage reaches should be considered for mitigation included.

Figure 8. Increase in inundated area

Grain-size distributions for material in the aggraded channel bed were not closely tied to the dam retrofit/removal scenarios. Rather, median grain size (D_{50}) tracked recent flow patterns, with wet years or years subsequent to notching allowing for the introduction of fine sediment to the channel, while dry years instigated armouring. Armouring in the reservoir was beneficial, allowing for reduced sediment output from the dam, while armouring in the Carmel River downstream of the dam tended to delay channel recovery by decreasing sediment mobility. Unlike bed material gradations, suspended sediment appeared to be more closely tied to dam notching scenarios, with high concentrations of suspended sediment correlated to high flows following the period of notching. All dam-notching scenarios introduced more coarse sediment into the Carmel River than was introduced under baseline conditions.

Channel Excavation

A feasibility analysis of a dam removal scenario for the San Clemente Dam on the Carmel River involving the mechanical excavation and transport of a sufficient portion of the stored sediment to restore both branches of the reservoir to their approximate pre-dam profiles was conducted. The work performed for this analysis included the development of appropriate channel geometry, consistent with stability characteristics demonstrated by self-formed natural channels. Preliminary specifications for rock riprap and articulated concrete block were also developed with which to evaluate the feasibility of protecting the channel banks (i.e., toe of the deposits) during various estimated peak-flow discharges in both the Carmel River and San Clemente Creek branches of the reservoir.

Results of the analysis show that approximately 1.5 million cubic metres (about 75 percent) of the existing deposits would need to be excavated from the reservoir in order to restore the Carmel River and San Clemente Creek branches to their pre-dam profiles. In addition, the hydraulics associated with the 100-year peak discharge are at the upper limits of the protective capabilities of both riprap and articulated concrete block. However, in sharp bends where the outside of the channel would probably abut the original valley wall, additional bank protection may not be necessary to protect the reservoir deposits from erosion. Figure 9 shows the proposed excavated channel against the original and existing ground surfaces, and Figure 10 shows a plan view of the excavation zone.

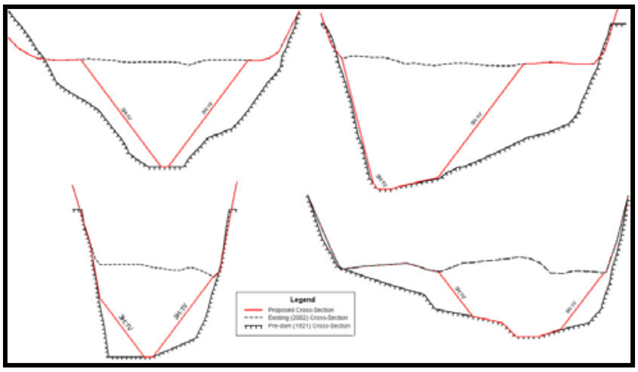

Figure 9. Pre-dam, current, and proposed sections

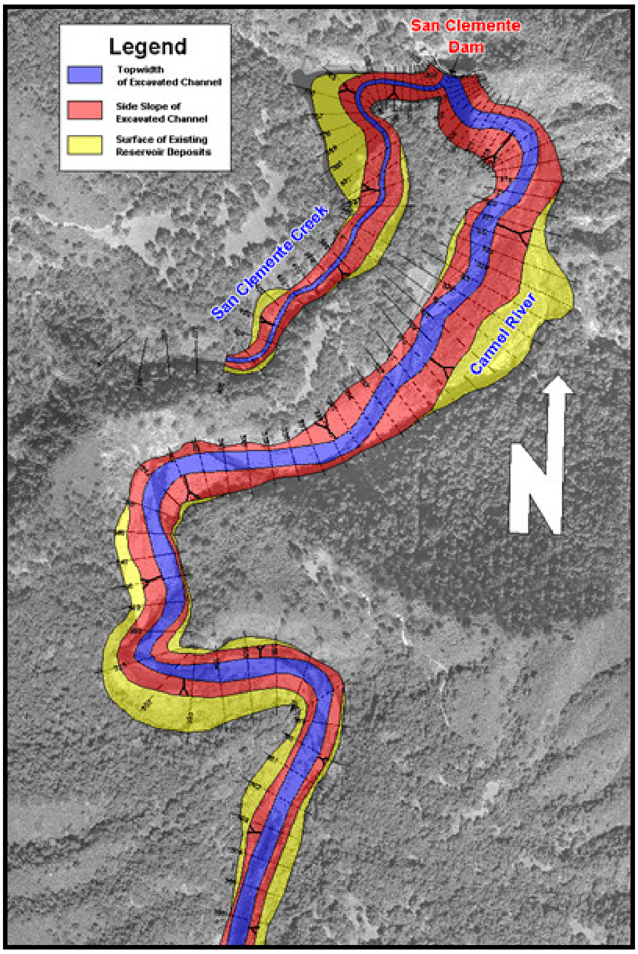

Figure 10. Excavated channel slope

The reconstructed channel through the existing reservoir under the notching and complete dam removal scenarios was sized to convey between the 1.5- and 2-year peak discharge. The natural gradient of the Carmel River in the vicinity of San Clemente Reservoir is relatively steep, and the bed material is much coarser than the material that has accumulated in the reservoir.

As a result, dynamic equilibrium between the transport capacity and upstream supply can be achieved in a sand-bed channel with a much flatter gradient than the natural gradient of the river. The long-term behaviour of the river across the reservoir deposits will depend in large part on whether or not an equilibrium channel develops that can carry the upstream sediment supply without excessive aggradation during flood flows that can carry relatively large amounts of sediment, even under baseline conditions. Integration of the upstream supply rating curve over the long-term flow record results in an average annual sediment supply which matches the observed rate of deposition in San Clemente Reservoir.

Because the deposits in the upstream portion of the reservoir are relatively coarse, the channel will respond to the excess sediment-transport capacity primarily by coarsening of the bed material. Over time, as the vegetation becomes more established, sediment is likely to deposit in the vegetated overbanks near the edge of the channel, forming natural levees that will increase the in-channel capacity. Additionally, the vegetation will tend to stabilise the banks; thus, the channel in this portion of the reach will tend toward a more stable condition with time. A large flow event that carried an unusually large sediment supply could, however, cause significant instability in this portion of the reach because of the relatively close balance between the baseline supply and transport capacity. In the downstream subreaches, the transport capacity is slightly higher than the upstream supply, indicating that the bed would coarsen somewhat from the existing condition.

Three feasible locations for in-channel detention of sediment were identified; however, off-channel detention of sediment released from San Clemente Dam was determined to be infeasible due to the lack of any suitable overbank areas adjacent to the river and due to technical problems in diverting the sediment from the main channel into an overbank facility. Because most of the sediment released from the dam is in the sand-size range, it is unlikely that a diversion structure would have a high enough diversion efficiency to remove the quantity of sediment necessary to achieve the objectives of the project. The diverted sediment would be weighted to the coarse fraction of the bed material load, leaving a relatively high percentage of the finer sand fraction to pass the diversion into the downstream reach.

The use of detention dams at any of the identified sites would result in a significant number of years where the estimated excess sediment supply would exceed the estimated storage volumes, with the available storage at each site being only a small fraction of the sediment excess during the years with the greatest sediment loading. Therefore, the use of dams would do little to minimize downstream impacts associated with the excess sediment loads.

Other problems associated with the in-channel detention basins include interruption of fish passage, temporary disturbance of in-channel habitat within and near the basin, and potential dam-safety issues. Any of these problems would be greater for the larger-sized dams. Other issues that would have to be addressed include identification of acceptable trucking haul loads, disposal areas for the sediment that is removed from the detention basins, and impacts to existing habitat associated with construction and operation of the basins.

Sluice

A range of possible configurations for a sluice gate that could be used to flush sediment away from the inlet of the fish ladder that would be required under the dam stabilisation alternatives were evaluated to identify an appropriate configuration that would meet the sluicing objective, and would be practical and economical to construct. An initial evaluation of hydraulic capacities and the associated reservoir elevations indicates that a 3-metre diameter sluice gate with the invert about 1 metre below the invert of the fish ladder inlet would achieve this objective. A simplified sediment routing model was developed to analyse the behaviour of the sluice gate over a range of possible sluicing discharges up to about 30 cms. Results from the model indicate that a channel would rapidly incise into the upstream reservoir deposits, and the incision would progress upstream at rates that depend on the total discharge in the river and the reservoir water-surface elevation.

The rate of upstream progression of the incised channel depends on the discharge in the river, the hydraulic capacity of the sluice gate, and the resulting water-surface in the reservoir. The rates decrease at higher discharges because of the backwater effects caused by the increasing water-surface elevation in the reservoir.

Based on the total quantity of the sediment that could be eroded from the reservoir, and thus the amount that would be evacuated from the channel feeding to the fish ladder over various durations of sluicing operations, the optimum range of sluicing discharges occurs for 7 to 16 percent of the time, on average, during the fish passage period that generally extends from December 1 through May 31. This duration equates to about 11 to 28 days, during the 180-day period, on average.

The sediment eroded from the reservoir will cause a temporary increase in the sediment loads immediately downstream from the dam. This sediment will typically be in the sand and fine gravel-size range; thus, the river will be capable of re-entraining and transporting the material farther downstream relatively rapidly. For a 24-hour operation, about 3,700 cubic metres of sediment would accumulate, and most of this sediment would be re-entrained and removed from the reach after an additional 24 hours.

The sluicing operations will cause a temporary increase in sediment loads in the downstream river, with the magnitude of the effects diminishing with increasing distance downstream from the dam due to the effects of both temporary and more permanent storage of the relatively fine-grained sediment in eddy zones and other low energy areas along the reach.

The estimated baseline sediment yield to San Clemente Reservoir averages about 20,000 cubic metres per year, and results from the baseline conditions modeling from the previous analysis indicate that an average of about 15,000 cubic metres of sediment would pass over the dam during the simulation period under the dam stabilisation alternatives. The maximum sediment load from the sluicing operations represents about 60 percent of the annual sediment load to the downstream river for complete dam removal, and about 80 percent of the average annual load under the dam stabilisation alternatives. Although the initial incision into the reservoir deposits during sluicing operations will cause a temporary increase in the total sediment load to the downstream river, the total load passing the dam over the long-term will be similar to complete dam removal, because the incised channel will store sediment during intervening periods when the sluice gate is closed.

After repeated operations, the incision will likely progress farther upstream, which is expected to increase the time before sediment begins to affect the fish ladder during non-sluicing periods. Controlling the amount of flow into the fish ladder to maintain the reservoir level as high as possible would also lengthen the time between sluicing operations because of the increased effects of the backwater upstream from the dam.

For the notching scenarios, the sediment deposits at the lower level of the notch are somewhat finer than those at the surface; thus, the transport rates through the sluice gate would be somewhat higher and the incision would occur at a faster rate. This would remove more sediment from the upstream channel, increasing the area available for sediment deposition during the intervening periods between sluicing operations, but also increasing the sediment load to the downstream river. Because the eroded sediment will be finer, it will also be transported through the downstream reaches at a faster rate, limiting the potential for accumulation.

Bypass

Comparison of the computed water-surface elevations under existing and design conditions indicates that the initial diversion channel configuration required to establish a bypass connection creates significant upstream backwater in the Carmel River at flows greater than about the 2-year event. Because the backwater effects would induce sediment deposition in the Carmel River branch upstream from the diversion channel, the geometry of the diversion channel was adjusted to eliminate the hydraulic constriction at the inlet. The revised configuration of the diversion channel maintains a 50 to 65-metre wide bottom width

Because of the relatively steep gradient of the reconstructed reach of San Clemente Creek and the diversion channel, minor changes to the low-flow channel geometry will likely have insignificant effects on the hydraulic conditions in the upstream Carmel River branch of the reservoir. Results from the hydraulic analysis indicate that the proposed design will adequately convey the PMF of 2,400 cms.

The configuration of the bypass alternative is shown with shaded relief in Figure 11. The bypass alternative requires the construction of a diversion dike and excavation through the existing hillside amounting to approximately 180,000 cubic metres.

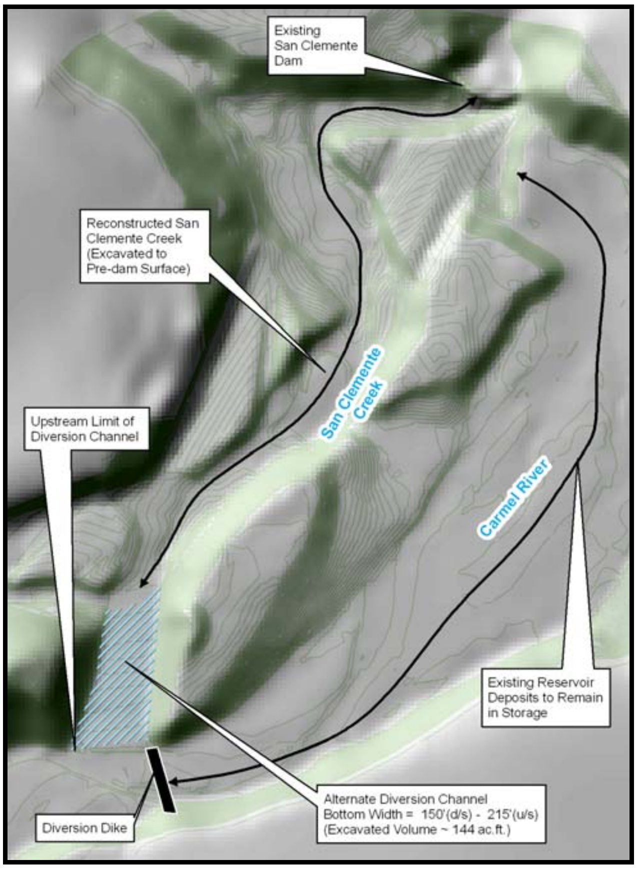

Figure 11. Diversion channel for bypass alternative

Alternative Selection

Following the evaluation of the hydrologic, hydraulic, and sediment transport modelling results, stakeholders met and decided to pursue the bypass alternative as the optimal balance for the project constraints. The notching scenarios were dismissed due to the environmental impacts and financial cost of accommodating the transported sediment. While the option to stabilise the dam and construct a sediment sluice is still under consideration as a lower-cost alternative, an agreement has been signed between the stakeholders to distribute planning, engineering, design, construction, and monitoring efforts associated with the implementation of the bypass alternative.

This alternative makes use of a tributary channel that has not experienced the same level of siltation as the mainstem creek. Utilising this corridor for the main flows represents a creative approach that was not initially part of the alternatives matrix but rather was developed during the process as various advantages and disadvantages of the other more standard approaches were being debated.

Implementation and Monitoring

Dam removal is anticipated to begin in 2013 with a three-year construction schedule. The removal of San Clemente Dam would constitute one of the largest dam removal projects to date in the United States. Several larger dams in the United States – including Matilija Dam in Southern California and Elwha Dam in Washington State – are likewise slated for removal along a similar timeline. The available data surrounding natural and induced habitat recovery following dam removal are notably sparse. These projects thus warrant significant monitoring efforts of the river system following project implementation in order to provide guidance and data that will contribute to the available science.

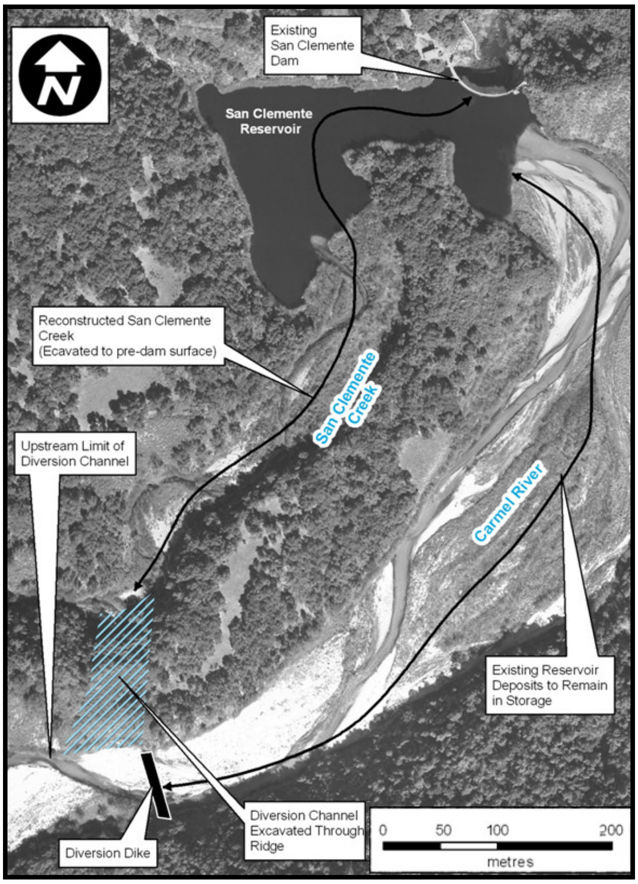

Figure 12. Features of preferred alternative

Application

San Clemente Dam and other overseas dam decommissioning efforts provide insights that may apply to similar systems in Australia as a significant number of large dams near the end of their design life in the coming decades. In Australia, Chanson and James documented siltation rates in reservoirs worldwide, including over twenty fully silted reservoirs in Australia (1999). Each of these cases is unique; however, the general lessons learnt in the San Clemente sedimentation studies – including the use of adjacent or historical tributary channels for diversion alternatives – may be warranted in some cases.

Conclusions

The complex and expensive consequences of reservoir siltation serve as a reminder to account for sluicing or potential decommissioning in future planning studies that are undertaken. Chanson admonishes that "fully-silted reservoirs stand as a source of embarrassment for scientists and for the public. Each reservoir failure must be a valuable teaching and pedagogic tool to heighten the awareness of students, professionals, local authorities, and the public." (Chanson 1998).

The U.S. Society of Dams, in their policy statement on decommissioning, state that "Decommissioning of dams is a reality that engineers and dam owners will be facing more and more in the next few decades. It is time to gather and begin to exchange ideas now. Costs associated with decommissioning can be many times the cost of repairs and upgrades. Much can be learned from reviewing the decision process from decommissioning case studies."

The decommissioning of San Clemente Dam will restore steelhead access to spawning and rearing habitat areas that are currently unavailable to the species and will remove an existing public safety hazard. This project will also address threats to the hydrologic and sediment regime, a critical step in providing riverine habitat conditions and characteristics that are consistent with the life history and habitat requirements of steelhead and many other species on the river.

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- U.S. Bureau of Reclamation

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