Appendix N

SUMMARY OF HYDRAULIC AND SEDIMENT-TRANSPORT ANALYSIS OF RESIDUAL SEDIMENT: ALTERNATIVES FOR THE SAN CLEMENTE DAM REMOVAL/RETROFIT PROJECT, CALIFORNIA
1. INTRODUCTION

Mussetter Engineering, Inc. (MEI) was retained by MWH Americas, Inc. (MWH) to perform an evaluation of the potential effects to the downstream river of residual sediment that would remain in the valley bottom during implementation of the Carmel River Bypass (Figure 1), Complete Removal and Dam Notching (Figure 2) Alternatives for the San Clemente Dam Removal/Retrofit project.

The baseline effects of the Bypass Alternative were evaluated in a previous study (MEI, 2005) under the assumption that all of the sediment deposits in the relevant portion of the reservoir would be excavated prior to removal of the dam. In practice, a portion of the existing deposits would likely remain in the valley bottom under either of the Complete Dam Removal or Bypass Alternatives because it is not practical to remove all of the sand from the pre-existing, coarse-grained bed material. In addition, depending on the actual design of either of these alternatives, it may be more practical to intentionally leave a limited amount of the existing deposits to provide material within which the reconstructed channel can adjust, rather than completely pre-forming the channel to the desired dimensions.

For the Dam Notching Option, the profile on the sediment deposits after excavation would intersect the pre-dam profile about one mile upstream from the dam in the Carmel River Branch and about 2,000 feet upstream from the dam in the San Clemente Creek Branch, assuming that the gradient across the remaining deposits after excavation is the same as the existing reservoir gradient (Figures 3 and 4). In the portion of the reach upstream from this intersection, the residual sediment issues will be similar to those for the Bypass and Complete Removal Alternatives. The sediment deposits beneath the reconstructed channel in the reach between the dam and the intersection with the pre-dam profile will be significantly finer than in the up- and downstream river, which will affect the transport rates and downstream sediment delivery.

Based on the above discussion, the following tasks were conducted to analyze the effects of the residual sediment under each of the three alternatives:
Carmel River Bypass Option

a. The HEC-6T sediment-routing model that was used to evaluate the Carmel River Bypass Option (MEI, 2005) was modified to reflect a residual sediment depth of 1.0 feet across the valley bottom.

b. Consistent with the previous modeling studies, the modified model was run with both the 1985 (dry starting period) and 1978 (wet starting period) hydrology.

Complete Dam Removal Option

a. Cross-sectional geometry was developed for appropriately sized, reconstructed channels in both the Carmel River and San Clemente Creek branches of the reservoir, with the channel profile at approximately the pre-dam elevations. A one-dimensional (1-D) step-backwater model of each reach was developed to evaluate the hydraulic conditions in the reconstructed reaches, and the resulting cross-sectional geometry was integrated into the HEC-6T sediment-routing model.

b. The HEC-6T sediment-routing model was modified to reflect the reconstructed channel geometry with a residual sediment depth of 1.0 feet.

c. The modified model was run for both the 1985 (dry starting period) and 1978 (wet starting period) hydrology.

Dam Notching Option

a. Cross-sectional geometry was developed for appropriately sized, reconstructed channels in both the Carmel River and San Clemente Creek branches of the reservoir, with the channel dimensions and gradient in the reach between the dam and the intersection with the pre-dam profile in each branch established to convey the inflowing baseload, and the profile upstream from that point at approximately the pre-dam elevations. This task included development and refinement of a 1-D step-backwater model of each reach to evaluate the hydraulic conditions in the reconstructed channels.

b. The HEC-6T sediment-routing model was modified to reflect the reconstructed channel geometry, with a residual sediment depth of 1.0 feet in the reaches upstream from the intersection of the excavated profile and the pre-dam bed elevations.

c. The modified model was run for both the 1985 (dry starting period) and 1978 (wet starting period) hydrology.

Results from each of the above described model runs were summarized and interpreted.

2. HYDRAULIC ANALYSIS

2.1. Model Development

A hydraulic analysis was performed to aid in developing appropriate profiles and cross-sectional shapes for the diversion channel and reconstructed reaches of the Carmel River and San
Clemente Creek under the Complete Dam Removal and Notching Alternatives, and the results were assessed to evaluate the hydraulic conditions and capacity of the resulting channels. The hydraulic analysis was performed using the U.S. Army Corps of Engineers’ one-dimensional (1-D) HEC-RAS step-backwater program, Version 3.1.3 (USACE, 2005).

2.1.1. Complete Dam Removal Alternative

Model topography for the reconstructed reaches of San Clemente Creek and the Carmel River was estimated based on the pre-dam (1921) 5-foot contour-interval mapping, under the assumption that the majority of the existing sediment deposits could be removed. The resulting slope is about 1.2 percent in the Carmel River Branch and about 2.5 percent in the San Clemente Creek Branch (Figures 5 and 6).

The cross-sectional geometry for the reconstructed channel was developed to convey between the 1.5- and 2-year peak discharges in each branch. Consistent with the original Carmel River Bypass Option design geometry (MEI, 2005), a two-stage, compound channel form was selected. The geometry in the Carmel River Branch includes a 20-foot wide, 1.8-foot deep low-flow channel and a 73-foot wide high-flow channel with an overall depth of 3.9 feet (Figure 7). In the San Clemente Creek Branch, the geometry includes an 8-foot wide, 0.8-foot deep low-flow channel and a 35-foot wide high-flow channel with an overall depth of 2.0 feet (Figure 8). The capacity of the low-flow channel is approximately 130 cfs and the capacity of the bankfull channel is approximately 1,330 cfs in the Carmel River branch, and the corresponding capacities in the San Clemente Creek branch are 20 and 318 cfs, respectively.

The cross-sectional geometry was inserted into the existing conditions model that was developed in MEI (2005) and executed over a range of flows including:

- the median flow at San Clemente Dam (15 cfs),
- the 2-year peak discharge (2,250 cfs),
- the maximum mean daily flow in the 41-year period of record from the CVSIM model (8,468 cfs),
- the 100-year peak discharge (22,700 cfs), and
- the probable maximum flood (PMF) that was estimated by CDWR to have a peak discharge of 81,200 cfs.

A roughness value (Manning’s $n$) of 0.035 was used for the main channel in the reconstructed reach of San Clemente Creek, and an $n$-value of 0.08 was used in the portion of the cross section that extends across the re-constructed floodplain to the valley wall under the assumption that vegetation will colonize the floodplain within a few years after construction.

2.1.2. Dam Notching Alternative

Under the Dam Notching Alternative, the profile on the sediment deposits after excavation will intersect the pre-dam profile about one mile upstream from the dam in the Carmel River Branch and about 2,000 feet upstream from the dam in the San Clemente Creek Branch, assuming that the gradient across the remaining deposits after excavation is the same as the existing reservoir gradient (Figures 3 and 4). In the portion of the reach upstream from this intersection, the residual sediment issues will be similar to those for the Bypass and Complete Removal Alternatives.
Consistent with the Bypass and Complete Dam Removal Alternatives, a two-stage channel was used to maintain reasonable flow depths and velocities over the range of flows. The channel in the Carmel River Branch includes a 20-foot wide, 1.8-foot deep low-flow channel bounded by a 76-foot wide high-flow channel with an overall depth of 4.5 feet (Figures 9 and 10). The bankfull capacity of the channel in the portion of the reach upstream from the intersection of the pre-dam surface is about 1,930 cfs approximately the 2-year flood peak and the low flow channel will convey about 130 cfs, and the bed-material transport capacity significantly exceeds the inflowing sediment load (Figures 11 and 12). Between the intersection and the dam, the low-flow channel capacity is about 35 cfs and the bankfull capacity only about 530 cfs due to the flatter slope. With this geometry, however, the transport capacity matches the inflowing sediment load very closely, indicating that the main channel in this reach will not significantly aggrade or degrade. The channel in this portion of the reach will eventually adjust to the 1.5- to 2-year peak by deepening as the overbanks continue to aggrade during the relatively frequent overbank flows.

The compound channel in the San Clemente Creek Branch includes an 8-foot wide, 0.8-foot deep low-flow channel bounded by a 35-foot wide high-flow channel with an overall depth of 2.0 feet (Figure 13). The capacities of the low flow and bankfull channels downstream from the intersection with the pre-dam surface are about 8 and 120 cfs, respectively, increasing to 20 and 320 cfs, respectively, in the upstream reach.

To establish the gradient of the channel across the remaining reservoir deposits under this alternative, it was assumed that the floodplain of the reconstructed channel will coincide with the crest elevation of the notch (506 feet), with the channel invert below the dam crest (Figure 3). To accommodate this configuration, a 4.5-foot deep by 30-foot wide low-flow notch will be cut into the lowered dam to convey the 2-year peak flow of 2,250 cfs under critical depth conditions.

2.2. Hydraulic Model Results

2.2.1. Complete Dam Removal Alternative

Under the Complete Dam Removal Alternative, the computed water-surface profiles in the Carmel River Branch indicate that the valley constriction in the vicinity of the existing dam causes a relatively significant backwater effect at flows greater than the 2-year peak (Figure 14). The backwater extends about 600 feet upstream from the constriction in the Carmel River branch and about 1,300 feet upstream in the San Clemente Creek branch at the 100-year discharge (Figure 15). The analysis also indicates that hydraulic jumps will occur at discharges greater than the 2-year event at other locations where the valley constricts the flow, causing a localized increase in energy slope. If this alternative is ultimately selected, it may be possible to eliminate some of these jumps at moderate flows in the 2- to 50-year range by adjusting the channel configuration and profile during the detailed design phase. At higher flows, the valley configuration controls the jumps, and it will probably not be possible to eliminate them. Given the infrequency of flows in this range, this is not considered to be a serious limitation of the Bypass option.

The model results indicate that average velocities in the reconstructed reach of the Carmel River Branch will range from about 2.4 fps at the median flow of 15 cfs to about 9 fps at the 2-year peak discharge of 2,250 cfs (combined Carmel River and San Clemente Creek flows).
Flow conditions at the 2-year peak are near-critical or supercritical. At the 100-year peak discharge, average main channel velocities are about 11.7 fps in areas with subcritical flow, but range up to 20.1 fps in supercritical areas. In the San Clemente Creek Branch, the average velocity is 1.7 fps at the median flow, increasing to 6.6 fps at the 2-year event and 10.7 fps at the 100-year event (Figure 17). Although the high velocities are expected given the relatively steep gradient of the reach, constraints on fish passage should be considered in the design phase.

**Table 1. Summary of average hydraulic parameters under the Complete Dam Removal Option for the median flow, the 2-year peak discharge, the 100-year peak discharge, and the PMF.**

<table>
<thead>
<tr>
<th>Flow</th>
<th>Discharge at Existing Dam (cfs)</th>
<th>Carmel Branch</th>
<th>San Clemente Creek Branch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Main Channel Velocity* (ft/s)</td>
<td>Hydraulic Depth* (ft)</td>
<td>Top Width* (ft)</td>
</tr>
<tr>
<td>Median Flow</td>
<td>15</td>
<td>2.5</td>
<td>0.4</td>
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<td>1.5-year Peak</td>
<td>1,193</td>
<td>7.7</td>
<td>2.1</td>
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<tr>
<td>2-year Peak</td>
<td>2,250</td>
<td>9.1</td>
<td>2.5</td>
</tr>
<tr>
<td>100-year Peak</td>
<td>22,700</td>
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<td>9.2</td>
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<tr>
<td>PMF</td>
<td>81,200</td>
<td>20.7</td>
<td>22.2</td>
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</table>

*Includes sections with supercritical flow.

### 2.2.2. Dam Notching Alternative

Under the Dam Notching Alternative, hydraulic conditions are similar to the Complete Dam Removal Alternative in both branches upstream from the intersection with the pre-dam surface, since the design geometries and channel profiles are similar. Downstream from the intersection, however, the significantly flatter slopes result in increased flow depths and top widths, and decreased velocities and energy gradients (Figures 18 and 19, Table 2). In the San Clemente Creek Branch, the backwater effects from the Carmel Branch extend about 200 feet upstream from confluence with the Carmel River at the 2-year peak flow, and about 2,000 feet upstream at the 100-year peak (Figure 19).

Downstream from the intersection in both branches, main channel velocities are relatively consistent at flows less than the 2-year event, when the flow is constrained to the reconstructed channel, but at flows greater than the 2-year event, constrictions in the valley cause locally high velocities (Figures 20 and 21). At the 2-year event, the average main channel velocity on the remaining reservoir deposits is about 4.0 fps in the Carmel River branch and about 3.4 fps in the San Clemente Creek Branch, increasing to 8.9 and 7.1 fps in the reaches upstream from the intersection with the pre-dam profile. Average main channel velocities downstream from the intersection for the 100-year event are about 9.1 and 3.6 fps in the Carmel River and San Clemente Creek Branches, respectively, increasing to 18.5 and 15.0 fps upstream from the intersection.
Table 2. Summary of average hydraulic parameters under the Notching Option for the median flow, the 2-year peak discharge, the 100-year peak discharge, and the PMF.

<table>
<thead>
<tr>
<th>Flow</th>
<th>Discharge at Existing Dam (cfs)</th>
<th>Main Channel Velocity* (ft/s)</th>
<th>Hydraulic Depth* (ft)</th>
<th>Top Width* (ft)</th>
<th>Energy Grade* (ft/ft)</th>
<th>Main Channel Velocity* (ft/s)</th>
<th>Hydraulic Depth* (ft)</th>
<th>Top Width* (ft)</th>
<th>Energy Grade* (ft/ft)</th>
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<tr>
<td></td>
<td>Carmel River Branch (Upstream)</td>
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<td>Carmel River Branch (Downstream)</td>
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<tr>
<td>Median Flow</td>
<td>15</td>
<td>2.6</td>
<td>0.4</td>
<td>14.9</td>
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<td>1.1</td>
<td>0.8</td>
<td>17.6</td>
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<td>San Clemente Creek (Downstream)</td>
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<td></td>
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<tr>
<td>Median Flow</td>
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<td>2-year Peak</td>
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<td>15.0</td>
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3. SEDIMENT-TRANSPORT ANALYSIS

The sediment-transport modeling for this study was performed using modified versions of the earlier HEC-6T models that were developed for MEI (2005). The following sections describe the model modifications and results.

3.1. Model Development

The following three scenarios were modeled for this study:

Scenario 1: the Carmel River Bypass Alternative,
Scenario 2: the Complete Dam Removal Alternative, and,
Scenario 3: the Dam Notching Alternative.

The model for each alternative was developed by substituting the cross sections discussed in the previous section into the appropriate locations in the existing conditions geometry file. No changes were made to the portion of the model that represents the river downstream from the dam for any of the scenarios. Consistent with the previous studies, two hydrologic scenarios were evaluated for each scenario to represent wet and dry conditions immediately after removal of the dam (1978 and 1985 start-dates, respectively).
3.1.1. Carmel River Bypass Alternative Model Development

The model geometry for the Carmel River Bypass Alternative was similar to the model geometry in MEI (2005), except that the channel bed geometry was adjusted in the reconstructed (Bypass) reach of San Clemente Reservoir by adding 1 foot of elevation to the cross section points located between the valley walls to account for the residual sediment (Figure 22). The sediment size-gradation in the 1-foot deep BSR between the diversion channel outlet and the dam was estimated based on the gradations for Zones 9A, 11, and 2A from MEI (2003) (Figures 23 and 24). Upstream from the diversion channel in the Carmel River Branch, the cross-sectional geometry and sediment gradation in the BSR was the same as that used in the MEI (2005) model. Consistent with the previous study, the portion of the Carmel River Branch that would remain in permanent storage below the diversion channel was not included in the model.

3.1.2. Complete Dam Removal Alternative Model Development

The model for the Complete Dam Removal Alternative was developed by inserting the cross-sectional geometry for both branches of the reservoir that was developed for this alternative (Section 2.1.1) into the existing conditions model. The geometry of the channel bed was then adjusted by adding 1 foot of elevation to the cross section points located between the valley walls to account for the residual sediments that would likely remain after excavation. The existing dam was removed from the model, and a BSR with a depth of 1-foot was added to the bottom of the model. The gradation of the BSR sediments in the Carmel Branch was based on Zones 9, 5, 3, 1, and 12, and Zones 9A, 11, 2A, and 1A in the San Clemente Creek Branch (Figures 23 and 24, Figure 25).

3.1.3. Dam Notching Alternative Model Development

The cross-sectional geometry for the Dam Notching Alternative Model was developed in a similar manner to the Complete Dam Removal Alternative by inserting the new geometry, as appropriate (Section 2.1.2), and adjusting the cross sections in the reach upstream from the intersection with the pre-dam surface to include an additional one foot of elevation along the channel bed to account for the residual sediment. Downstream from the intersection with the pre-dam profile, the BSR includes the portion of the reservoir deposits that will remain below the notched dam. The geometry of the dam was adjusted by lowering the crest to an elevation of 506 feet and adding the 30-foot wide, 4.5-foot deep low flow notch to tie into the assumed geometry of the upstream reconstructed channel. Based on the profiles shown in Figures 23 and 25, the gradation of the BSR was adjusted to include Zones 8, 5, 3, 1 and 12 in the Carmel River Branch, and Zones 10, 2A and 1A in the San Clemente Creek Branch.

3.2. Reservoir Model Results

Results from the sediment-transport models were evaluated to determine the effects of the alternatives on the timing, volume, and distribution of sediments evacuated from the reservoir and deposited in the downstream Carmel River. Potential impacts were evaluated by comparing results from each of the alternatives with results from the baseline (with dam) conditions model that was presented in MEI (2005) that represents the no-action or dam-thickening alternatives. The results from the Carmel River Bypass Alternative were also
compared to the Bypass Alternative with no BSR from MEI (2005) to assess the effects of the residual sediments.

3.2.1. Carmel River Bypass Alternative

The general direction and magnitude of the predicted responses for the Carmel River Bypass Alternative are very similar to those from the earlier study (Carmel River Bypass Alternative with no BSR), but there are differences that are important to interpretation of the effects of the BSR for the other alternatives evaluated in this study. The total volume of sediment passing the existing dam location at the end of the 41-year simulation is about 556 ac-ft for the flow sequence with the 1985 start-date and about 576 ac-ft for the 1978 start date (Figures 26 and 27). This represents an increase of 12 to 15 ac-ft over the results from the previous model with no BSR. Because the HEC-6T program interprets the BSR as the depth below the cross section thalweg elevation to which any point along the cross section can erode, it is possible for more than one foot of erosion to occur outside of the low-flow channel (Figure 28). This interpretation of the BSR is believed to reasonably reflect conditions after excavation to the pre-dam surface that will likely include areas where the residual sediments are more than 1 foot deep, or where the pre-dam surface included fine-grained alluvial deposits.

The total load passing the existing dam location is 12 percent (1985 start date) to 14 percent (1978 start date) higher than under baseline conditions. Most of the increase occurs in the gravel and cobble size-ranges, with a volume of about 70 ac-ft under both start dates compared to about 23 ac-ft under baseline conditions (Figure 29). This indicates that about 77 percent of the inflowing gravel would be transported to the existing dam location, compared to 25 percent under baseline conditions. The results also indicate that 97 ac-ft (1978 start date) to 117 ac-ft (1985 start date) of additional sediment is stored in the reservoir upstream from the existing dam location (Figures 30 and 31). Despite net storage, 15 ac-ft (1985 start date) to 28 ac-ft (1978 start date) of material is eroded from the residual sediments in the reconstructed reach of San Clemente Creek, and therefore, between 128 and 132 ac-ft is stored on the Carmel River delta upstream from the diversion channel.

3.2.2. Complete Dam Removal Alternative

Results from the Complete Dam Removal Alternative indicate that this option has the largest impact on sediment loading to the downstream river, with about 670 ac-ft of total load passing the dam at the end of the 41-year simulation with both start dates (Figures 26 and 27). This represents a 30 percent increase over baseline conditions. The majority of the increase occurs in the coarse sand and gravel size ranges, with about 380 ac-ft of medium to coarse sand and 104 ac-ft of gravel (Figure 29). This indicates that all of the inflowing sand and gravel is transported to the existing dam location, and an additional 13 ac-ft of gravel is entrained from the upstream portion of the delta and transported to the location of the existing dam, representing an increase of about 14 percent over baseline conditions. The increased loading at the location of the existing dam is primarily due to the removal of the flat portions of the delta and the relatively large amount of residual sediment that is exposed in the reconstructed channel bed and overbanks in the Carmel River Branch. As expected, the amount of sediment stored in the existing reservoir is significantly less than under the other alternatives, with only about 3 ac-ft (1985 start date) to 4 ac-ft (1978 start date) of material that is primarily stored in the overbanks of the reconstructed channel in areas where the valley widens and the energy gradient flattens at higher flows.
3.2.3. Dam Notching Alternative

Results from the Dam Notching Alternative indicate that the total load passing over the reconfigured dam during the 41-year simulation period is similar to the Carmel River Bypass Alternative [573 ac-ft (1985 start date) to 585 ac-ft (1978 start date)] (Figures 24 and 25). The primary difference in the sediment loading over the notched dam is an increase in the amount of fine material and a decrease in the amount of gravel. Under the Dam Notching Alternative, 197 ac-ft (1985 start date) to 201 ac-ft (1978 start date) of very fine to fine sand is delivered over the dam, compared to 172 to 178 ac-ft of this material under the Bypass Alternative. The volume of gravel passing the dam is 55 ac-ft (1978 start date) to 59 ac-ft (1985 start date), compared to about 70 ac-ft under the Bypass Alternative. These gravel volumes represent 60 percent (1978 start date) to 65 percent (1985 start date) of the inflowing gravel. The increased fine material loads and the decreased gravel loads passing over the dam result from the reduced gradient and transport capacity of the reconstructed reaches downstream from the intersection with the pre-dam surface. The increase in fine sediment loading results in an overall reduction in the amount of material trapped in the reservoir [100 ac-ft (1985 start date) to 89 ac-ft (1978 start date), compared to 97 to 117 ac-ft under the Bypass Alternative, and 177 to 168 ac-ft under the baseline conditions].

3.3. Model Results for the Carmel River Downstream from the Existing Dam

Potential impacts of the alternatives on the river downstream from the dam were assessed based on the magnitude of sediment storage along the reach and the resulting changes in bed elevation, the effects of these changes on flood potential, and the volume of gravels that remain in storage within the main channel. The evaluations were performed on a reach-by-reach basis using the 10 subreaches that were identified in MEI (2002a) (Table 3).

3.3.1. Sediment Storage Volumes

Under the Bypass Option with one foot BSR to account for the residual sediment in the reconstructed reach of San Clemente Creek, the maximum increase in the total volume of sediment stored in the river during the simulation period is about 19 ac-ft, occurring in the sixth year of the simulation for the 1978 start date and the eighth year of the simulation for the 1985 start date (Figures 32 and 33). For the 1978 start date, the curves in Figure 32 for the Bypass Alternative (with and without the BSR) are generally parallel after the first 10 years of the simulation, indicating that no additional sediment accumulates in the river after this time. Interestingly, for the 1985 start date (Figure 33), after the initial increase in sediment deposition that occurs in Years 8 through 10, the curves for the Bypass Alternative (with and without the BSR) slowly converge, indicating that the river eventually recovers from the effects of the residual sediments. This difference in the 1978 and 1985 start dates is likely a result of relatively large amounts of coarse material that are deposited in the river at the beginning of the 1978 start-date simulation and armor the channel bed, thereby protecting the underlying finer material. This process does not occur to the same extent under the 1985 start-date simulation. The total volume of material that is deposited in the river at the end of the simulation ranges from 57 ac-ft (1985 start date) to 73 ac-ft (1978 start date), a moderate increase over the baseline (with dam) conditions that represents 10 to 12 percent increase in the load passing the location of the existing dam (Figure 34). The distribution of sediment storage along the reach varies significantly, with net degradation in Subreaches 8.3 and 8.7, little or no net degradation or aggradation in Subreaches 6.3 and 6.7, and net aggradation in the remainder of the reach.
Subreach 9, downstream from Highway 1, is the most strongly aggradational of the subreaches. Of the above storage volumes, 74 percent (1978 start-date) to 79 percent (1985 start-date) is located in the overbanks, and the remainder is in the main channel of the river. The model results also indicate that 2 ac-ft (1978 start-date) to 9 ac-ft (1985 start-date) of gravel is stored in the main channel at the end of the simulation (Figure 36). The majority of the gravel is stored in the lagoon area downstream from Highway 1 (Subreach 9) and in the reach between Robinson Canyon and Shulte Road (Subreaches 7.3 and 7.7), while some depletion of gravel occurs between Garzas Creek and Randazzo Bridge (Subreach 6.7) and between Valley Green Bridge and Highway 1 (Subreach 8.7).

As expected, the volume of sediment stored in the river at the end of the simulation is larger under the Complete Dam Removal Alternative (Scenario 2) than under the other alternatives since the trapping effect of the reservoir is completely removed. Under this scenario, 123 ac-ft (1985 start date) to 170 ac-ft (1978 start date) of sediments are stored in the river at the end of the 41-year simulation, or about 18 to 25 percent of the inflowing sediment load passing the location of the existing dam (Figures 32 through 34). The model results indicate that in-channel degradation will occur in Subreach 6.7 for both start-dates (Figures 35a and 35b). Subreaches 8.3 and 8.7 would be essentially in equilibrium, and aggradation will occur in the remaining subreaches. Consistent with the Bypass Alternative (Scenario 1), Subreach 9 is the most strongly aggradational. Because the reconstructed reaches of the reservoir deliver all of the inflowing gravel to the downstream river, the volume of in-channel gravels is higher than the other alternatives, with about 18 ac-ft (1978 start date) to 35 ac-ft (1985 start date) stored in the main channel at the end of the simulation. In spite of the overall increase in gravel storage, there is net depletion of gravel in Subreach 6.7 with both start dates and in Subreach 7.3 with the 1978 start date, and insignificant net change in Subreaches 8.3 and 8.7 (Figure 36).

Under the Notching Alternative, 58 ac-ft (1978 start date) to 60 ac-ft (1985 start date) of total sediment is stored in the river at the end of the simulation, a slight increase over baseline (with-dam) conditions due to the larger volume of coarse material that passes the dam. This represents about 10 percent of the load passing over the notched dam, similar to the percentage under Scenario 1. The distribution of sediment along the reach is also similar to Scenario 1 (Figures 35a and 35b), with generally less aggradation in the upstream three subreaches. For the overall downstream river, about 6 ac-ft (1978 start date) to 7 ac-ft (1985 start date) of additional gravel is stored in the main channel, similar in magnitude and distribution to Scenario 1 but substantially less than under Scenario 2 (Figure 36).

These results indicate that the Complete Dam Removal Alternative would result in more sediment storage in the river over the long-term than would occur under either the Bypass or Dam Notching Alternatives, and the differences between the Bypass Alternative and the Dam Notching Alternative are likely within the uncertainty in the model. In addition, the impacts of each of the alternatives evaluated in this study to the downstream river are relatively small compared to the impacts that would occur under the previously analyzed dam notching and dam removal scenarios (Figure 37).

### 3.3.2. Reach-averaged Bed Elevation Change

As an additional step in understanding the potential effects of the additional sediment storage in the river, the change in mean bed elevation at the end of the 41-year simulation was computed for each of the subreaches using methods described in MEI (2003). As discussed in MEI
As expected, the largest changes in bed elevation occur under the Complete Dam Removal Alternative (Scenario 2) because the changes in in-channel sediment storage are greatest under this scenario. The overall change is, however, relatively small, with a distance-weighted average increase of about 0.1 feet over the entire reach. The largest changes occur in the upstream subreaches (Subreaches 4.3, 4.7, and 5), with increases of 0.24 to 0.43 feet at the end of the simulation. Average increases of about 0.2 feet occur in Subreaches 7.3 and 7.7, and Subreaches 6.3 and 9 increases by about 0.15 feet. A net decrease in bed elevation of about 0.11 feet occurs in Subreach 6.7, and the remainder of the subreaches (Subreaches 8.3 and 8.7) show essentially no change in mean bed elevation.

Under the Dam Notching Alternative (Scenario 3), the patterns of aggradation and degradation through the study reach are similar to those under Scenario 1, but the changes are slightly smaller in most areas. Exceptions occur in Subreaches 7.7 and 9, where the increase in mean bed elevation is slightly larger than predicted under Scenario 1.

3.3.3. Effects of Sediment Storage on Flood Conditions

The effects of the indicated aggradation or degradation on flood potential along the reach under each scenario were evaluated by importing the cross sections from the HEC-6T model into a detailed HEC-2 step-backwater model that includes all of the bridges and other hydraulic controls along the reach, running each model with the 100-year peak discharge, and comparing the resulting water-surface profiles. The specific steps that were used in the evaluation were as follows:

1. The year during the simulation when the aggradation impacts on April 1 are largest was identified for each of the 10 subreaches. A separate, modified floodplain model was then developed for the worst-case conditions within each subreach by substituting the cross-sectional geometry from the HEC-6T model for the target year into the existing conditions floodplain model. This resulted in the development of 10 separate models for each HEC-6T model run.

2. The updated floodplain models for each case were then run with the 100-year peak discharge to develop a 100-year water-surface profile for the entire study reach.

3. An envelope water-surface profile incorporating the highest 100-year water-surface elevation at each cross section was then developed, and this envelope profile was compared to the 100-year profile under existing conditions.

The results from this analysis indicate that the flooding impact is about the same and relatively small under the Bypass Option and the Notching Option, and the impact under the Complete
Dam Removal Option is somewhat larger, especially in the upstream subreaches (Figure 39 and 40). To aid in comparing results among the alternatives and subreaches, distance-weighted average increase in water-surface elevation were computed for each of the subreaches (Figures 41 and 42). The results generally indicate that, under each of the alternatives, the most significant changes from existing conditions occur in the upstream portion of the study reach (Subreaches 4.3, 4.7, and 4.5), with the most significant impacts occurring under the Complete Dam Removal Alternative. Under this scenario, the average change in water-surface elevation ranges from 0.25 to 0.40 feet, with worst-case increases of as much as 2.2 feet in certain locations (Figures 39 and 40). Under the other two alternatives, the maximum increase in water-surface elevation ranges from 0.03 feet (Subreach 5, Dam Notching Alternative, 1985 start date) to about 0.2 feet (Subreach 4.3, Carmel River Bypass Alternative, 1978 start date). Downstream from the Boronda Bridge (Subreaches 6.7 through 9), the worst-case increases in water-surface elevation are relatively small for each of the alternatives (except for the relatively large increase that occurs upstream from Rancho San Carlos Road Bridge), and the differences among the three alternatives are relatively insignificant.

4. SUMMARY AND CONCLUSIONS

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 Carmel River Bypass, Complete Dam Removal and Dam Notching Alternatives for the San Clemente Dam Removal/Retrofit project. A variety of analyses were performed to complete this evaluation, including the following:

1. 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 under the Complete Dam Removal and Dam Notching Alternatives.

2. Sediment-transport modeling to evaluate the sediment-transport characteristics through the reservoir and impacts to the downstream river for each of the three scenarios, and

3. An additional hydraulic analysis to evaluate the potential effect of changes in sediment storage on flood potential in the downstream river.

The reconstructed channel through the existing reservoir under the Complete Dam Removal Scenario was sized to convey between the 1.5- and 2-year peak discharge. For the Dam Notching Alternative, the selected channel dimensions will convey the 2-year peak discharge upstream from the intersection with the pre-dam surface with transport capacity that exceeds the upstream supply. In the flatter reach across the remaining reservoir deposits, the bankfull capacity is only about 530 cfs, but the transport capacity is approximately in balance with the upstream supply.

Sediment-transport modeling was conducted for each of the three scenarios to determine the pattern of sediment erosion and transport over a simulated 41-year period, both within the existing reservoir and downstream into the Carmel River. The model results generally indicate that the impacts to the downstream river for the Bypass and Dam Notching Alternatives will be similar to those for baseline (with dam) conditions. The impacts from the Complete Dam Removal Option are somewhat greater, but generally on the same order-of-magnitude, as
baseline conditions. Under the Complete Dam Removal Alternative, very little additional sediment would be stored in the reservoir over the 41-year simulation period, compared to nearly 180 ac-ft under the baseline (with dam) conditions (Figure 43). The total volume of sediment stored in the downstream river is also relatively small, ranging from 57 ac-ft under the Bypass Alternative to 127 ac-ft under the Complete Dam Removal Alternative.

The impact of the indicated changes in sediment storage on flood potential is also relatively small. Under the Bypass and Dam Notching Alternatives, average changes in 100-year water-surface elevation of 0.1 to 0.2 feet occur in the portion of the reach upstream from Rosie’s Bridge, but increase to between 0.2 and 0.4 feet under the Complete Dam Removal Alternative. The differences in water surface in the downstream portions of the reach are considerably smaller, with average changes of less than 0.1 feet for the Bypass and Dam Notching Alternatives, and less than about 0.15 feet for the Complete Dam Removal Alternative.

5. REFERENCES


Figure 1. Proposed elements of the Carmel River Bypass Alternative.
Figure 2. Proposed elements of the Complete Dam Removal and Dam Notching Alternatives.
**Figure 3.** Longitudinal profile of the existing reservoir deposits, the pre-dam surface, and the constructed profile under the Notching Alternative in the Carmel Branch of San Clemente Reservoir.
Figure 4. Longitudinal profile of the existing reservoir deposits, the pre-dam surface, and the constructed profile under the Notching Alternative in the San Clemente Creek Branch of San Clemente Reservoir.
Figure 5. Profiles of the existing sediment deposits and reconstructed reach of the Carmel River Branch for the Complete Dam Removal Alternative.
Figure 6. Profiles of the existing sediment deposits and reconstructed reach of the San Clemente Creek Branch for the Complete Dam Removal Alternative.
Figure 7. Typical cross section and design channel geometry for the reconstructed reach of the Carmel River Branch under the Complete Dam Removal Alternative.
Figure 8. Typical cross section and design channel geometry for the reconstructed reach of the San Clemente Creek Branch under the Complete Dam Removal Alternative.
Figure 9. Typical cross section and design channel geometry (upstream from the intersection with the pre-dam surface) for the reconstructed reach of the Carmel Branch under the Notching Alternative.
Figure 10. Typical cross section and design channel geometry (downstream from the intersection with the pre-dam surface) for the reconstructed reach of the Carmel Branch under the Notching Alternative.
Figure 11. Inflowing sediment load (base load) and computed transport capacity of the reconstructed reach of the Carmel River between the dam and the intersection with the pre-dam surface.
Figure 12. Computed peak flood-frequency curve for the combined flow (based on the Robles Del Rio flood-frequency analysis), and for the Carmel River and San Clemente Creek Branches of San Clemente Reservoir (as discussed in MEI, 2005).
Figure 13. Typical cross section and design channel geometry for the reconstructed reach of the San Clemente Creek Branch under the Notching Alternative.
Figure 14. Computed water-surface profiles for selected discharges in the Carmel Branch of San Clemente Reservoir under the Complete Dam Removal Alternative.
Figure 15. Computed water-surface profiles for selected discharges in the San Clemente Creek Branch of San Clemente Reservoir under the Complete Dam Removal Alternative.
Figure 16. Computed main-channel velocity profiles for selected discharges in the Carmel River Branch of San Clemente Reservoir under the Complete Dam Removal Alternative.
Figure 17. Computed main-channel velocity profiles for selected discharges in the San Clemente Creek Branch of San Clemente Reservoir under the Complete Dam Removal Alternative.
Figure 18. Computed water-surface profiles for selected discharges in the Carmel Branch of San Clemente Reservoir under the Notching Alternative.
Figure 19. Computed water-surface profiles for selected discharges in the San Clemente Creek Branch of San Clemente Reservoir under the Notching Alternative.
Figure 20. Computed main-channel velocity profiles for selected discharges in the Carmel Branch of San Clemente Reservoir under the Notching Alternative.
Figure 21. Computed main-channel velocity profiles for selected discharges in the San Clemente Creek Branch of San Clemente Reservoir under the Notching Alternative.
Figure 22. Typical cross section in the reconstructed reach of San Clemente Creek under the Carmel River Bypass Alternative showing the existing section, the pre-dam (1921) section, the design section (MEI, 2005), and the adjusted design section for this study.
Figure 23. Profile of reservoir sediment zones and the channel invert for the Bypass, the Complete Dam Removal, and for the Notching Alternatives, San Clemente Creek Branch of San Clemente Reservoir.
Summary of Hydraulic and Sediment-transport Analysis of Residual Sediment: Alternatives for the San Clemente Dam Removal/Retrofit Project, California

Figure 24. Gradation curves for the model sediment zones (from MEI, 2005).
Figure 25. Profile of reservoir sediment zones and the channel invert for the Complete Dam Removal Alternative and for the Notching Alternative, Carmel Branch of San Clemente Reservoir.
Figure 26. Inflowing base load and estimated sediment load passing the location of the existing dam for baseline (with dam) conditions evaluated in MEI (2005) and for the Bypass, Complete Dam Removal, and Notching Alternatives evaluated in this study (1978 start date). Also shown are the results from the Bypass Alternative with no BSR evaluated in MEI (2005) for the 1978 start date.
Figure 27. Inflowing base load and computed sediment load passing the location of the existing dam for baseline (with dam) conditions evaluated in MEI (2005) and for the Bypass, Complete Dam Removal, and Notching Alternatives evaluated in this study (1985 start date). Also shown are the results from the Bypass Alternative with no BSR evaluated in MEI (2005) for the 1985 start date.
Figure 28. Typical cross section in the reconstructed reach of San Clemente Creek showing erosion of sediments in excess of 1.0 feet in the overbanks.
Figure 29. Total bed-material load, by size-range, passing San Clemente Dam during the 41-year simulation for baseline (with-dam) conditions evaluated in MEI (2005) and the Bypass, Complete Dam Removal, and Notching Alternatives for this study. Also shown is total sediment supply to the reservoir.
Figure 30. Total volume of sediment trapped in the reservoir (upstream of the existing dam) during the 41-year simulation for the baseline (with dam) conditions evaluated in MEI (2005) and for the Bypass, Complete Dam Removal, and Notching Alternatives in this study (1978 start date).
Figure 31.  Total volume of sediment trapped in the reservoir (upstream of the existing dam) during the 41-year simulation for the baseline (with dam) conditions evaluated in MEI (2005) and for the Bypass, Complete Dam Removal, and Notching Alternatives in this study (1985 start date).
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Figure 32. Total volume of sediment stored in the Carmel River downstream from San Clemente Dam for the 41-year simulation under baseline (with dam) conditions evaluated in MEI (2005) and for the Alternatives evaluated in this study (1978 start date).
Figure 33. Total volume of sediment stored in the Carmel River downstream from San Clemente Dam for the 41-year simulation under baseline (with dam) conditions evaluated in MEI (2005) and for the Alternatives evaluated in this study (1985 start date).
Figure 34. Total volume of sediment stored in the downstream Carmel River for the baseline (with dam) scenario (MEI, 2005) and the alternatives evaluated in this study.
**Figure 35a.** Sediment volume stored in the river downstream from San Clemente Dam at the end of the 41-year simulation, by subreach, for the baseline (with dam) conditions evaluated in MEI (2005) and for the alternatives evaluated in this study (1978 start-date).

**Figure 35b.** Sediment volume stored in the river downstream from San Clemente Dam at the end of the 41-year simulation, by subreach, for the baseline (with dam) conditions evaluated in MEI (2005) and for the alternatives evaluated in this study (1985 start-date).
Figure 36. Volume of gravels stored in the main channel in each of the subreaches under the baseline (with dam) conditions evaluated in MEI (2005) and under the alternatives evaluated in this study.
Figure 37. Comparison of total sediment volume stored in the Carmel River below the existing dam location at the end of the 41-year simulation under scenarios evaluated in MEI (2003) and evaluated for this study.
Figure 38. Change in mean bed elevation at the end of the simulation for each of the subreaches under the baseline (with dam) conditions evaluated in MEI (2005) and under the alternatives evaluated in this study.
Figure 39. Maximum difference in 100-year water-surface elevation from existing conditions for the alternatives evaluated in this study (1978 start date).
Figure 40. Maximum difference in 100-year water-surface elevation from existing conditions for the alternatives evaluated in this study (1985 start date).
Figure 41. Distance-weighted average difference in maximum 100-year water-surface elevation from existing conditions, by subreach, for the alternatives evaluated in this study (1978 start date).
Figure 42. Distance-weighted average difference in maximum 100-year water-surface elevation from existing conditions, by subreach, for the alternatives evaluated in this study (1985 start date).
Figure 43. Summary of sediment-transport modeling results at the end of the 41-year simulation.