Chapter 5

Simulation of dam impacts at the Searsville Lake watershed

Abstract

A physics-based hydrologic-response model with sediment-transport capabilities, the Integrated Hydrology Model (InHM), is used to simulate the long-term hydrologic and geomorphologic impacts of dam construction and removal for the Searsville Lake watershed in Portola Valley, California. Four dam-related scenarios (pre-dam, early dam, current, and post-dam) are considered. For each scenario an InHM boundary-value problem is constructed based on the available watershed information including topography, reservoir bathymetry, geology, soils, land use, and climate. Each scenario is simulated with InHM using the same ten-year sequence of synthetically-generated rainfall and evapotranspiration. The simulation results are presented in terms of temporal characteristics (i.e., annual water balance components, sediment discharge, and peak discharge) and spatial characteristics (i.e., maps of simulated saturation, evapotranspiration and exchange fluxes, water table elevation, and sediment concentration). An event-based sensitivity analysis indicates which model parameters exert the greatest control over the simulated watershed response and gives a measure of the parameter-related uncertainty in the model predictions. Commonalities and differences between the four scenarios are discussed. The effort described here demonstrates that physics-based modeling can provide a useful characterization of dam-related impacts on hydrologic and geomorphologic processes at the watershed scale.
5.1 Introduction

The upstream impacts of dams on hydrologic and geomorphologic watershed processes stem from a rise in hydrologic base level. These impacts include but are not limited to (i) inundation of previously exposed land surface, (ii) a rise in the water table near the reservoir, (iii) decreased surface water velocities and sediment transport capacity in the inundated channel areas, (iv) deposition of sediment in the reservoir, and (v) evaporation from the reservoir. Dam removal, on the other hand, causes a drop in hydrologic base level, and is expected to impact the upstream watershed in an opposite fashion. Dam removal impacts include, for example, re-exposure of inundated land surface, a drop in the water table near the reservoir, and net erosion of sediment from the reservoir area. The removal of older dams, especially those whose usefulness as a water storage location has been compromised by large upstream sediment deposits, is becoming a more common and accepted practice (Pohl, 2003) and can improve the ecology of the river system by reconnecting once disconnected reaches (Gup, 1994; Ward and Stanford, 1995; Stanley et al., 2002). As dam removal becomes more common, the issues associated with dam removal impacts are emerging into a new cross-disciplinary field of study in the natural sciences (Grant, 2001; Doyle et al., 2003a).

Few of the studies in this emerging field have focused on the upstream impacts of dam removal. The downstream transport of sediment from a dam removal site has been studied extensively (e.g., Williams, 1977; Blodgett, 1989; Simons and Simons, 1991; Stoker and Williams, 1991; Egan et al., 2000; Stillwater Sciences, 2000; Doyle et al., 2002; Pizzuto, 2002; Stanley et al., 2002; Doyle et al., 2003b), presumably due to concerns about sediment aggradation in the downstream channel and the possibility of contaminated sediment exposure and mobilization. While downstream impacts mainly concern the hydrologic and geomorphologic regime of the channel, upstream impacts are more closely tied to the decrease in hydraulic head of the surface and subsurface flow systems (expressed most noticeably by the decrease in surface water depth and water table elevation) in an broader area surrounding the former reservoir called the zone of influence. In particular, the hydrology within the zone of influence
can exert first-order controls over the existence of wetlands in certain topographic settings. Therefore consideration of the upstream domain should not be overlooked when approaching the dam removal question.

5.2 The Searsville Lake Watershed

The focus of the effort described here is the Searsville Lake watershed, in Portola Valley, California. The 39 km² watershed (Figure 5.1), with Searsville Dam and the surrounding wetland at its base, provides an opportunity to examine a “real-world” dammed system on a scale that is manageable within the physics-based modeling approach. The fact that dam management alternatives for Searsville include dam removal (as well as other base-level changing options such as dam lowering) also motivates interest in this particular watershed (http://jrbp.stanford.edu/watershed.php, accessed January 5, 2007).

5.2.1 Land Use History

The Searsville Lake watershed was inhabited for many centuries (i.e., at least 5,000 years) by indigenous people belonging to the loose-knit group of native Americans called the Ohlone, which occupied the entire San Francisco Bay area (Emanuels, 1994; Costo and Costo, 1995). The native people lived as hunter-gatherers and had a light and sustainable impact on the natural surroundings. The first Europeans to visit the area were members of the expedition up the California coast led by the Spanish explorer Gaspar de Portola in 1769. Following the initial phase of exploration, California was quickly settled by missionaries who established a string of missions extending from San Diego to Solano, including the Mission Santa Clara de Asís about 25 km east of the Searsville watershed (Hoover et al., 1990). The continued arrival of European settlers through the middle of the 19th century brought increased resource utilization in the area, especially in the form of logging of old-growth redwood forests for timber. Following the dismantling of the mission system the land was divided into ranchos, most prominently the Rancho Canada del Corte de Madera (Hoover et al., 1990).
Figure 5.1. Location map for the Searsville Lake watershed showing surface water features, land use boundaries, and locations of field measurements (see Table 5.1 for specific measurement information). The base image is a shaded-relief DEM with a 10-m horizontal resolution (USGS Mapping Division).
Today the Searsville Lake watershed is composed of a mixture of high-value residential property, small farms and vineyards, and rugged forested slopes. Within the watershed there are three open space preserves (i.e., Coal Creek, Windy Hill, and Thornewood) belonging to the Mid-Peninsula Regional Open Space District, as well as Wunderlich Park, part of the San Mateo County park system.

Construction of Searsville Dam downstream of the confluence of Corte Madera, Sausal, Dennis Martin, and Alambique Creeks was completed in 1891 by the Manzanita Valley Water Company. Originally intended as a water supply for Stanford University, the lake was never used as a potable water source due to the high concentration of suspended sediment. The lake was used for recreation for much of the early 20th century, with grazing and scientific research occurring on Stanford-owned lands nearby. The Jasper Ridge Biological Preserve, which includes Searsville Lake and wetland and Jasper Ridge, was formally designated in 1973 by Stanford University, restricting public access and dedicating the land to scientific research.

5.2.2 Watershed Properties
5.2.2.1 Geologic Setting

The Searsville watershed lies on the eastern side of the Santa Cruz Mountains, a part of the California Coast Range. The range in elevation is from 102 m at the dam spillway to approximately 792 m along the southeastern boundary (see Figure 5.2a). The San Andreas Fault, shown in Figure 5.1, is a right-lateral strike-slip fault with minor compression that traverses the watershed from southeast to northwest, defining the linear valley along which Sausal Creek flows, and separating older Cretaceous rocks on the north side from younger Eocene rocks on the south side. The Pilarcitos Fault, also a right-lateral strike-slip fault, runs roughly parallel to the San Andreas Fault. The geology of the watershed (see Figure 5.2c) has been mapped on several occasions (e.g., Diblee, Jr., 1966; Brabb et al., 2000; Coleman, 2004). The principle rock types are sedimentary: shales of the Lambert, San Lorenzo, and Monterey formations; massive sandstones of the Purisima, Whiskey Hill, and Butano formations; the weakly consolidated gravelly/sandy conglomerate of the Santa Clara
Figure 5.2. Searsville Lake watershed geographic information. (a) Topographic contours, ranging from 83 m above sea level at the catchment outlet (below the dam) to 782 m above sea level in the southeast corner; the green contour is 190 m, the yellow contour is 390 m, and the red contour is 630 m (adapted from USGS DEM; Northwest Hydraulic Consultants, Inc., 2002). (b) Soil associations (after Lindsey, 1970); see Table 5.2 for texture and depth characteristics of each association. (c) Surface geology, with units listed generally in order of increasing age (adapted from Diblee, Jr., 1961; Brabb et al., 2000; Coleman, 2004). (d) Land cover (adapted from the National Land Cover Database).
Formation; and unconsolidated alluvium. Small areas of intrusive basaltic rock occur in the upper elevations of the southeast corner of the watershed. Within the Jasper Ridge Biological Preserve and the lower foothills north of the San Andreas Fault are outcrops of the Franciscan formation, consisting of metamorphosed marine sedimentary and volcanic rocks, typically greenstone. Slope instability in the steep mountainous areas has resulted in many small landslides, which are regularly re-activated by hydrologic and seismic forces.

5.2.2.2 Hydrologic Features

The Searsville watershed contains several surface streams that flow perennially except in the driest years (see Figure 5.1). Three major streams drain directly into the Searsville Lake wetland from the south and west: Alambique Creek, Sausal Creek, and Corte Madera Creek. Westridge Creek drains into Corte Madera Creek from the eastern foothills shortly before the latter enters the wetland area. A small tributary whose drainage area is comprised of parts of the Jasper Ridge enters Searsville Lake from the east side. Sausal Creek and the upper reaches of Corte Madera Creek are fed by several smaller streams which emanate from the steep forested hillslopes that make up the entire southwestern portion of the watershed. An important tributary to Sausal Creek is Dennis Martin Creek.

5.2.2.3 Topographic Attributes

Figure 5.3 shows certain topographic attributes of the Searsville watershed. The map of surface slope (Figure 5.3a) clearly shows the three hydrographic areas: the steep upland area in the west, the flat narrow valley along the San Andreas Fault Zone, and the highly dissected foothill region on the northeast. Slopes up to 40 degrees are present in the upland areas, where mass wasting events are common in the winter months. Figure 5.3b shows the aspect of the land surface, with 0 and 360 degrees corresponding to north. The main feature shown in Figure 5.3b is the distinction between the generally northwards-facing slopes of the uplands and the generally southwards-facing slopes of the foothills. The combination of slope and north-south
Figure 5.3. Topographic attributes of the Searsville watershed. (a) Slope. (b) Aspect (0° and 360° indicate northward facing slopes, 90° indicates eastward facing slopes, 180° indicates southward facing slopes, and 270° indicates westward facing slopes). (c) Curvature (positive values indicate convex topography and negative values indicate concave topography). (d) Hypsometric curve (i.e., area-elevation curve).
aspect can have impacts on the degree of insolation and hence evapotranspiration. Figure 5.3c shows the curvature of the land surface, highlighting hollows and ridges of the uplands and foothill regions, and the relatively flat areas of the San Andreas Fault Zone. It is also evident from Figure 5.3c that the foothill area has a higher drainage density than the upland area, suggesting that the different bedrock geology of the foothill area influences drainage network development. Figure 5.3d shows the hypsometric curve relating land surface elevation to the watershed area below that elevation. The curve shows the contributions of the low elevation areas between 100 and 200 m, a break in slope at the transition to the upland areas around 200 m elevation, and the relatively minor contributions of the high elevations above 600 m.

5.3   Methods

The approach for this study was to conduct detailed physics-based simulations of hydrologic response and sediment transport using the Integrated Hydrology Model (InHM) (VanderKwaak, 1999), driven by the best available information. This section describes the methods used to construct boundary-value problems for concept-development simulations focused on the upstream effects of Searsville Dam.

5.3.1   Watershed Data Compilation

5.3.1.1   Existing Information

The existing hydrogeologic data compiled for this study include (i) spatial data (i.e., topography, geology, soil types, land cover), (ii) historical climate information, and (iii) historical response data (e.g., streamflow, water table depth). This information, in concert with published sources relating surface and subsurface attributes (e.g., soil type) to hydraulic properties (e.g., hydraulic conductivity), provides the foundation for the InHM boundary-value problem construction, including boundary and initial condition specifications.
5.3.1.2 Field Investigation

To supplement the basic geologic, geographic, and meteorological data described in the previous section new spatially- and temporally-varying data of selected hydrogeologic variables were obtained through field measurements. This additional information includes semi-weekly pressure head, and soil-water content data at eight locations over the course of one year (June 2005 to June 2006), as well as saturated hydraulic conductivity, and stream sediment concentration at various times and locations. The field data provide a baseline for how the watershed functions on an annual time scale as a spatially heterogeneous system and serve as a qualitative “reality check” for the simulated response. Figure 5.1 and Table 5.1 show, respectively, the locations and types of field measurements made in the Searsville watershed. The field data in their entirety are presented in Appendix C.

Figure 5.4 shows, for the period of observations, plots of (a) daily rainfall, (b) average, minimum, and maximum pressure head, (c) average soil-water content at two depth intervals, and (d) discharge at a gauge on San Francisquito Creek approximately 7 km downstream from Searsville Dam (drainage area is 96.9 km²). The most prominent feature of this annual record is the contrast between the dry summer and the wet winter, as shown by the rainfall (Figure 5.4a) and pressure head data (Figure 5.4b). The line of maximum pressure head (Figure 5.4b) corresponds to a tensiometer installed at location #1 in the wetland (see Figure 5.1), which remained close to saturation over the entire year. This tensiometer also was the slowest to decrease from near-zero values (i.e., close to saturation) to lower (drier) values in the summer of 2005. The minimum pressure heads were observed at locations that were unshaded (resulting in high evapotranspiration) and/ or topographically convex (resulting in divergence of both surface and subsurface flow paths). The soil-water content pattern (Figure 5.4c) generally resembles the pressure head pattern, and the topmost soil layer (0 – 0.15 m) is wetter than the underlying layer (0.15 – 0.3 m). The wettest measurements were again from location #1, which stayed relatively wet in May-June 2006 while the soil-water content values at all other locations were decreasing. The
Table 5.1. Hydrologic data collected for the Searsville watershed.

<table>
<thead>
<tr>
<th>Location</th>
<th>Tensiometer depth (m)</th>
<th>TDR waveguide length (m)</th>
<th>Number of hydraulic conductivity measurements</th>
<th>Number of suspended sediment concentration measurements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.20, 0.37</td>
<td>0.15, 0.30, 0.45</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.12, 0.31</td>
<td>0.15, 0.30, 0.45</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>0.15, 0.30</td>
<td>0.15, 0.30, 0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.11, 0.25</td>
<td>0.15, 0.30, 0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>0.13, 0.28</td>
<td>0.15, 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>0.13, 0.28</td>
<td>0.15, 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>0.14, 0.30</td>
<td>0.15, 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>0.15, 0.28, 0.38</td>
<td>0.15, 0.30</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12</td>
<td></td>
<td></td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td></td>
<td></td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td></td>
<td></td>
<td>1</td>
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<td>2</td>
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</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

1 See Figure 5.1
Figure 5.4. Observed data for the period from June 2005 to June 2006. (a) Daily rainfall at the Jasper Ridge Biological Preserve (Note: rainfall data period extends through April 27, 2006). (b) Pressure head, mean, minimum, and maximum at eight sites. (c) Soil-water content mean at eight sites for two depth intervals. (d) Discharge at downstream gauge (USGS gauge 11164500 San Francisquito Creek, Stanford University, CA; Drainage area of 96.9 km$^2$ includes Searsville watershed).
stream discharge record (Figure 5.4d) shows many individual peaks correlated to rainfall events, demonstrating that even at this larger watershed scale (approximately 2.5 times larger than the Searsville watershed) discharge is highly variable during the wet season.

5.3.2 Physics-Based Simulation with InHM

To evaluate the impacts of changing boundary conditions (i.e., dam construction, reservoir sedimentation, and dam removal) on watershed hydrologic response four scenarios representing four different periods during the dam’s lifespan were developed for simulation with InHM. The first scenario, “pre-dam”, represents conditions prior to the construction of Searsville Dam. The second scenario, “early dam”, represents the period shortly after dam construction, when the newly created reservoir was not yet filled with deposited sediment. The third scenario, “current”, represents current (i.e., circa 2006) conditions, with a dammed reservoir mostly filled with sediment. The fourth scenario, “post-dam”, represents conditions immediately following dam removal, where the impounding structure is removed but the reservoir sediments remain. The Searsville watershed boundary-value problem includes topographic, hydrogeologic, and hydraulic parameterizations, as well as meteorological/climatological forcings and boundary conditions.

5.3.2.1 Topography

Simulations with InHM necessitate a 3D mesh of triangular elements that reflects the topography of the area. The topography for the Searsville Lake simulations was based on three topographic datasets: (i) a digital elevation model with resolution of 10 m and 1 m in the horizontal and vertical directions, respectively (based on the U.S.Geological Survey 7.5-minute Topographic Map Series); (ii) a survey of the 2002 topography and bathymetry of Searsville Lake and wetland with resolution of 0.6 m (2 ft) in the vertical direction (Northwest Hydraulic Consultants Inc., 2002), used for the current and post-dam scenarios; and (iii) a topographic map of the Searsville Lake and wetland areas prior to dam construction (Trevor Herbert, Jasper Ridge Biological
Preserve, personal communication, 2006), used for the pre-dam and early dam scenarios. The four surface meshes (i.e., one for each scenario) each contained 9,049 nodes and 17,856 triangular elements. The spacing of nodes was smallest in the lake and wetland area and varied from 50 m along the channels to 150 m around the watershed boundary. The triangular elements had a mean plan-view area of 2185 m² with a standard deviation of 1151 m². Figure 5.5, depicting the surface mesh used in this study for the current scenario, clearly shows the areas of greater detail around the channels, Searsville Lake, and the wetland. Below the surface mesh 17 subsurface node layers were added. The thickness of the layers varied from 0.15 m (for the top 0.6 m), to 0.3 m (for the next 0.9 m), to 2 m (for the next 10 m), and the bottom five layers had variable exponentially-increasing thicknesses down to a base elevation of 1 m using an exponent of 1.3. The total number of nodes in the 3D mesh was 162,882. In addition to placing node strings along the main channels of the watershed, node strings were placed in all of the minor hollows and ridges to facilitate more realistic flow paths in these areas.

5.3.2.2 Surface and Subsurface Parameters

To parameterize the surface and subsurface domains for simulation with InHM the watershed was divided into multiple zones based on land cover, soil type and the underlying bedrock type. The available land cover, soil and geologic information (see Figure 5.2) was employed to provide sufficient detail without over-speculation of the nuances in the spatial distributions. This characterization, which is summarized for soil data in Table 5.2 and depicted graphically for soils, geology, and land use in Figure 5.2, resulted in the division of the watershed into four land cover types (i.e., forest, grassland, mixed, and residential), three soil types (i.e., loam, clay loam, and sandy loam) and six geologic units (i.e., greenstone, shale, sandstone, conglomerate, older alluvium and recent alluvium). The three soil types were further divided into areas underlying residential land cover (see Figure 5.2d) and all other areas, the former assumed to have lower permeability due to greater compaction and paved area. Three
Figure 5.5. Surface mesh for the Searsville Lake boundary-value problem. Also shown are the locations of a vertical cross section trace (A to A’) for Figure 5.13, and a bounding box (B-C-D-E) for Figures 5.13, 5.15 and 5.16.
Table 5.2. Texture and depth characteristics of the six soil associations that occur within the Searsville Lake watershed (after Lindsey, 1970).

<table>
<thead>
<tr>
<th>Soil association</th>
<th>Top soil texture</th>
<th>Subsoil texture</th>
<th>Topsoil depth (m)</th>
<th>Subsoil depth (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zamora-Pleasanton-Danville Association (2)</td>
<td>CL/GCL (30%)</td>
<td>CL</td>
<td>0.6</td>
<td>0.9</td>
</tr>
<tr>
<td>Gaviota-Los Gatos-Gilroy Association (10)</td>
<td>L (50%)</td>
<td>WB (SS)</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Los Gatos-Gilroy-Gaviota Association (11)</td>
<td>L/CL (40%)</td>
<td>CL</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>Hugo-Butano-Josephine association (15)</td>
<td>SNL/L (35%)</td>
<td>GSNL</td>
<td>0.6</td>
<td>0.3</td>
</tr>
<tr>
<td>Maymen-Los Gatos association (16)</td>
<td>L (50%)</td>
<td>none (WB (SS))</td>
<td>0.6</td>
<td>0</td>
</tr>
<tr>
<td>Sweeney-Mindego association (18)</td>
<td>CL/L (60%)</td>
<td>SNCL</td>
<td>0.6</td>
<td>0.3</td>
</tr>
</tbody>
</table>
Table 5.2 (continued). Texture and depth characteristics of the six soil associations that occur within the Searsville Lake watershed (after Lindsey, 1970).

1 See Figure 2b. Number in parentheses is the soil association number, as designated in Lindsey (1970).

2 CL = clay loam, GCL = gravelly clay loam, L = loam, SC = silty clay, WB = weathered bedrock, SS = sandstone, SNL = sandy loam, SNCL = sandy clay loam
Values in parentheses denote the percentage of occurrence of each soil type within the association. Textural abbreviations in italics denote the generalized soil type assigned to the soil layer for this study.
of the geologic units (i.e., sandstone, greenstone, and shale) were divided into weathered (the top 10 m) and unweathered zones, with a higher permeability assigned to the weathered condition. The conglomerate and alluvium zones were not divided into weathered and unweathered zones because they are younger, and not yet fully consolidated to the point where weathered zones are differentiable from the rest.

Tables 5.3 and 5.4 outline the parameterization of the subsurface and surface zones, respectively, for the Searsville simulations. The unsaturated characteristic relationships for the soils and bedrock (Figure 5.6) were parameterized using the van Genuchten (1980) model for soil-water retention. For the soil zones the van Genuchten parameters and saturated hydraulic conductivity values were based upon texture and the catalogue of Carsel and Parrish (1988). For all other porous medium zones (i.e., bedrock and alluvium zones) the saturated hydraulic conductivity values and van Genuchten parameters were estimated from published ranges (Freeze and Cherry, 1979; Wu et al., 1996).

### 5.3.2.3 Initial Conditions

Initial conditions, namely pressure head values at all subsurface nodes and water depth at all surface nodes, were generated for each of the four scenarios by conducting a one-year transient simulation starting from the following condition:

\[ \psi_{t=0} = \max[-0.1, (0.98 \times Z_{surf} - Z)] \]  

(5.1)

where \( Z_{surf} \) [L] is the elevation of the land surface directly above the node and \( Z \) [L] is the elevation of the node. This specification causes the water table to assume the form of a subdued replica of the surface topography and the unsaturated zone to have a minimum value (i.e., -0.1 m) for pressure head. From this specified state the one-year simulation results in further drainage, surface water accumulation in the channels (and reservoir for the scenarios with the dam), and a self-consistent set of hydraulic head values in the variably-saturated subsurface. The choice of 0.98 as the surface elevation scaling factor was driven by knowledge of the water table depth, which averages approximately 3 to 4 m for wells at an elevation of 150 masl (Sokol, 1963).
Table 5.3. Parameterization of the subsurface zones for the Searsville hydrologic response and sediment-transport simulations.

<table>
<thead>
<tr>
<th>Zone</th>
<th>$K_{sat}$ (^1)</th>
<th>$\theta_s$ (^2)</th>
<th>$\alpha$ (^3)</th>
<th>$\beta$ (^4)</th>
<th>$\theta_r$ (^5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(m s(^{-1}))</td>
<td>(-)</td>
<td>(m(^{-1}))</td>
<td>(-)</td>
<td>(-)</td>
</tr>
<tr>
<td>Sandstone</td>
<td>1.0 x 10(^{-7})</td>
<td>0.30</td>
<td>4.3</td>
<td>1.25</td>
<td>0.023</td>
</tr>
<tr>
<td>Shale</td>
<td>1.0 x 10(^{-11})</td>
<td>0.10</td>
<td>4.3</td>
<td>1.25</td>
<td>0.007</td>
</tr>
<tr>
<td>Greenstone</td>
<td>1.0 x 10(^{-9})</td>
<td>0.20</td>
<td>4.3</td>
<td>1.25</td>
<td>0.015</td>
</tr>
<tr>
<td>Weathered sandstone</td>
<td>3.0 x 10(^{-7})</td>
<td>0.30</td>
<td>4.3</td>
<td>1.25</td>
<td>0.023</td>
</tr>
<tr>
<td>Conglomerate</td>
<td>1.0 x 10(^{-5})</td>
<td>0.35</td>
<td>4.3</td>
<td>1.25</td>
<td>0.026</td>
</tr>
<tr>
<td>Weathered shale</td>
<td>3.0 x 10(^{-11})</td>
<td>0.10</td>
<td>4.3</td>
<td>1.25</td>
<td>0.007</td>
</tr>
<tr>
<td>Weathered greenstone</td>
<td>3.0 x 10(^{-9})</td>
<td>0.20</td>
<td>4.3</td>
<td>1.25</td>
<td>0.015</td>
</tr>
<tr>
<td>Older alluvium</td>
<td>5.0 x 10(^{-5})</td>
<td>0.35</td>
<td>14.5</td>
<td>2.68</td>
<td>0.035</td>
</tr>
<tr>
<td>Clay loam</td>
<td>7.2 x 10(^{-7})</td>
<td>0.41</td>
<td>1.9</td>
<td>1.31</td>
<td>0.094</td>
</tr>
<tr>
<td>Clay loam - residential</td>
<td>3.6 x 10(^{-7})</td>
<td>0.41</td>
<td>1.9</td>
<td>1.31</td>
<td>0.094</td>
</tr>
<tr>
<td>Loam</td>
<td>2.9 x 10(^{-6})</td>
<td>0.43</td>
<td>3.6</td>
<td>1.56</td>
<td>0.077</td>
</tr>
<tr>
<td>Loam - residential</td>
<td>1.45 x 10(^{-6})</td>
<td>0.43</td>
<td>3.6</td>
<td>1.56</td>
<td>0.077</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1.2 x 10(^{-5})</td>
<td>0.41</td>
<td>7.5</td>
<td>1.89</td>
<td>0.066</td>
</tr>
<tr>
<td>Sandy loam - residential</td>
<td>6.0 x 10(^{-6})</td>
<td>0.41</td>
<td>7.5</td>
<td>1.89</td>
<td>0.066</td>
</tr>
<tr>
<td>Channel deposits</td>
<td>2.0 x 10(^{4})</td>
<td>0.35</td>
<td>14.5</td>
<td>2.68</td>
<td>0.10</td>
</tr>
<tr>
<td>Recent alluvium (^6)</td>
<td>1.0 x 10(^{4})</td>
<td>0.35</td>
<td>14.5</td>
<td>2.68</td>
<td>0.035</td>
</tr>
</tbody>
</table>

\(^1\) Saturated hydraulic conductivity
\(^2\) Saturated water content (porosity)
\(^3\) Parameter related to the inverse of the air-entry pressure (van Genuchten, 1980)
\(^4\) Parameter related to the pore-size distribution (van Genuchten, 1980)
\(^5\) Residual soil-water content
\(^6\) Recent alluvium zone applies only to the current and post-dam scenarios
Table 5.4. Parameterization of the surface zones for the Searsville hydrologic-response and sediment-transport simulations.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Number</th>
<th>$n$</th>
<th>$\Psi_{immobile}$</th>
<th>$h_{mt}$</th>
<th>$c_f$</th>
<th>$\phi$</th>
<th>$\sigma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forest</td>
<td>1</td>
<td>0.05</td>
<td>0.0005</td>
<td>0.005</td>
<td>0.01</td>
<td>1 x 10^{-7}</td>
<td>0.75 / 0.25</td>
</tr>
<tr>
<td>Residential</td>
<td>2</td>
<td>0.03</td>
<td>0.0005</td>
<td>0.005</td>
<td>0.1</td>
<td>1 x 10^{-7}</td>
<td>0.75 / 0.25</td>
</tr>
<tr>
<td>Grass</td>
<td>3</td>
<td>0.10</td>
<td>0.0005</td>
<td>0.005</td>
<td>1</td>
<td>1 x 10^{-7}</td>
<td>0.75 / 0.25</td>
</tr>
<tr>
<td>Mixed</td>
<td>4</td>
<td>0.06</td>
<td>0.0005</td>
<td>0.005</td>
<td>0.1</td>
<td>1 x 10^{-7}</td>
<td>0.75 / 0.25</td>
</tr>
<tr>
<td>Channel, slope $&gt; 0.05$</td>
<td>5</td>
<td>0.07</td>
<td>0.0005</td>
<td>0.005</td>
<td>0</td>
<td>1 x 10^{-7}</td>
<td>0 / 1.0</td>
</tr>
<tr>
<td>Channel, slope $\leq 0.05$</td>
<td>6</td>
<td>0.03</td>
<td>0.0005</td>
<td>0.005</td>
<td>0</td>
<td>1 x 10^{-7}</td>
<td>0 / 1.0</td>
</tr>
<tr>
<td>Recent alluvium</td>
<td>7</td>
<td>0.06</td>
<td>0.0005</td>
<td>0.005</td>
<td>0.1</td>
<td>0</td>
<td>0.5 / 0.5</td>
</tr>
</tbody>
</table>

1 See Figures 5.1, 5.2c, and 5.2d; 2 Manning’s roughness coefficient (VanderKwaak, 1999); 3 Immobile water depth (VanderKwaak, 1999); 4 Average height of non-discretized micro-topography (VanderKwaak, 1999); 5 Rainsplash erosion coefficient (Heppner et al., 2006); 6 Surface erodibility (Heppner et al., 2006); 7 Sediment source fractions (silt / sand) (Heppner et al., 2006); 8 Recent alluvium zone applies only to the early dam, current, and post dam scenarios
Figure 5.6. Porous media characteristic curves for the Searsville soils, bedrock, and alluvium.
5.3.2.4 Boundary Conditions

5.3.2.4.1 Generation of Synthetic Rainfall Time-Series

Simulation of the Searsville watershed with InHM requires that time-series of rainfall intensity be applied to the surface nodes of the mesh to drive the hydrologic response. Sokol (1963) compiled annual precipitation data in the San Francisquito Creek watershed (which includes the Searsville watershed), showing a distinct orographic trend of greater precipitation at higher elevations. To capture both the orographic effect and the temporal variations of intensity over time scales ranging from minutes to months synthetic rainfall time-series are needed, as observed data are not available over the long-term or at the different elevations. In this study synthetic rainfall time-series were generated based on long-term rainfall records from the nearby Woodside Fire Station (see Figure 5.1), which included the mean and standard deviation of annual and monthly rainfall.

Long-term time-series of rainfall were generated based on the assumption that rainfall is a stochastic process. Annual rainfall depth, monthly rainfall depth, and log-transformed rainfall intensity are treated as normally-distributed variables. The 15-step procedure for generating a one-year rainfall time-series relative to monthly rainfall characteristics (steps 1-5), external storm characteristics (steps 6-8), internal storm characteristics (steps 9-12), and the construction of an annual rainfall time series (steps 13-15) is described in Appendix D.

Table 5.5 lists the values of the rainfall generation parameters used for this study. The monthly and annual mean rainfall amounts, along with their standard deviations, are based on long-term records from a nearby rain-gauge (Woodside Fire Station 1, CA #049792). The mean depth and duration for single storm events, along with their standard deviations, was specified as a best-guess estimate (i.e., no data on these parameters exists for the site). Finally, a scaling factor for each of four elevation-based zones was specified, based on knowledge of the orographic rainfall gradient (Sokol, 1963). Figure 5.7 shows the cumulative rainfall amounts (at the second lowest elevation zone) for each of the ten synthetically-generated annual rainfall time-series.
Table 5.5. Parameter values for the generation of synthetic rainfall time-series.

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual rainfall depth (m)</td>
<td>0.768</td>
<td>0.295</td>
</tr>
<tr>
<td>Monthly rainfall depth (m)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>January</td>
<td>0.153</td>
<td>0.107</td>
</tr>
<tr>
<td>February</td>
<td>0.146</td>
<td>0.108</td>
</tr>
<tr>
<td>March</td>
<td>0.117</td>
<td>0.081</td>
</tr>
<tr>
<td>April</td>
<td>0.044</td>
<td>0.042</td>
</tr>
<tr>
<td>May</td>
<td>0.018</td>
<td>0.024</td>
</tr>
<tr>
<td>June</td>
<td>0.004</td>
<td>0.007</td>
</tr>
<tr>
<td>July</td>
<td>0.001</td>
<td>0.003</td>
</tr>
<tr>
<td>August</td>
<td>0.004</td>
<td>0.011</td>
</tr>
<tr>
<td>September</td>
<td>0.007</td>
<td>0.010</td>
</tr>
<tr>
<td>October</td>
<td>0.033</td>
<td>0.030</td>
</tr>
<tr>
<td>November</td>
<td>0.101</td>
<td>0.088</td>
</tr>
<tr>
<td>December</td>
<td>0.140</td>
<td>0.114</td>
</tr>
<tr>
<td>Event rainfall depth (m)</td>
<td>0.015</td>
<td>0.010</td>
</tr>
<tr>
<td>Event duration (s)</td>
<td>43,200</td>
<td>21,600</td>
</tr>
<tr>
<td>Rainfall intensity (m s$^{-1}$, log$_{10}$)</td>
<td>-6.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Elevation range (m)</th>
<th>Scaling factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 – 190</td>
<td>0.86</td>
</tr>
<tr>
<td>190 – 390</td>
<td>1.0</td>
</tr>
<tr>
<td>390 – 630</td>
<td>1.11</td>
</tr>
<tr>
<td>630 – 790</td>
<td>1.18</td>
</tr>
</tbody>
</table>

| Storm time step (s)             | 900             |
Figure 5.7. Cumulative rainfall for the ten synthetically-generated annual time-series. Totals are representative of the 190 – 390 m elevation range. Solid vertical lines are the 12 equally-spaced output times (approximate one month intervals). Dashed line indicates long-term average. Inset: total annual rainfall.
5.3.2.4.2 Potential Evaporation Estimation

Potential evapotranspiration (PET) was estimated for this study using climatological data from a weather station located in the Jasper Ridge Biological Preserve for three areas (i.e., the grass zone; the combined forest, mixed and residential zones; the open water area of Searsville Lake). The available data used in this estimation included daily values of (i) maximum, minimum, and average temperature [°C]; (ii) maximum, minimum, and average relative humidity [%]; (iii) maximum, minimum, and average vapor pressure [kPa]; (iv) average wind velocity [m s⁻¹]; (v) net radiation (both short- and long-wave) [MJ m⁻² d⁻¹]; and (vi) total photosynthetically-active radiation (PAR) [mol m⁻² d⁻¹]. The conversion of PAR to net short-wave solar radiation [MJ m⁻² d⁻¹] assumes that PAR has a uniform distribution of wavelengths from 400 to 700 nm, and constitutes 0.47 of the total solar radiation (the rest arriving in infrared and ultraviolet wavelengths). All data except for the net radiation data were from years 1997 through 2004; the net radiation data was from 2002 only. The calculations used to estimate PET are described in Appendix B.

5.4 Results

Results from the long-term simulations are presented in four sections: (i) temporal characteristics of the simulated hydrologic response, (ii) spatial characteristics of the simulated hydrologic response, based on snapshots extracted from the simulations, (iii) simulated sediment characteristics, both temporal and spatial, and (iv) a comparison of the four dam-related scenarios.

5.4.1 Temporal Characteristics of the Simulated Hydrologic Response

Table 5.6 shows the simulated surface water outflow component of the long-term water balance. Inspection of Table 5.6 shows that year 1 and, to a lesser extent, year 2 produced high amounts of surface water outflow, especially for the pre-dam and early-dam cases. This suggests that the watershed was still draining from the specified initial condition, and for this reason years 1 and 2 are henceforth considered warm-up years. The simulated results in Table 5.6 show a positive correlation between annual rainfall
<table>
<thead>
<tr>
<th>Year</th>
<th>Surface water outflow, mm (%) ¹</th>
<th>Pre-dam</th>
<th>Early dam</th>
<th>Current</th>
<th>Post-dam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>568 (80.8)</td>
<td>523 (74.4)</td>
<td>369 (52.6)</td>
<td>377 (53.7)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>222 (45.0)</td>
<td>217 (44.0)</td>
<td>186 (37.8)</td>
<td>188 (38.0)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>192 (34.8)</td>
<td>188 (34.0)</td>
<td>177 (32.0)</td>
<td>178 (32.3)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>371 (39.9)</td>
<td>368 (39.5)</td>
<td>362 (38.9)</td>
<td>363 (39.0)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>346 (40.4)</td>
<td>343 (40.0)</td>
<td>342 (38.9)</td>
<td>343 (39.0)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>540 (46.7)</td>
<td>537 (46.5)</td>
<td>537 (46.5)</td>
<td>538 (46.6)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>393 (45.5)</td>
<td>389 (45.1)</td>
<td>391 (45.3)</td>
<td>392 (45.5)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>155 (32.5)</td>
<td>151 (31.6)</td>
<td>154 (32.2)</td>
<td>155 (32.5)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>294 (35.1)</td>
<td>290 (34.7)</td>
<td>293 (35.0)</td>
<td>294 (35.1)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>255 (36.6)</td>
<td>251 (36.0)</td>
<td>253 (36.4)</td>
<td>255 (36.6)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>334 (43.7)</td>
<td>326 (42.6)</td>
<td>306 (39.7)</td>
<td>308 (39.9)</td>
<td></td>
</tr>
<tr>
<td>Average (years 3 – 10)</td>
<td>318 (38.9)</td>
<td>315 (38.4)</td>
<td>314 (38.3)</td>
<td>315 (38.4)</td>
<td></td>
</tr>
</tbody>
</table>

¹ Surface water outflow is expressed both as a spatially-normalized depth of water (in mm), and as a percentage of annual rainfall.
and annual runoff on both absolute and percentage of rainfall bases. Years 1 and 2 are exceptions to this pattern, showing high runoff percentages for relatively small annual rainfall amounts, further evidence that those early years are influenced by initial conditions. Simulated outflow ranges from approximately 150 to 540 mm yr\(^{-1}\), or 32 to 47 percent of annual rainfall, averaging approximately 40 percent.

Peak surface water outflow rates, shown in Table 5.7, usually occur during a given year in response to an event with a high rank in terms of rainfall depth and peak rainfall intensity. Peak outflow rates range from 6 to 184 m\(^3\) s\(^{-1}\) and vary between the different scenarios. For all years except years 3, 4, and 7, the peak discharge occurs in response to the same event for all four scenarios. In years 3, 4, and 7 the pre-dam scenario has a peak discharge for a different event than the other three scenarios. Minimum surface water outflow rates typically occur between mid-July and mid-August, and range from approximately 0.07 to 0.14 m\(^3\) s\(^{-1}\).

Table 5.8 shows the simulated evapotranspiration rates for the ten simulated years. ET is positively correlated with annual rainfall, while ET as a percentage of rainfall is negatively correlated with annual rainfall. This indicates that, although wetter near-surface conditions occurring during rainier years contribute to enhanced ET because more water is available, the enhancement does not keep pace with the increase in rainfall, so the ET percentage of rainfall is smaller. The simulated ET ranges from approximately 400 to 550 mm yr\(^{-1}\), and as a percentage of rainfall from 47 to 89 percent (not including years 1 and 2).

### 5.4.2 Spatial Characteristics of the Simulated Hydrologic Response

The distributed nature of InHM allows one to examine the spatial occurrence of hydrological and geomorphological processes within the simulated domain. Instantaneous snapshots of the domain are extracted from the simulations and plotted in map view. The effects of topography, surface and porous media characteristics, and boundary conditions can be seen in the resulting plots. The specific patterns that arise depend, of course, on the time at which the snapshot is taken relative to previous
Table 5.7. Simulated peak discharge for the four dam-related scenarios.

<table>
<thead>
<tr>
<th>Year</th>
<th>Peak discharge (m$^3$ s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-dam</td>
</tr>
<tr>
<td>1</td>
<td>69.0</td>
</tr>
<tr>
<td>2</td>
<td>46.0</td>
</tr>
<tr>
<td>3</td>
<td>40.5</td>
</tr>
<tr>
<td>4</td>
<td>39.4</td>
</tr>
<tr>
<td>5</td>
<td>47.7</td>
</tr>
<tr>
<td>6</td>
<td>67.4</td>
</tr>
<tr>
<td>7</td>
<td>35.1</td>
</tr>
<tr>
<td>8</td>
<td>9.9</td>
</tr>
<tr>
<td>9</td>
<td>184.2</td>
</tr>
<tr>
<td>10</td>
<td>48.2</td>
</tr>
</tbody>
</table>
Table 5.8. Simulated evapotranspiration for the four dam-related scenarios.

<table>
<thead>
<tr>
<th>Year</th>
<th>Evaporation, mm (%)</th>
<th>Pre-dam</th>
<th>Early dam</th>
<th>Current</th>
<th>Post-dam</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>502 (71.5)</td>
<td>505 (71.9)</td>
<td>475 (67.7)</td>
<td>474 (67.5)</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>395 (80.0)</td>
<td>399 (80.8)</td>
<td>390 (79.0)</td>
<td>389 (78.8)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>405 (73.3)</td>
<td>409 (74.1)</td>
<td>403 (73.1)</td>
<td>402 (72.8)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>480 (51.6)</td>
<td>484 (52.0)</td>
<td>479 (51.5)</td>
<td>478 (51.4)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>507 (59.1)</td>
<td>511 (59.5)</td>
<td>507 (59.1)</td>
<td>506 (58.9)</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>549 (47.5)</td>
<td>552 (47.8)</td>
<td>548 (47.4)</td>
<td>547 (47.4)</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>498 (57.7)</td>
<td>501 (58.1)</td>
<td>498 (57.7)</td>
<td>497 (57.6)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>422 (88.6)</td>
<td>426 (89.4)</td>
<td>423 (88.7)</td>
<td>422 (88.4)</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>501 (59.8)</td>
<td>504 (60.2)</td>
<td>501 (59.8)</td>
<td>499 (59.7)</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>456 (65.5)</td>
<td>460 (66.1)</td>
<td>457 (65.6)</td>
<td>456 (65.4)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>471 (65.5)</td>
<td>475 (66.0)</td>
<td>468 (65.0)</td>
<td>467 (64.8)</td>
<td></td>
</tr>
<tr>
<td>Average (years 3 – 10)</td>
<td>477 (62.9)</td>
<td>481 (63.4)</td>
<td>477 (62.9)</td>
<td>476 (62.7)</td>
<td></td>
</tr>
</tbody>
</table>

1 Evaporation is expressed both as a spatially-normalized depth of water (in mm), and as a percentage of annual rainfall
occurrences of, for example, rainfall. In the following section all snapshots are taken from the current scenario.

Surface-subsurface exchange fluxes result from potential gradients across the continuum interface. Figure 5.8 illustrates several patterns that are general to all of the scenarios. Figure 5.8a shows the exchange flux rate (m s\(^{-1}\)) at the end of year 4, when the catchment was in a relatively dry state, and Figure 5.8b shows the exchange flux rate at the end of the second month of year 4, when the catchment was in a wet state. In Figure 5.8 positive exchange flux values indicate exfiltration and negative values indicate infiltration. The most general pattern apparent in Figure 5.8 is that exchange fluxes tend to be strongest and in the direction of exfiltration in the channel areas and in non-channelized concavities, and in the direction of infiltration everywhere else. An exception to this general pattern occurs in the reservoir area, where infiltration occurs due to the large hydrostatic pressure of the impounded water. A second pattern that is common in the simulated snapshots is the occurrence of alternating infiltration and exfiltration along many stretches of channel, a phenomenon which results from slight changes in channel gradient and can be viewed as simulated hyporheic exchange (e.g., Harvey and Bencala, 1993; Boulton et al., 1998; Saenger et al., 2005). A third common pattern in the simulated snapshots is that areas of infiltration tend to occur where the steep, confined channels of the mountainous region exit onto the valley floor area, an effect that is especially pronounced when the channels cross into a zone underlain by the permeable older alluvium and conglomerate zones. The magnitude of the exchange fluxes depends on the soil type as well, with lower permeability zones associated with smaller fluxes and vice versa.

The patterns of porous media saturation at the land surface for two snapshots are shown in Figure 5.9. The snapshots are from the same dry and wet times as those shown in Figure 5.8. Comparison of Figures 5.9a and 5.9b shows the difference between dry and wet periods. In both snapshots the saturation patterns reflect the underlying soil type (see Figure 5.2b). The finer textured soils of associations 2, 11, and 18 typically retain more water than the coarser soils of associations 10, 15, and 16.
Figure 5.8. Simulated surface-subsurface exchange flux rates. (a) Year 4, end of month 12. (b) Year 4, end of month 2.
Figure 5.9. Simulated porous medium saturation at the surface. (a) Year 4, end of month 12. (b) Year 4, end of month 2.
The concave areas (both channels and non-channelized areas) are generally wetter than the convex hillslopes (see Figure 5.3c). The influence on surface saturation of the underlying bedrock is apparent in Figure 5.9b, where areas underlain by shale are wetter, for the same soil type, than areas underlain by sandstone. In certain portions of the channels the saturations are very low due to the high conductivity of the channel zone, which causes these areas to drain rapidly when not covered with surface water.

Figure 5.10 shows simulated snapshots of ET flux rate (m s\(^{-1}\)) for the same dry and wet times as Figure 5.8 and 5.9. Again, the role of topographic flow convergence is shown by the higher rates of ET flux in the channels and concavities. The snapshot in Figure 5.10a is from a time when potential ET is greater than for the time shown Figure 5.10b, so the rates are generally higher even though soil saturation is lower. In Figure 5.10b the effect of the hydrologic characteristics of the underlying bedrock is seen in the greater ET flux rates from areas underlain by shale compared to areas underlain by sandstone, a direct result of the increased saturation discussed previously.

### 5.4.3 Simulated Sediment Characteristics

Table 5.9 shows the cumulative simulated sediment outflow for both sediment species for each year, normalized by area (i.e., units of kg m\(^{-2}\) year\(^{-1}\)). Sediment outflow is shown to vary considerably from year to year, and has similar characteristics as surface water outflow (i.e., it is positively correlated with the amount of rainfall). Sediment discharge is greater in most cases for the silt-sized sediment than for the sand-sized sediment. Total sediment outflow ranges from 0.09 to 1.88 kg m\(^{-2}\) year\(^{-1}\); outflow for the silt-sized sediment ranges from 0.06 to 1.41 kg m\(^{-2}\) year\(^{-1}\); outflow for sand-sized sediment ranges from 0.01 to 0.84 kg m\(^{-2}\) year\(^{-1}\).

Sediment concentrations at any specific location fluctuate depending on local hydrologic conditions, sediment properties, and zone properties. Concentrations of sand tend to be higher than silt in many channel areas due to the source fractions assigned to this zone (i.e., 100% sand). Any increases in silt concentration in the channel are due to influx from neighboring elements. In the reservoir area, for the early dam and current cases, the sand concentrations tend to decrease more rapidly.
Figure 5.10. Simulated ET flux rate. (a) Year 4, end of month 12. (b) Year 4, end of month 2.
Table 5.9. Simulated normalized cumulative sediment discharge for the four dam-related scenarios.

<table>
<thead>
<tr>
<th>Year</th>
<th>Cumulative sediment discharge, kg m(^{-2})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-dam (silt, sand)</td>
</tr>
<tr>
<td>1</td>
<td>0.41, 0.78</td>
</tr>
<tr>
<td>2</td>
<td>0.16, 0.25</td>
</tr>
<tr>
<td>3</td>
<td>0.21, 0.23</td>
</tr>
<tr>
<td>4</td>
<td>0.70, 0.57</td>
</tr>
<tr>
<td>5</td>
<td>0.62, 0.51</td>
</tr>
<tr>
<td>6</td>
<td>1.04, 0.84</td>
</tr>
<tr>
<td>7</td>
<td>0.68, 0.58</td>
</tr>
<tr>
<td>8</td>
<td>0.06, 0.14</td>
</tr>
<tr>
<td>9</td>
<td>0.49, 0.41</td>
</tr>
<tr>
<td>10</td>
<td>0.39, 0.34</td>
</tr>
<tr>
<td>Average</td>
<td>0.48, 0.47</td>
</tr>
<tr>
<td>Average (years 3 – 10)</td>
<td>0.52, 0.45</td>
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</table>
after storm events due to their faster settling velocity. On hillslopes concentrations tend to be higher for sand during rainfall events (due to greater rainsplash erosion susceptibility, see Figure 2.2) until surface-water depths reach the mobile-water depth, at which point overland flow and hydraulic erosion begin to occur, raising silt concentrations rapidly as rainsplash erosion is diminished. The interactions are complex but can be traced to the processes and/or parameterization of InHM.

Figures 5.11 and 5.12 show pairs of snapshots of simulated sediment concentration for silt and sand, respectively. The snapshots are from the same dry and wet times as Figures 5.8, 5.9 and 5.10. In both pairs of snapshots the wetter time corresponds to more widespread areas of higher concentration. Sediment concentration in the channels is shown to increase in the downstream direction for both silt and sand. The higher concentrations for sand relative to silt for the wetter time period shown in Figures 5.12b and 5.11b, respectively, is due to greater susceptibility to rainsplash erosion for sand. Contrastingly, the higher silt concentrations in the reservoir area are caused by the slower settling velocity of silt, which leaves a greater amount in suspension.

5.4.4 Comparison of Dam Scenarios

The simulated hydrologic-response and sediment-transport results presented in Tables 5.6 through 5.9 show differences between the four dam-related scenarios that are driven by differences in the scenarios’ parameterizations. These differences include:

- Cumulative surface water outflow (Table 5.6) is typically greatest for the pre-dam scenario, followed by the early dam, post-dam, and current scenarios. The differences are small, especially for the later years. Relative to the current scenario the average percent difference for surface water outflow is 2.1% for the pre-dam scenario, 0.7% for the early dam scenario, and 0.5% for the post-dam scenario (note, these averages exclude years 1 and 2 which are considered warm-up years).
Figure 5.11. Simulated silt concentration. (a) Year 4, end of month 12. (b) Year 4, end of month 2.
Figure 5.12. Simulated sand concentration. (a) Year 4, end of month 12. (b) Year 4, end of month 2.
• Peak surface water discharge (Table 5.7) varies consistently between the scenarios in the following descending order: pre-dam, early dam, post-dam, current. The differences between the pre-dam, early dam, and current scenarios are significant. Relative to the current scenario the average percent difference for peak discharge rate is 40.1% for the pre-dam scenario, 8.8% for the early dam scenario, and 0.8% for the post-dam scenario.

• Cumulative ET (Table 5.8) is typically greatest for the early dam scenario, followed by the pre-dam, current, and post-dam scenarios. Relative to the current scenario the average percent difference for ET is 0.1% for the pre-dam scenario, 0.8% for the early dam scenario, and -0.2% for the post-dam scenario.

• Total normalized sediment outflow, the sum of the outflow rates for silt and sand (Table 5.9), is generally greatest for the pre-dam scenario, followed by the early dam, post-dam, and current scenarios. In the relatively dry years 2, 3, and 8, the pre-dam scenario has lower sediment outflow than the early dam scenario. For individual species, the early dam scenario consistently has the highest discharge of silt, followed by the post-dam, current and pre-dam scenarios (in years 4 and 9 the pre-dam scenario has marginally more silt outflow than the current scenario). For sand the highest outflow is for the pre-dam scenario, followed by the post-dam, current and early dam scenarios. The proportion of total sediment outflow that is silt is highest for the early dam scenario, followed by the current, post-dam, and pre-dam scenarios.

Beyond the cumulative and integrated measures given in Tables 5.6 through 5.9 distributed simulation allows for a spatial comparison of the four dam scenarios and their impact on hydrologic and geomorphologic response. Figure 5.13 through 5.16 show several examples of such comparisons.

Figure 5.13 shows the simulated surface-subsurface exchange rates for the four dam scenarios at the end of month 7 (i.e., end of April) of year 9, a time which is neither very wet nor very dry. The area depicted in each snapshot is a close-up of the reservoir area (box B-C-D-E in Figure 5.5). The greatest differences between the four
Figure 5.13. Simulated surface-subsurface exchange flux rates at the end of the month 7 of year 9. (a) Pre-dam scenario. (b) Early dam scenario. (c) Current scenario. (d) Post-dam scenario.
Figure 5.14. Four vertical cross-sections through the Searsville Lake area at the end of month 12 of year 4. (a) Pre-dam scenario. (b) Early dam scenario. (c) Current scenario. (d) Post-dam scenario. Contours are total hydraulic head with a 1 m interval. White lines are flow lines beginning every 250 m along the transect at an elevation of 80 m. The direction of flow is from left to right.
Figure 5.15. Simulated water table elevation at the end of the month 7 of year 9. (a) Pre-dam scenario. (b) Early dam scenario. (c) Current scenario. (d) Post-dam scenario. Contour interval in blue area is 1 m; contour interval in red/yellow area is 10-20 m.
Figure 5.16. Simulated sand concentration at the end of the month 7 of year 9. (a) Pre-dam scenario. (b) Early dam scenario. (c) Current scenario. (d) Post-dam scenario.
scenarios occur in the area directly beneath the reservoir and the area of accumulated sediment. The pre-dam case (Figure 5.13a) shows the presence of the channel in the valley, with spatially-variable infiltration and exfiltration. The early dam case (Figure 5.13b) shows a large area of infiltration where the surface water is impounded. The current case (Figure 5.13c) shows infiltration beneath the impounded surface water and a complex pattern of infiltration and exfiltration in the wetland area, driven by subtle variations in topography. The post-dam case (Figure 5.13d) shows the same complex pattern in the wetland as the current case, with a partial return to the spatially-variable infiltration and exfiltration pattern in the reservoir area that was seen in the pre-dam case.

Figure 5.14 shows, for all four scenarios, a vertical slice through the subsurface along a north-south line extending from the reservoir in the north through the wetland areas to the steeper terrain in the south (line A-A’ in Figure 5.5). Contours of hydraulic head are shown, as well as flow lines whose starting points are identical for all four cases. The configuration of equipotential and flow lines indicates areas of recharge (e.g., beneath the local topographic high point in the south) and discharge (e.g., directly upstream from the reservoir). Figure 5.14 clearly shows the influence of the changing base level on subsurface flow paths and head distributions. Comparing the early dam scenario (Figure 5.14b) to the pre-dam scenario (Figure 5.14a) it is evident that a recharge zone has been created near the dam where there once was a discharge zone. Comparing the current scenario (Figure 5.14c) with the early dam scenario it is shown that hydraulic head in the upstream subsurface has increased slightly (1-2 m) due to the thicker delta sediments that have accumulated. Comparing the post-dam scenario (Figure 5.14d) to the current scenario it is shown that the hydraulic head in the reservoir area has begun to decline, although the area is still a recharge zone. It is likely that if the reservoir sediments were allowed to erode in the post-dam simulation, lowering the base level towards pre-dam conditions, the area would eventually become a discharge zone.

Figure 5.15 shows the simulated water table elevation for the four dam scenarios for the same time as Figure 5.13. The elevation of the water table is clearly influenced
by the presence of the dam (i.e., comparing pre-dam to early dam scenarios). Water
table elevation is also influenced by the topography of the accreted sediments; it is
higher in the upper and middle lake areas (to the southwest of the main reservoir) for
the current (Figure 5.15c) and post-dam (Figure 5.15d) scenarios than for the early
dam (Figure 5.15b) scenario. The main areas where the water table differs from one
scenario to the next are the reservoir area and the wetland areas upstream. After dam
removal the water table begins to decline, especially at the downstream end of the
reservoir. Interestingly, the post-dam water table elevation is still quite similar to the
current scenario for many parts of the wetland, suggesting that if channel incision in
the reservoir can be prevented (as it is in these simulations) the wetland may preserve
nearly the same hydrologic conditions as they have with the dam in place.

Figure 5.16 shows the simulated sand concentration for the four dam scenarios for
the same time as Figures 5.13 and 5.15. The pre-dam scenario (Figure 5.16a) shows
the channel running through the valley with a relatively high concentration of sand,
due to the high velocity of the channel flow. The early dam scenario (Figure 5.16b)
shows that the still water of the upper and middle lake areas has caused sand to settle
out. The current scenario (Figure 5.16c) shows that sand concentrations decline in the
lower end of the reservoir, perhaps due to a diverted flow path for Corte Madera
Creek, entering the wetland from the southeast, which forces water and sediment to
the west before entering the reservoir (i.e., a topographic control on surface flux
patterns). In the post-dam scenario (Figure 5.16d) the higher surface water velocities
through the drained reservoir cause sand concentrations to remain high through the
whole valley, much like the pre-dam scenario. In all four scenarios there are two
locations east of the reservoir where a combination of strong topographic convergence
and limited mesh resolution causes the simulated water depths and velocities to be
unrealistically high, which produces very high sediment concentrations. It should be
noted that this phenomenon is unique to these specific locations and does not affect
the vast majority of the simulated domain which has ample mesh resolution for the
underlying topography.
5.5 Sensitivity Analysis

Each of the four scenarios simulated in this study uses a set of parameters that is based on the best information available. To investigate the effect of certain parameters on the simulated hydrologic and sediment response, a sensitivity analysis is performed for a single rainfall-runoff event. The event chosen for this analysis is a relatively large (24 mm of rainfall) event from year four of the ten-year simulation period. The “base case” for this analysis is the response generated by the current scenario parameterization. The following parameters were individually adjusted: (1) the saturated hydraulic conductivity, $K_{\text{sat}}$ [LT$^{-1}$], for all porous medium zones that intersect the surface (i.e., three soil types, the same three soil types in their reduced permeability “residential” state, the channel zone, and the recent alluvium zone); (2) the Manning’s roughness coefficient for all surface zones; (3) the depth over which ET is distributed; (4) the rainfall time-series interval; (5) the height of microtopography; (6) the immobile water depth; (7) the hydraulic erosion coefficient for all surface zones; and (8) the rainsplash erosion coefficient for all surface zones. There are 26 cases considered here, in addition to the base case. The simulations start a short (25,200 sec) time before the beginning of the rainfall event and the initial conditions for all cases are identical (i.e., the base case initial conditions). The results of the sensitivity analysis, in terms of percent difference from the base case, are given in Table 5.10.

Inspection of Table 5.10 highlights the complexity and non-linearity of near-surface hydrologic-response processes. Runoff-generation behavior is closely tied to the parameters that influence infiltration rate, including those that affect the land surface’s ability to accept water from the surface (i.e., the saturated hydraulic conductivity and the height of microtopography), those that affect the depth of ponding and, therefore, the driving force for infiltration (i.e., the immobile water depth and the Manning’s roughness coefficient), and those that affect the rate at which water arrives at the surface (i.e., the rainfall time-series interval).

In general, there is an inverse correlation between the event response (i.e., total and peak water discharge) and the simulated infiltration rate. For example, the event
Table 5.10. Sensitivity analysis for selected parameters in terms of percent difference relative to the base case.

<table>
<thead>
<tr>
<th>Scenario/parameter</th>
<th>$Q_{\text{max}}$</th>
<th>$t_{Q_{\text{max}}}$</th>
<th>$Q_{\text{total}}$</th>
<th>ET$_{\text{total}}$</th>
<th>Infil$_{\text{total}}$</th>
<th>Qsed$_{\text{total}}$</th>
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<tbody>
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<td>Base case</td>
<td>26.0 m$^3$s$^{-1}$</td>
<td>16,891 s</td>
<td>0.0115 m</td>
<td>0.0041 m</td>
<td>0.0123 m</td>
<td>0.0395 kg m$^{-2}$</td>
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<td>K$_{\text{sat}}$ of all surface zones</td>
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<tr>
<td>Increase (x 10)</td>
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<td>15.9</td>
<td>-5.8</td>
<td>-23.4</td>
<td>-4.5</td>
</tr>
<tr>
<td>Increase (x 3)</td>
<td>-19.1</td>
<td>4.1</td>
<td>-2.4</td>
<td>-2.2</td>
<td>-0.5</td>
<td>-6.2</td>
</tr>
<tr>
<td>Decrease (x 3$^{-1}$)</td>
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<td>-5.3</td>
<td>10.4</td>
<td>0.7</td>
<td>-8.5</td>
<td>10.1</td>
</tr>
<tr>
<td>Decrease (x 10$^{-1}$)</td>
<td>65.5</td>
<td>-9.4</td>
<td>27.6</td>
<td>-0.1</td>
<td>-24.1</td>
<td>24.3</td>
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<td></td>
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<tr>
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<td>ET distribution depth</td>
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<td></td>
</tr>
<tr>
<td>Increase (x 3)</td>
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<td>0.2</td>
<td>8.0</td>
<td>-0.1</td>
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<td>Increase (x 4), 1 hr</td>
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<td>0.4</td>
<td>5.9</td>
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Table 5.10 (continued). Sensitivity analysis for selected parameters in terms of percent difference relative to the base case.

<table>
<thead>
<tr>
<th>Scenario/ parameter</th>
<th>$Q_{\text{max}}$</th>
<th>$t_{Q_{\text{max}}}$</th>
<th>$Q_{\text{total}}$</th>
<th>$ET_{\text{total}}$</th>
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<td>Increase (x 20), whole event</td>
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<td>-7.2</td>
<td>0.4</td>
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</tr>
<tr>
<td>Increase (x 3)</td>
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<td>16.7</td>
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<td>2.4</td>
<td>-2.2</td>
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<td>-10.4</td>
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<tr>
<td>Increase (x 10)</td>
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<td>0</td>
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</table>
Table 5.10 (continued). Sensitivity analysis for selected parameters in terms of percent difference relative to the base case.

<table>
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<tr>
<th>Scenario/parameter</th>
<th>$Q_{\text{max}}$</th>
<th>$t_{Q_{\text{max}}}$</th>
<th>$Q_{\text{total}}$</th>
<th>ET$_{\text{total}}$</th>
<th>Infil$_{\text{total}}$</th>
<th>Qsed$_{\text{total}}$</th>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-0.2</td>
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</tbody>
</table>

1 Peak water discharge  
2 Time to peak water discharge since start of rainfall event  
3 Total normalized water discharge since start of simulation  
4 Total normalized evapotranspiration since start of simulation  
5 Total normalized infiltration since the start of the simulation  
6 Total sediment discharge since start of simulation  
7 Base case values are the current scenario responses. All other entries are in terms of percent difference in response from the base case. Base case parameter values are given in Tables 5.3 and 5.4.
response is increased by a decrease in the immobile water depth, which causes water to flow rather than pond and infiltrate. Similarly, the event response is increased by an increase in the height of microtopography, which makes the surface less saturated for a given water depth, reducing infiltration and increasing runoff. Contrastingly, the event response is reduced by an increase in the Manning’s roughness coefficient, which causes water depths to be greater and slows down the surface runoff velocities, leading to more infiltration. Increasing the rainfall time-series interval causes the applied intensities to be less, increasing infiltration and reducing the event response, as expected. Figure 5.17 shows the event hydrograph for all sensitivity cases that involve a hydrologic parameter.

There are several cases in the sensitivity analysis that lead to non-intuitive event response effects, forcing one to look deeper. The saturated hydraulic conductivity, for example, is expected to vary inversely with event response, an assumption that holds true for all cases except the ten-fold increase case. In the ten-fold increase case, event response is actually augmented (and infiltration reduced), albeit with lower and time-lagged peak discharge. The explanation for this is that the increase in conductivity causes increased exfiltration from the most permeable channel zone that overshadows the increased infiltration over the rest of the watershed.

Simulated ET is much less sensitive than runoff for the parameters tested. In general, cumulative infiltration and cumulative ET are positively correlated, with changes in infiltration causing percent changes in ET of approximately one order of magnitude less. The largest impacts on ET result from changes to the ET distribution depth. All three distribution depth cases (two increase cases and one decrease case) result in increased ET. The increase in ET for decreased distribution depth is likely caused by greater water availability due to recent rainfall in the uppermost soil layers. The increase in ET for increased distribution depth likely results from the “tapping” by the ET boundary condition of deeper layers that were previously untapped and therefore had greater soil-water contents at the start of the simulation. Presumably, this tapping effect would diminish over longer periods of simulation time until the ET rate
Figure 5.17. Hydrograph comparison of sensitivity analysis simulations versus the base case. (a) Saturated hydraulic conductivity for all surface zones. (b) Height of microtopography. (c) Manning’s roughness coefficient. (d) Rainfall interval length. (e) ET distribution depth. (f) Immobile water depth.
became dominated by porous medium hydraulic properties, which tend to be less permeable with increased depth (see Tables 5.2 and 5.3).

Simulated sediment discharge varies consistently with surface water outflow for most of the sensitivity simulations involving hydrologic parameters. In most cases the percent change in sediment discharge is roughly equal to the percent change in surface water outflow. Sediment discharge is roughly twice as sensitive to Manning’s roughness coefficient as surface water outflow. Sediment discharge is most sensitive in these simulations to changes in the hydraulic erosion coefficient, although the sensitivity is non-linear; there is a greater increase in sediment discharge for a given increase in hydraulic erosion coefficient than there is a decrease in discharge for the same decrease in the coefficient. The simulations are not very sensitive to the rainsplash erosion coefficient, perhaps because the water depths are either too great to have much rainsplash erosion (e.g., in the channels and reservoir area), or too small to transport that sediment to the catchment outlet (e.g., on hillslopes).

Complex models like InHM require as input many physically-based (measurable) parameters, each of which has its own degree of uncertainty. Overall, the sensitivity simulations reported here show that the simulated response for a single event at the Searsville watershed is quite insensitive to relatively large changes in most of the analyzed parameters. This suggests that although the model parameterization, based in large part on published values for similar media and/or surfaces, contains uncertainty, the generated response is not likely to vary significantly from the base case behavior reported here when different values are used.

5.6 Discussion

The long-term simulations performed for this study provide, to the extent that they are founded upon realistic descriptors of the processes and physical characteristics of the system, insight into how the Searsville watershed system functions and how the presence of the dam and the deposited sediments affects this functioning. In the following paragraphs the simulation results are discussed in terms of (i) differences
between the four dam scenarios, (ii) impacts in the near-reservoir area, and (iii) watershed response to varying climatic and anthropogenic forcings.

The four dam scenarios differ from each other to varying degrees depending on the phenomenon in question. The main water balance components (Tables 5.6 and 5.8) differ by only a few percent between the four cases for any given year. Water balance component differences stem from varying degrees of surface-subsurface-atmosphere exchange due to different patterns of surface-water ponding, which are ultimately controlled by the topography of the reservoir and wetland area. Peak flow rates for individual events do vary significantly between the four scenarios, with implications for flood conveyance in the downstream channel. Since total surface water outflow volume does not vary significantly, the shape, and not necessarily the integrated volume, of event hydrographs (i.e., the timing and magnitude) is impacted the most. Sediment discharge from the watershed does show significant differences (Table 5.9), which can be attributed to the sensitivity of erosion and transport processes to surface water hydraulics, differences in the zone sediment characteristics (e.g., source fractions and erodibility coefficients), and the trapping/retarding effects of the dam and delta sediments.

The most important upstream impact of dam construction (or removal) is the creation (or destruction) of a surface-water impoundment where there once was channelized (or impounded) flow. Therefore the surface water flow regime in the entire upstream area that lies below the dam crest elevation is profoundly affected by dam-related activities. The simulations reported here show that upstream deposition of sediments can result in altered surface water flow paths and depths as well. The simulation results indicate that the zone of influence for surface water is generally defined by the combined areas below the dam crest and where newly deposited sediments are found (i.e., significant effects do not extend farther upstream). Downstream from the dam the simulations indicate that channel flow (e.g., peak discharge) is significantly altered by the dam’s construction or removal. The spatial patterns of surface-subsurface exchange (Figure 5.13), subsurface flow nets (Figure 5.14), water table depth (Figure 5.15), and sediment concentration (Figure 5.16) all are
perturbed by the distinct base level and topography of each scenario, but the effects are generally limited to areas directly under and around the reservoir and delta.

It is clear from the simulation results that climatic forcings are of first-order importance in controlling watershed hydrologic and geomorphologic response. The differences in response from one year to the next far outweigh the differences between scenarios for a single year. This suggests that future watershed behavior may be influenced much more strongly by climatic factors (e.g., changes in precipitation amount or intensity) than by human-induced geomorphologic changes. The sensitivity analysis reveals, however, that certain near-surface hydrogeologic and/or land surface characteristics affect hydrologic response in complex, non-linear ways, suggesting that climatic or anthropogenic disturbances to these factors can significantly alter the system behavior.

5.7 Summary

The effort reported here demonstrates an approach to characterizing the impacts of changing base level caused by the installation and removal of a dam for the 39 km² Searsville watershed. The approach, physics-based simulation with a comprehensive hydrologic model with sediment-transport capabilities (InHM), is shown to be useful in identifying and quantifying the impacts of dams. The degree of process representation in the model, the physical basis of the parameters, and the ability to examine both temporal and spatial patterns of hydrologic and geomorphologic phenomena make this research approach well suited for the dam problem. This work sets the stage for further applications of this approach to other watershed systems.
References


Dibilee, Jr., T.W., 1966, Geologic Map and Sections of the Palo Alto 15’ Quadrangle, California, Division of Mines and Geology, State of California, prepared in cooperation with U.S. Geological Survey.


