Auburn Ravine-Hemphill Diversion Assessment Sediment Transport Study

Prepared for:

Nevada Irrigation District

NID

Prepared by:

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March 2021

March 3, 2021

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1 INTRODUCTION

The Hemphill Diversion Dam provides infrastructure for maintaining agricultural irrigation delivery of Nevada Irrigation District (NID) imported water from Auburn Ravine. Auburn Ravine flows into the Eastside Canal, which flows into the Sacramento River just downstream of the confluence with the Feather River. The Sacramento River and its tributaries have been identified by the Central Valley Steelhead Draft Recovery Plan (NMFS, 2014) as a good candidate for habitat restoration. Additionally, Auburn Ravine supports chinook salmon as indicated in recent studies by California Department of Fish and Wildlife, Placer County and NMFS. The current Hemphill Diversion Dam is a fish passage barrier and removing it would add approximately 6 additional miles of headwater habitat for Steelhead and Chinook Salmon.

Nevada Irrigation District (NID) has requested that Balance Hydrologics ('Balance') characterize the nature of channel bed evolution and sediment transport, as associated with different dam removal alternatives. We understand that NID is still in the process of evaluating and selecting a preferred alternative, a process which involves many components including diversion replacement alternatives, fish count surveys, and evaluation and documentation of environmental impacts, as required under CEQA. This report is limited to a sediment transport modeling study, intended to characterize how sediment transport and channel evolution may be affected by three general dam removal alternatives.

The modeled alternatives are not necessarily those that will ultimately be considered through CEQA, but are developed to represent the range of probable sediment transport response associated with different dam removal scenarios:

- Alternative 1: Dam removal and no active sediment management
- Alternative 2: Dam removal and active sediment management
- Alternative 3: Incremental dam removal and no active sediment management

At this time, we understand that the general project alternatives being considered fall into one of these categories with respect to sediment transport and we have limited our analysis to these three alternatives for clarity and simplicity. Each sediment transport alternative can ultimately be compared to the "No Action" scenario which is run as an existing conditions scenario, which was also used to help parameterize the sediment transport model.

For the purposes of this study, “Dam removal” means complete removal of hardened structures within the active channel area, including the bed and bank protection rip rap around the dam.

“Incremental dam removal” refers to removal of the dam incrementally over three different construction seasons. We have not evaluated whether the existing dam construction or materials are suitable for an incremental removal. Due to the nature of the numerical model as outlined below, we have modeled incremental dam removal of the approximately 8-foot-high dam as follows:

- Step 1: Removal of 2 feet of dam
- Step 2: Removal of 5 total feet of dam
- Step 3: Removal of all 8 feet of the dam; this is the same as Alt. 1 and so not modeled separate (see below)

“Active sediment management” refers to excavating and grading the impounded deposits into a designed quasi-stable position to limit the total volume of sediment released to downstream areas. We have modeled one generalized channel configuration for this purpose, but more detailed design work would be required before implementing that alternative, especially in light of the unstable streambanks upstream of the dam. Alternatives 1 and 3 (no active sediment management) involve removing all or part of the dam and letting natural sediment production and transport processes evolve the channel as flow capacity allows.

This study was carried out to evaluate each alternative in terms of the following questions and geomorphological impacts:

1. What flow magnitudes and durations are required for the channel to return to a state of quasi-stable equilibrium after implementing each alternative?
2. What is the potential for erosion and deposition within the model domain?

The general benefits and limitations of each alternative are discussed from a geomorphological perspective, but we have not included potential short- or long-term impacts to fish habitat as a result of the introduction of the impounded sediment downstream.

2 SITE BACKGROUND

2.1 Site Location

The Hemphill Diversion Dam is located on Auburn Ravine approximately 2 miles east of Lincoln, California in Placer County (**Figure 2-1**). The project site is located just north of the Turkey Creek Golf Club and accessed from Virginiatown Road. The contributing watershed is approximately 25.9 square miles with the headwaters originating at elevation 1687 feet[1] and the project site at 207 feet (Stream Stats, 2020). Average watershed elevation is approximately 840 feet (**Figure 2-2**).

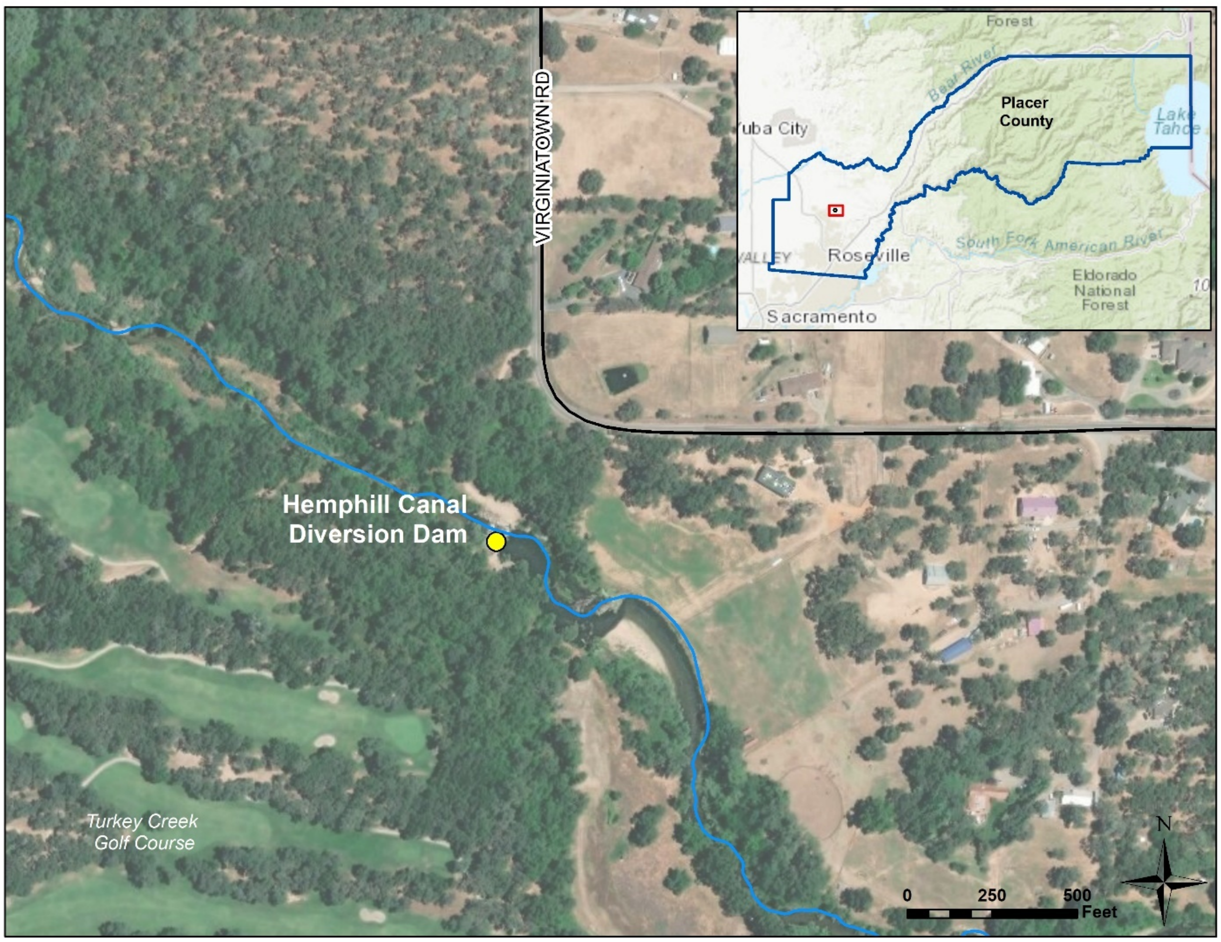


Figure 2-1 Site location overview map.

[1] Unless otherwise specified, all elevations in this report are relative to the NAVD 88 vertical datum.

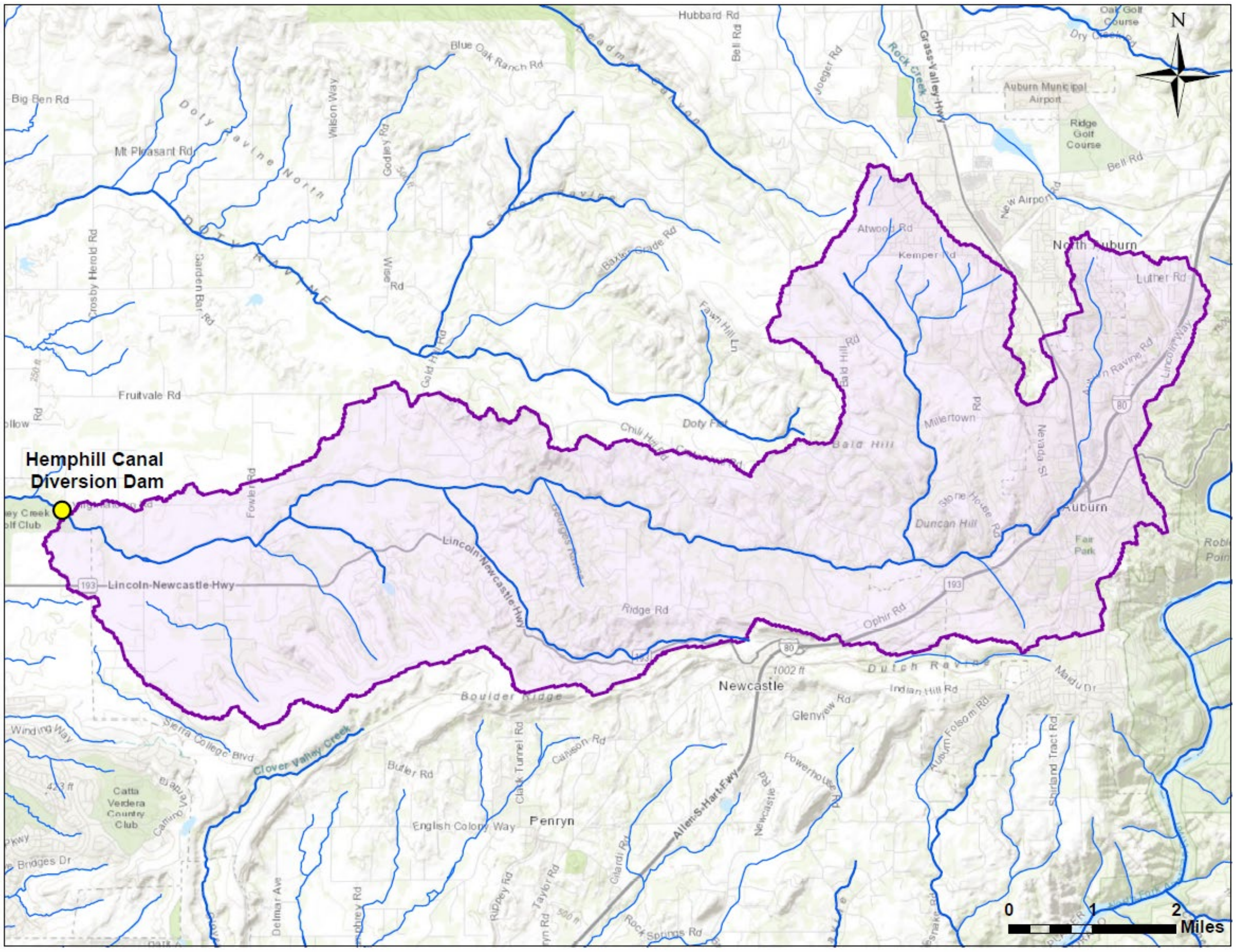


Figure 2-2 Contributing watershed for Auburn Ravine at Hemphill Diversion Dam.

The Hemphill Diversion Dam is approximately 8 feet high and constructed out of concrete. During the diversion season, 3-foot flashboards can be installed to increase ponding depths in the impoundment area and direct flow into the Hemphill Canal. An approximately 5-foot-deep scour pool is present on the downstream side of the dam, which is partially armored with placed boulders. The channel banks immediately adjacent to the dam are hardened with boulder rip rap or concrete.

2.2 Soils

Soils in the Auburn Ravine watershed are primarily comprised of coarse sandy loam, and silt loam, with approximately 18 percent rock outcrop coverage (NRCS, 2020). The NRCS classifies all soils into one of four Hydrologic Soil Groups (HSG) which denote soil permeability and infiltration rate, ranging from Group A soils with high potential infiltration rates to Group D soils with the lowest potential for infiltration. The Hemphill Diversion Dam contributing watershed is dominated by type C soils (45%), followed by type D soils (25%), and type B soils (15%). Approximately 15% of the watershed is mapped as Xerorthents, or cut and fill material which has been displaced primarily as the result of mining activity.

2.3 Geology

The geology in the water is largely comprised of Mesozoic volcanic and metavolcanic rocks (Wagner, et al., 1981). The most notable rock formation is the Penryn Pluton, which outcrops in the vicinity of the project site just east of Lincoln, California to the western edge of Auburn, California, and covers a majority of the watershed. The Penryn Pluton is comprised of medium- to coarse-grained quartz diorite containing plagioclase feldspar, quartz, hornblende, and biotite (Olmsted, 1971). The feldspar and quartz typically weather to a medium to coarse sand, or 'decomposed granite' that is found throughout much of the watershed and along stream channels.

2.4 Geomorphic Observations

After an initial site visit, Balance staff returned to the site to conduct a reconnaissance-level geomorphic assessment of the project area on March 9, 2020. Ground-based topographic survey data was also collected that same week by the NID survey crew. These field-based observations are summarized below and also coupled with a LiDAR-derived topographic dataset collected between August 2018 and March 2019 and published January 7, 2020 to illustrate geomorphic conditions in the model domain area (**Figure 2-3**).

Valley-fill sediment overlies the granitic bedrock at the diversion dam location, and consist of moderately well-graded silt, sand and gravel floodplain and alluvial deposits. Auburn Ravine primarily flows within these deposits, migrating laterally over time. As flow regimes and bed elevation controls have changed, the stream appears to have incised into these deposits, eroding older floodplain deposits and forming an inset floodplain downstream of the diversion dam, as well as bar deposits within the active channel belt. Immediately upstream of the dam, the channel is migrating to the right (looking downstream), and multiple inset floodplains have developed downstream of the dam.

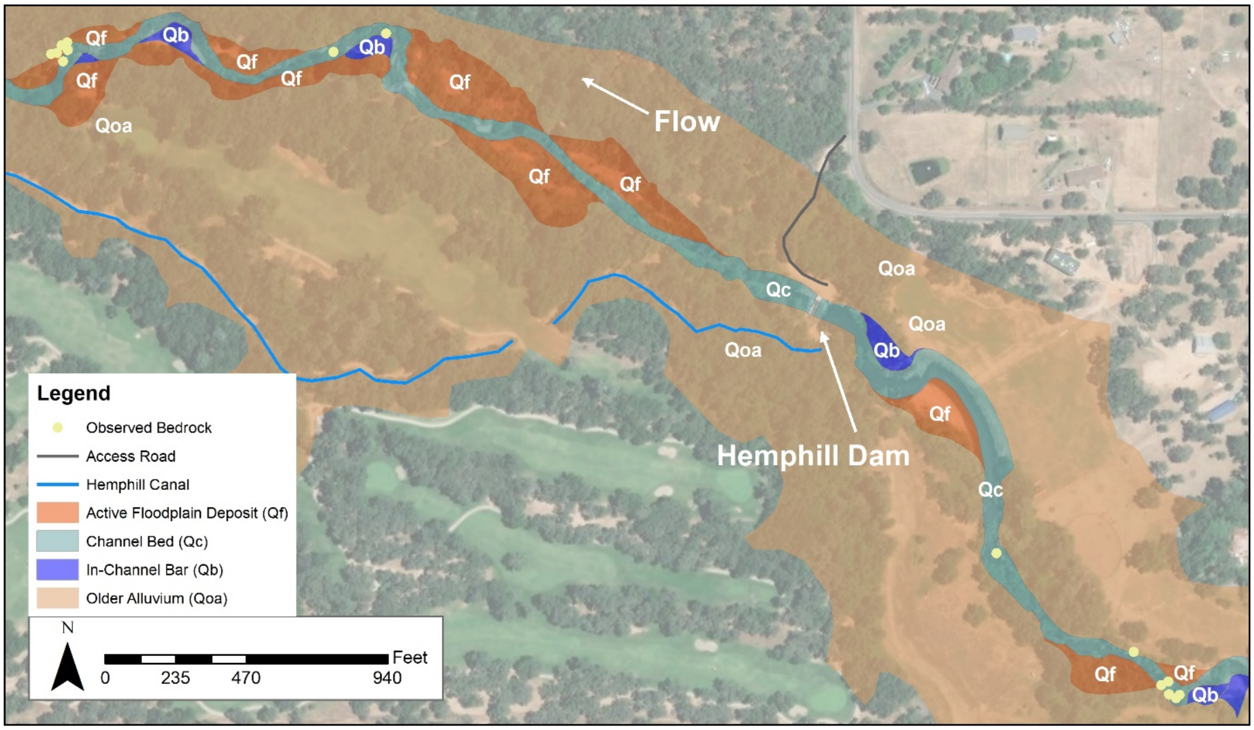


Figure 2-3 **Geomorphic units.** Based on topographic data, field observations, and aerial imagery.

The channel bed is generally composed of sand and gravel, with cobbles present on higher channel bars. Loosely-compacted deposits observed on gravel bars consisted of coarse sand and fine gravels (**Figure 2-4**). The channel thalweg elevation was measured by NID in March 2020 during the ground-based survey. Based on this survey, average channel slope is approximately 0.2 percent upstream of the dam and 0.4 percent downstream of the (**Figure 2-5**). Upstream of the diversion dam, the channel slope is likely directly influenced the dam, which serves to control the bed elevation and gradient. Immediately downstream of the diversion dam, the channel structure is more tightly packed, with a more consistent armor layer of cobbles and boulders and less sand on the bed surface (Holdrege & Kull, 2017).

Figure 2-4 Example of outcropping bedrock and sand and gravel bar, located upstream of Hemphill Dam, looking upstream.

Lidar reflections cannot penetrate water and are therefore typically removed from lidar point clouds in post-processing. However, the digital elevation model (DEM) of lidar point clouds in the wetted channel area can give an approximate water-surface elevation. Assuming that the inferred water-surface elevation is approximately parallel to the bed elevation over several thousand river miles, we estimate the overall channel slope in the areas outside of the direct influence of the dam and the impoundment area to be approximately, 0.4%, the same as the model domain reach downstream of the diversion dam.

Within the report study area, large quartz diorite boulders or bedrock are visible on the bed and in the channel banks (**Figure 2-4**). While it is possible that some of these large boulders have been placed, we interpret the larger occurrences to be bedrock outcrop that likely provides a control on bed elevations, channel stability, and lateral channel migration.

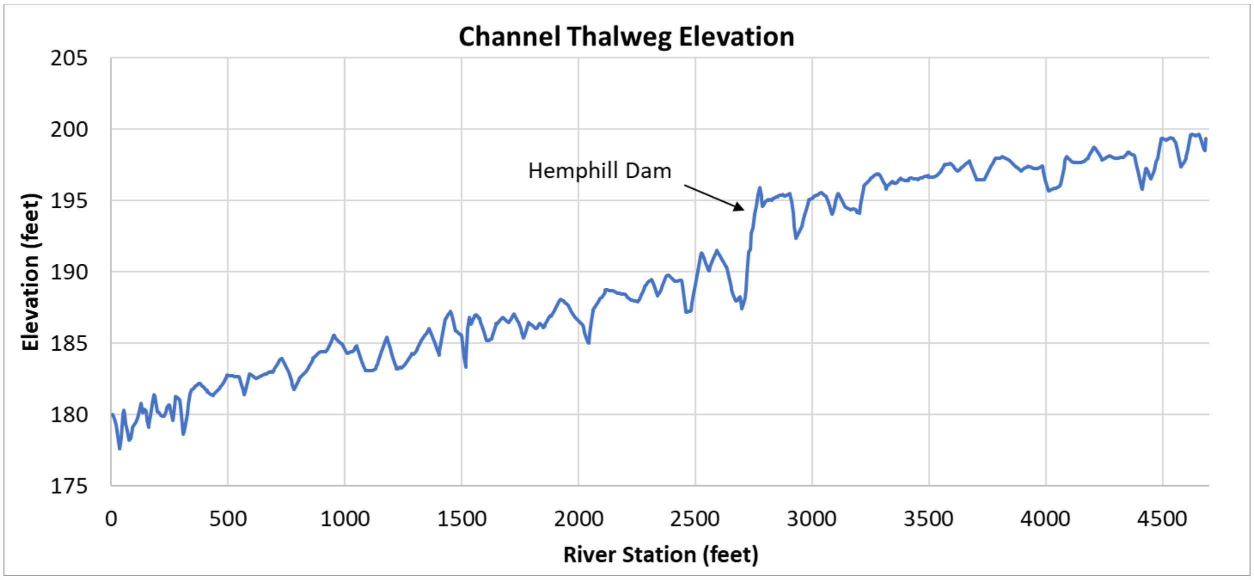


Figure 2-5 Channel thalweg elevation within the model domain.

As such, we have established the sediment transport and channel behavior model domain to include bedrock outcrop at the upstream end, where channel incision and lateral migration is expected to be minimal. For example, at the upstream end of our model domain, a channel bar has formed over the last decade, migrating toward the right bank and depositing sediment on the inside bend. Historical aerial imagery illustrates a laterally dynamic channel with active sediment deposition and transport processes. In contrast, the reach just downstream of this has outcropping bedrock on the right bank and lateral migration has been arrested over the same period (**Figure 2-6**). It is therefore assumed that the exposed bedrock will slow bed incision in this reach.

A 2- to 3-foot high beaver dam was observed approximately 1200 feet downstream of the diversion dam during our March 2020 field reconnaissance, and is also visible in the 2018-2019 LiDAR-based topography, suggesting that it is a relatively stable feature.

Figure 2-6 **Aerial images of upstream model boundary comparing May 2002, June 2011, September 2019.** White outline of May 2002 active channel on 2011 and 2019 images. Note white bedrock in 2011 image, also observed in the field in March 2020. Reach is approximately 1,300 feet upstream of the dam.

3 MODELING METHODOLOGY

The sediment transport model was completed using SRH2D version 3.2.4 via the Aquaveo SMS software package version 13.0.12. Each alternative was modeled using the 2-, 10-, and 25-year design storm to evaluate a range of responses to different flow rates. The model input data and model parameters are described below in more detail for each of the project alternatives.

3.1 Input Design Storm Hydrographs

Available gaging data in this watershed does not include high flow data, which typically transports the largest proportion of total sediment. Therefore, we constructed a simplified hydrologic model using the U.S Army Corps of Engineers' HEC-HMS platform (version 4.3) to derive representative hydrographs for use in the sediment transport model. We understand that additional flow data sources may be available but were not reviewed for this study.

The modeling approaches and assumptions used in the HEC-HMS modeling are summarized below.

3.1.1 Design Storms and Rainfall

The elevation-duration rainfall depths (inches) were taken from the Placer County Stormwater Management Manual, and linearly interpolated for the mean basin elevation of approximately 800 feet. The precipitation values used for each design storm are summarized in **Table 3-1**.

Table 3-1 Precipitation depths scaled to 800 feet elevation

	Partial-Duration Depth (inches)					
Duration	**2- year Frequency**	**5-year Frequency**	**10-year Frequency**	**25-year Frequency**	**50-year Frequency**	**100-year Frequency**
5 min	0.14	0.20	0.25	0.31	0.36	0.42
15 min	0.25	0.36	0.44	0.55	0.64	0.72
1 hr	0.50	0.70	0.84	1.03	1.16	1.30
2 hr	0.72	0.99	1.17	1.42	1.60	1.79
3 hr	0.87	1.20	1.42	1.70	1.92	2.14
6 hr	1.22	1.65	1.95	2.33	2.63	2.74
12 hr	1.75	2.38	2.82	3.35	3.79	4.17
1 day	2.39	3.22	3.85	4.54	5.09	5.63

3.1.2 Watershed Characteristics

The watershed is approximately 25.9 square miles, with a mean basin elevation of 844 feet (Gotvald, 2012, e.g. StreamStats). The average percentage of impervious area is approximately 7.2 percent according to the 2011 National Land Cover Database. The soils in the watershed are predominantly well drained, coarse sandy to silty loams.

3.1.3 Hydrograph Parameterization and Model Calibration

Hydrologic methodology follows Placer County drainage guidelines for a simplified rainfall-runoff model and uses parameterization techniques from the Sacramento County guidelines when not specified by Placer County.

Total runoff is derived using both an Initial and Constant rate of infiltration. The constant infiltration amount was derived based on HSG type C soils over predominantly woody land cover with fair cover, resulting in an infiltration rate of 0.13 inches per hour. The Initial Loss was estimated to be 0.15 in, which is consistent with Sacramento County initial losses and average water capacity of the soil types in the watershed.

The selected Hydrograph transform was the Snyder Unit Hydrograph, consistent with the Placer County guidance for a lump-parameter model. The Snyder Unit hydrograph is parameterized by a lag time in hours and a peaking coefficient. Peak flows were calibrated to available peak flow estimated values for the project site derived using standard regional regression methodology (Gotvald, 2012). Lag time was calibrated to each peak flow rate (**Table 3-2**). Peaking coefficient was set to a uniform value of 0.5 which is consistent with standard values in other counties, but as the lag time is calibrated to the published peak flow values, the choice is largely immaterial for determining the flow range for each of the design storms.

Calibrated lag times were verified against the lag times calculation following the Sacramento County Drainage Manual (1996), where lag time (T_{lag}, in hours) equals:

$$T_{lag} = Cn \times \left(\frac{L \times L_c}{S^{0.5}}\right)^{0.33}$$

where C is a constant of 1560, n is dependent on the basin land use and condition of the main drainage course, L is the length of the main watershed drainage path, in miles, L_c is the length along the main drainage path from the point of interest to the centroid of the watershed in miles, and S is the overall slope of the main watercourse (feet/mile).

Calculated lag times ranged from approximately 4 hours to 6 hours depending on the size of the flow event, and consistent with calibrated lag times in **Table 3-2** above.

The resulting design storm hydrographs for the 2-, 10-, and 25-year design storms are plotted in **Figure 3-1**.

Table 3-2 Peak design flows (Gotvald, 2012) and calibrated lag time values

Design Storm	Peak Flow (cfs)	Lag Time (hr)
2- year	752	6.25
5-year	1690	4.75
10-year	2390	4.25
25-year	3250	4.10
50-year	3960	4.00
100-year	4660	3.75

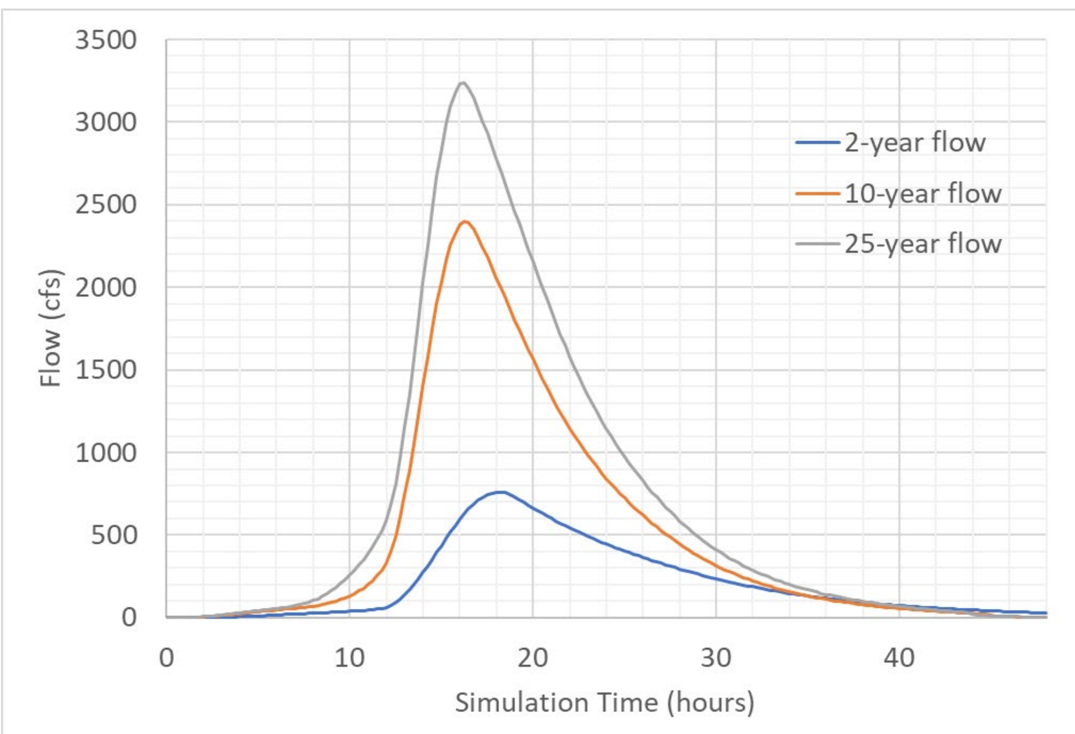


Figure 3-1 Design storms for the 2-, 10-, and 25-year event.

3.2 Model Domain Mesh

The sediment transport model is parameterized with an initial digital elevation model (DEM) derived from a combination of several datasets which represent the existing conditions. The first is a Lidar dataset collected between August 2018 and March 2019 and published January 7, 2020. Recent Lidar datasets provide excellent high-resolution look at elevations over a large area but do not see through standing water. Therefore, the lidar data was supplemented with ground-based surveys in the low-flow channel collected by NID survey staff during the week of March 9, 2020. The survey included elevations of the channel thalweg and two additional channel bottom points. Additional points were collected on floodplain/terrace areas to confirm agreement between the two datasets. A DEM was created using the ground-based survey data in the low-flow channel area to the interpreted water-surface edge. The ground-based DEM and lidar datasets were merged at the water-edge boundaries to create a combined DEM for the entirety of the model domain. The DEM used for all model simulations assumes that the diversion-season flashboards are not used since all models simulate high-flow events which typically occur outside of the diversion season.

For Alternative 2 (Sediment Management), the existing conditions DEM was altered to reflect an excavated channel and bed surface in the impounded sediment beginning downstream of the existing dam structure and ending upstream of the previously impounded sediment. The purpose of a pilot channel would be to remove previously impounded sediment to minimize geomorphic change associated with dam removal, and to reduce potential bank and bed instability as the channel adjusts. As noted above, the channel was developed at a conceptual level and ties together upstream and downstream channel bed elevations. The preliminary pilot channel was designed under the following considerations: a) a uniform channel width of 25 feet, as based on apparently stable channel widths upstream and downstream of the constructed channel, b) pilot channel path which maintains sinuosity and channel slope within the channel meander belt zone, c) re-routing the thalweg away from the actively eroding private property on the right bank upstream of the dam and into a high-flow side channel in the existing bar. The pilot channel bottom outline is depicted in **Figure 3-2**, and would require excavation of approximately 8,000 to 8,500 cubic yards of material. Some of this material could potentially be re-used on site further protect the failing right bank, but some amount of off-haul would still be required. Out of necessity, the pilot channel is steeper than either the upstream or downstream reaches, with a slope of approximately 0.0065 feet per foot. While the pilot channel slope is steeper than the upstream and downstream bed slope, construction of a pilot channel would likely allow for more gradual change to the pre-dam bed conditions compared to no management of the impounded sediment. As noted above, additional channel design work would be required prior to implementing this concept.

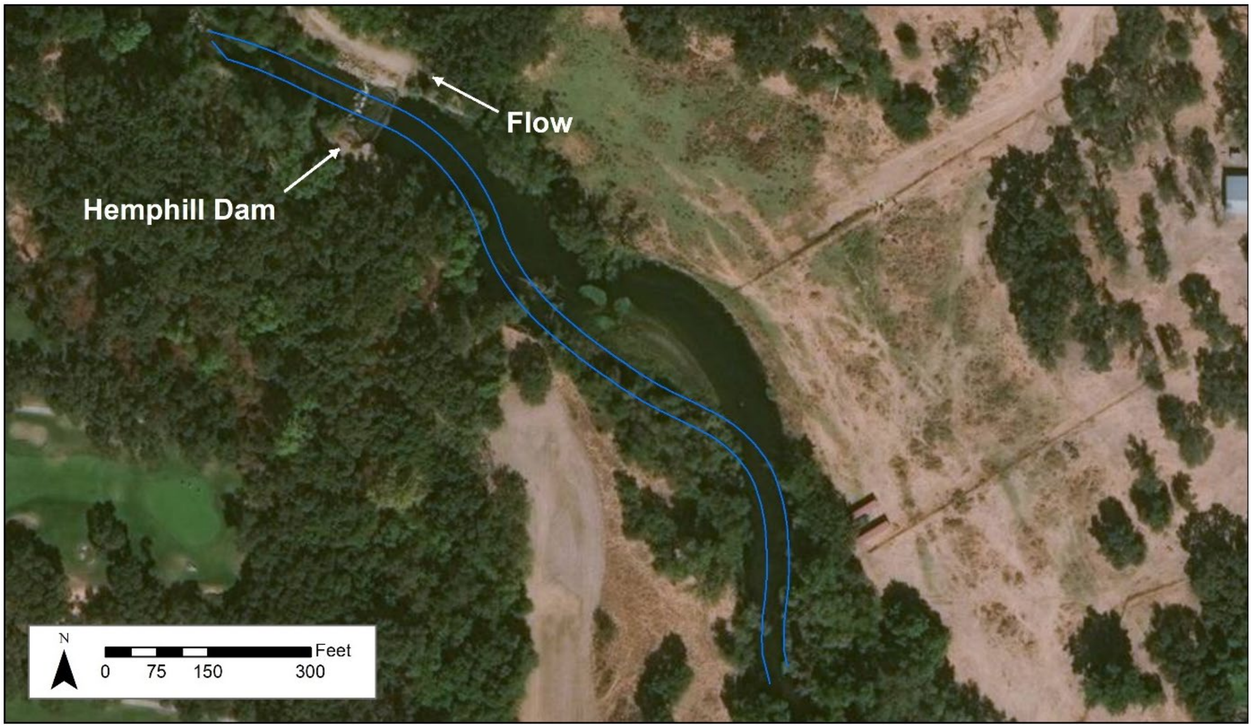


Figure 3-2 Preliminary pilot channel orientation used in the Sediment Management Alternative (Alt. 2).

The downstream model domain boundary was selected at a large arrangement of boulders or exposed bedrock which will likely continue to act as a grade control. The upstream boundary condition was selected to be just upstream of a reach with likely bedrock control (**Figure 2-6**) and with enough of the upstream bed outside of the impoundment backwater area to establish a reach-scale channel slope.

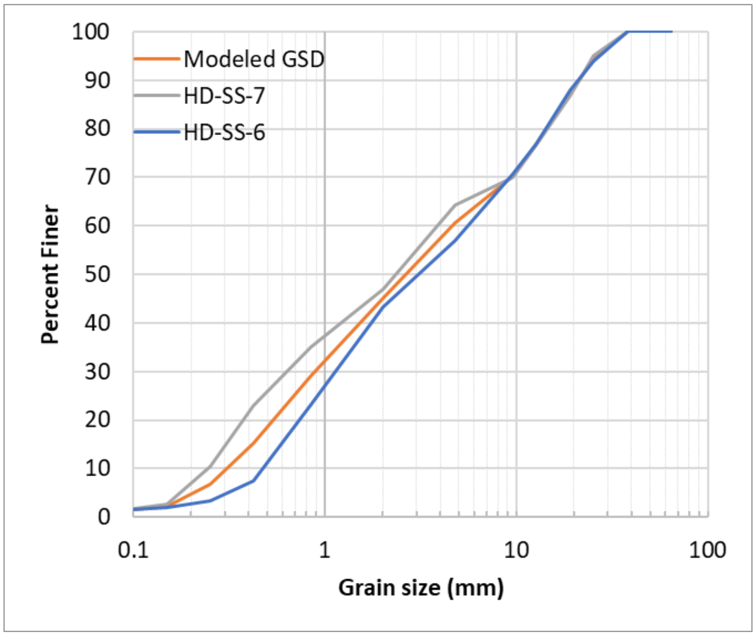
3.3 Bedload Transport Function

SRH2D has several published and widely used sediment transport equations included. Selection of the sediment transport function can significantly affect the results and so it is important to select a function which can appropriately represent the conditions at the project site. Auburn Ravine at Hemphill Dam is a sand-dominated system with approximately 45 percent of grains finer than 2 mm (Holdrege & Kull). We therefore evaluated three potential sediment transport functions: Meyer-Peter Müller (1948), Engelund-Hansen (1972), and Yang (1979) for sand with Yang (1984) for gravel. We found that Engelund-Hansen (1972) produced the most stable and reliable model results for the No Action model runs and have used it for this analysis.

The model is simulated on a timestep that produces a stable model result, typically 0.5 to 2 seconds and simulated for 48-hour duration so that the recession of each design storm is included.

3.4 Channel Grain Size Distributions

Available bed grain size distribution (GSD) data was measured by NV5 in March 2017 and reported in the Geotechnical Engineering and Hydraulic Report (NV5 2020). Five total bulk samples were collected in the impoundment backwater area and three Wolman pebble count transects were conducted just downstream of the dam in the scoured area. Two of the bulk GSD samples were collected at the upstream end of the impounded deposit area, HD-SS-6 and HD-SS-7 which are likely the best representation of the general sediment supply in the model reach. The entire bed was therefore parameterized using the average GSD of the two samples. **Figure 3-3** shows the model GSD compared to the bulk samples. For more details on sample collection, see NV5 (2020). Bedload transport is modeled in nine grain size bins ranging from 0.0025 mm to 32 mm in size, with the large end of the range the largest grain found in the bulk samples.



grain size bins (mm)	
min size	max size
0.0025	0.0625
0.0625	0.125
0.125	0.25
0.25	0.5
0.5	2
2	4
4	8
8	16
16	32

Figure 3-3 Modeled surface and subsurface grain size distributions (GSD) (left), and modeled grain size bins (right).

3.5 Channel Bed Erodibility

As is the case with most sediment transport models, SRH2D does not explicitly model the additional bank strength or cohesion of typical riparian vegetation (e.g. willows, blackberry, etc.). To appropriately model the lateral extent of erosion in the presence of bank vegetation we have designated many floodplain terraces as "non-erodible" (**Figure 3-4**).

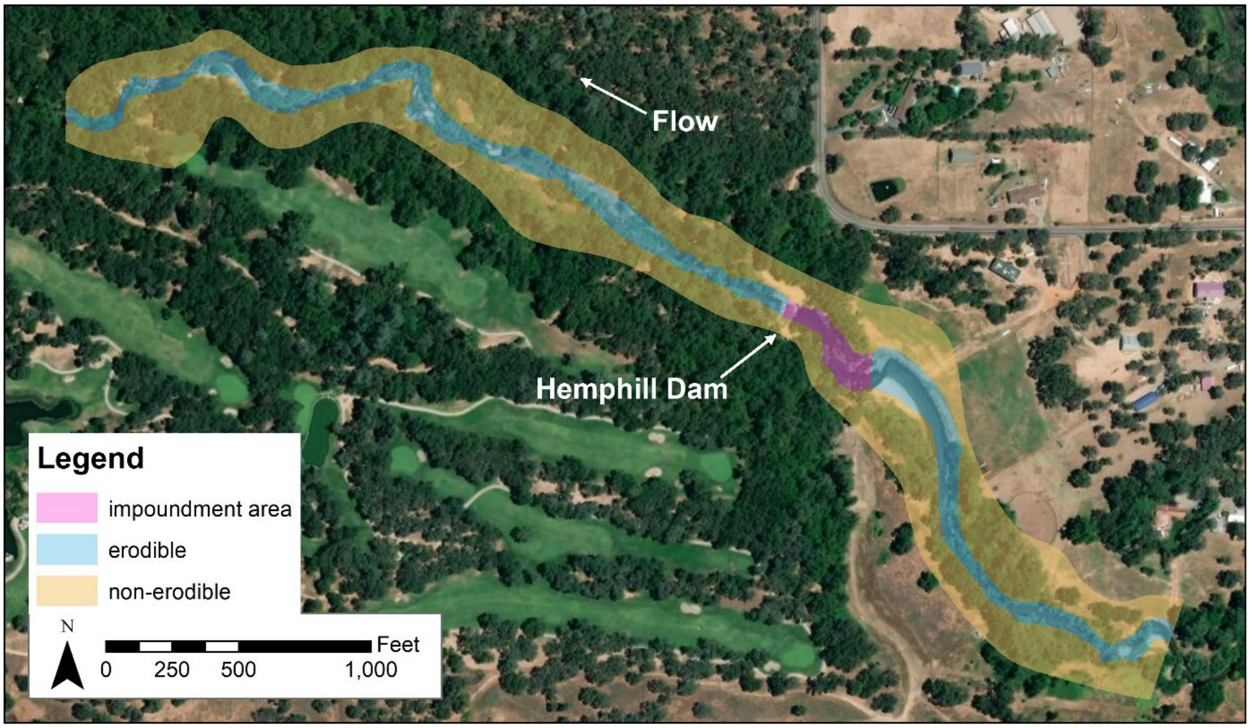


Figure 3-4 Erodible and non-erodible areas in the No Sediment Management alternative (Alternative 1). See above text for description of how erodibility in the impoundment area is handled for each modeled alternative.

3.6 Channel Roughness

Manning's N, or channel roughness coefficient, is parameterized for the model domain. Although Manning's typically varies with bed GSD, vegetation type, and even flow depth, it is sufficient to parameterize the model domain in terms of averaged roughness given the spatial scale and level of detail in the model. Due to the numerical dependency of bed shear stress on water depth and therefore Manning's n value, spatially variable Manning's n values which account for vegetation can counterintuitively accelerate erosion in overbank areas compared to the low-flow channel. Thus, Manning's N is set separately for erodible and non-erodible areas of the channel, 0.035 and 0.06, respectively.

3.7 Active Layer Depth

Sediment transport models parameterize the channel in layers, with the top-most layer as the "active layer" which stores numerical information about surface GSD and the depth of that surface layer. Bed erosion occurs when hydraulic forcing exceeds the threshold of motion for the grains at the surface. When erosion occurs, the thickness of the active layer is removed from the modeled node. As a result, the magnitude of the cumulative bed scour is highly sensitive to the choice of active layer depth. A sensitivity analysis of the 2-year No Action model run was completed to choose an appropriate active layer depth for this system, selecting a depth which produced final scour depth in a similar range as the surveyed channel thalweg. We selected an active layer depth of 5 millimeters, and which is finer than approximately 61 percent of the bed surface GSD (**Figure 3-3**).

3.8 Upstream Boundary Conditions

At the upstream boundary of the model domain, flow is input as an Input Flow Hydrograph for the 2-, 10-, or 25-year flow event. Flow is distributed across the model mesh using the cross-sectional area of the inlet cross-section. In order for the entire model domain to experience a similar flow rate as the design storm propagates through the reach, we have seeded each model run with a flow-only hydraulics model run using a constant inflow of 10 cfs (i.e. “Wet Start”).

Sediment input can either be modeled to be equal to the hydraulic capacity of the channel, or explicitly input as a sediment-discharge rating curve. Most rivers do not transport sediment rates equal to the hydraulic capacity at higher flows as a result of bedrock controls, watershed urbanization, channel incisions, invasive vegetation colonization, bank stabilization efforts, reservoirs or other sediment sinks, or flood peak regulation. We therefore used the 2-, 10- and 25-year No Action model runs to select a sediment capacity ratio and found that upstream sediment loading of 50 percent of the total capacity was appropriate for maintaining channel characteristics in the No Action 2-year model run used for model calibration. **Figure 3-5** shows the modeled input sediment transport rating curve for each grain size bin.

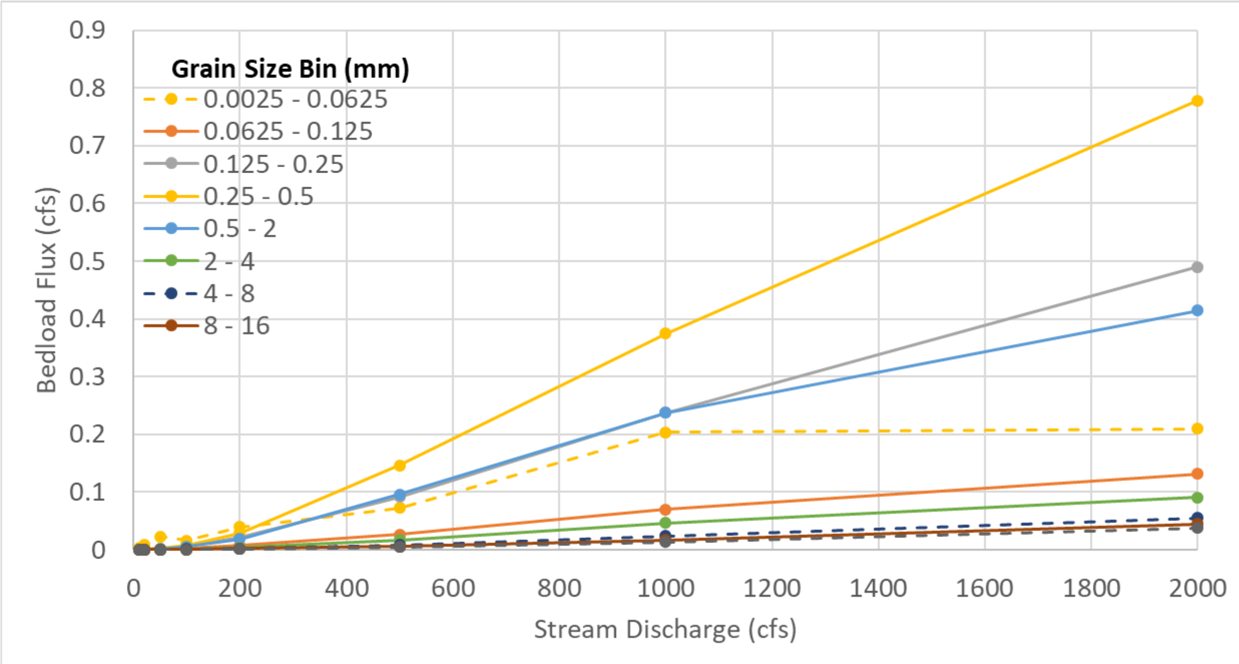


Figure 3-5 Input sediment rating curves for each grain size bin. Represents approximately 50 percent of the available sediment transport capacity.

3.9 Downstream Boundary Conditions

The downstream hydraulic boundary conditions were derived using the Hydraulic Design Function within HEC-RAS version 5.0.7 (**Figure 3-6**). The water-surface elevation (WSE) was calculated in a representative cross-section using Manning's Equation for a range of flows, using a local slope of 0.0033 feet per feet and a composite Manning's N value of 0.06 to account for the presence of large boulders and other channel roughness elements near the downstream model boundary conditions.

3.10 Model Representation of Alternatives

Appropriate representation of the processes that would occur under the range of dam alternatives is often constrained by numerical or even software limitations. Here we outline the approaches we used to best approximate the most representative conditions under the range of dam removal alternatives. The alternative-specific model parameters discussed below are in addition to the general parameterization outlined above.

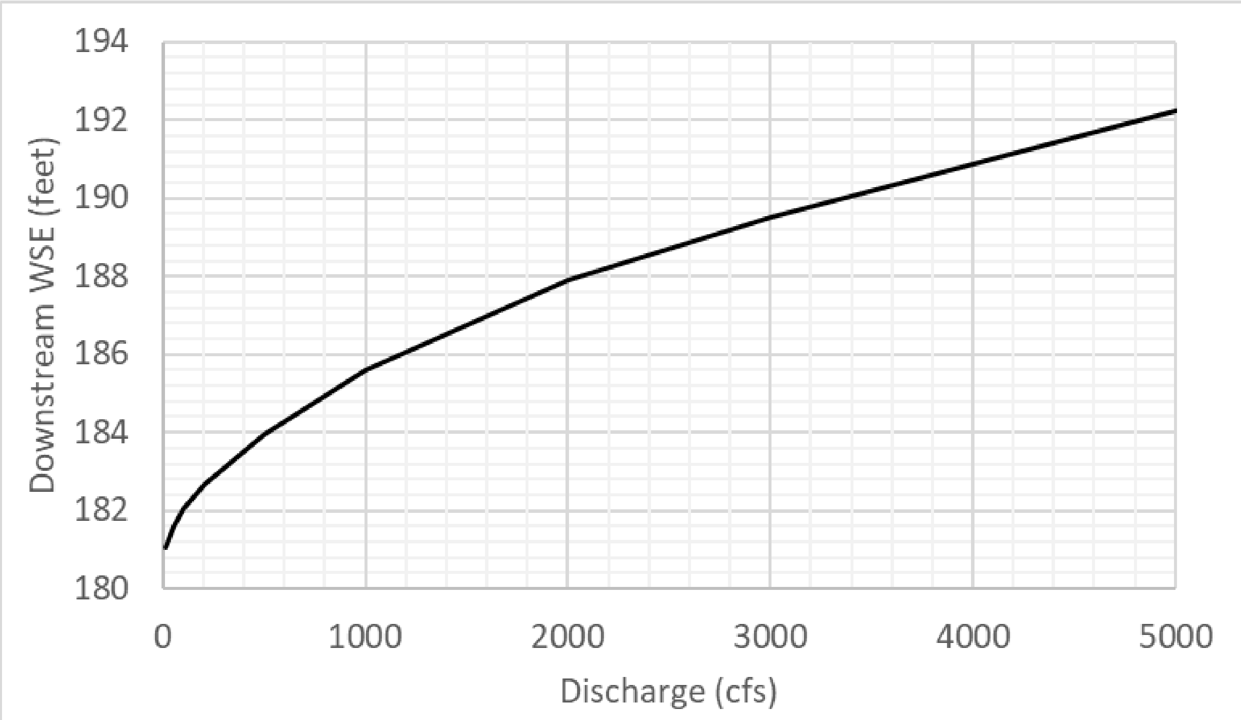


Figure 3-6 Downstream hydraulic rating curve.

3.10.1 No Action

The No Action scenario was initialized with the existing conditions DEM. To prevent appreciable scour in the backwater area immediately upstream of the dam, the bed was set to non-erodible in this area; sediment was allowed to accumulate freely. This choice was made to prevent sediment being transported over the dam unrealistically. It is possible that further model refinement could result in a different result.

3.10.2 Alternative 1: Dam Removal and No Sediment Management

In the case of dam removal with no sediment management, the bed surface is allowed to erode or accumulate freely throughout the model domain.

3.10.3 Alternative 2: Dam Removal and Sediment Management

The dam removal with sediment management alternative was initialized with a bed surface DEM which included a pilot channel design concept as described above. The bed could freely erode or deposit throughout the model domain.

3.10.4 Alternative 3: Incremental Dam Removal and No Sediment Management

Given the choice of using design storms to parameterize bed channel response to dam alternatives, an incremental removal or "notching" of the dam under sequential design storms was not realistic, given the low recurrence probabilities of the design storms. For example, it is unlikely that notching the dam by 2 feet in Step 1 and total 5 feet in Step 2 would each be followed by a large enough event to achieve channel equilibrium after a single event. Further, because sediment transport models are deterministic, the bed adjustment in response to sequential design storms of the same size (i.e. two 10-year storms in a row) produces minimal bed change outside of the immediate dam area as the bed adjusted to the deterministic quasi steady-state condition after the first storm.

After multiple iterations and given the limitation of a numerical modeling method, we ultimately chose to represent the incremental dam removal alternative by modeling separately a 2-foot dam removal and separately a 5-foot dam removal, representative of Year 1 and Year 2 of the incremental dam removal alternative. Because this is a deterministic model, Year 3 of this alternative is the same as Alternative 1, (removal of the entire 8-foot-high dam with no sediment management). If the incremental removal is pre-scheduled (rather than according to monitoring flow rates and channel response), it is possible that a year with low peak flows could result in minimal reworking of the impounded sediment after partial removal and so it is helpful to characterize the 5-foot scenario as a worst-case scenario in an incremental dam removal alternative. Incremental dam removal to specific depths are parameterized so that the bed is set to be non-erodible more than 2 or 5 feet in depth in the impoundment backwater area.

A realistic approach to understanding incremental dam removal could include analysis of annual hydrographs, perhaps including a range of hydrologic responses over the course of a year or multiple years (e.g. dry, average, wet periods). As previously discussed, the design storm approach was selected for this stage in the project development. This is discussed more in Section 5.

4 MODELING RESULTS

Modeling results for the No Action scenario and the three dam alternatives are presented in Appendix A as a series of channel maps and profiles showing areas of bed erosion and deposition. In this case the plot is of *erosion*—positive numbers and cool colors indicate net bed erosion, and negative numbers and warm colors indicate deposition or channel aggradation. Included in each figure is a profile plot through a representative thalweg. The orange profile is the initial condition bed elevation profile (either existing conditions or existing conditions with a pilot channel). The blue lines represent the bed elevation throughout the 48-hour model simulation, progressing from light blue to dark blue. The dark blue profile shows the final simulated channel elevation. It is important to note the representative thalweg location was chosen as the best approximation of a channel bottom which can migrate laterally throughout a simulation and therefore may or may not represent the lowest bed elevation during each timestep. These plots are, however, useful for evaluating the overall channel slope, and general trends in deposition and erosion.

It is also important to note that many of the simulation results show considerable (2+ feet) of deposition at the upstream-most portion of the model domain. This is likely in response to the wide cross-sectional area which includes a large gravel bar and does not include the effect of possibly higher velocities entering the cross-section from the narrower upstream reach. This section of the model domain is more dependent on the model boundary conditions than realistic in-channel conditions, and should therefore not be considered to be indicative of probable geomorphic change.

4.1 No Action

The No Action scenario was evaluated both as a model calibration tool, and to understand the potential range of response to the existing dam structure under a range of design storms. Figures A1 – A3 illustrate an increasing depth of sediment deposited upstream of the Hemphill Dam which is expected as a result of the backwater and grade control effects created by the dam structure. Peak flows close to the 2-year flow event are often estimated to transport the majority of total sediment load over time because flows are large enough to transport a range of grain sizes and occur frequently. Thus, channel form is often largely influenced by flows in the 2-year event range. As expected, simulated channel response to the 2-year flow event (Figure A1) produces a similar bed structure (i.e. pool depths and riffle heights) as compared to the existing channel profile. In contrast, the larger events, 10- and 25-year events, both fill some existing pools and form new, or even deeper pools. This is consistent with the literature on bed response during larger flow events.

4.2 Alternative 1: Dam Removal and No Sediment Management

The first Alternative (Alt. 1) evaluated is the case in which the dam is removed, but no previously-impounded sediment is removed from the channel (Figures A4 – A6). In this case, flows are allowed to freely transport and re-work the stored sediment, transporting it downstream. Simulations indicate that after a 2-year flow event (Figure A4), a new channel thalweg would be carved through the impounded sediment and transported downstream, but channel slope adjustment would not propagate upstream without additional or larger-magnitude flow events. Up to approximately 2 feet of sediment is predicted to be deposited downstream under this simulation.

After a 10-year event, model results indicate that overall channel adjustment would propagate farther upstream (to approximately station 4000) and an average of 3 to 4 feet of sediment would be deposited in the existing downstream scour pool. In this scenario the overall channel slope is predicted to become mostly adjusted to the slope of the reach downstream of the dam, but additional flow events would likely result in further channel change upstream of the impoundment, as allowed by bedrock control.

After a 25-year event, model results indicate that channel adjustment would propagate farther upstream throughout the model domain. Additionally, a local slope break, or "bump" in the sediment accumulation downstream of the former dam (approximately station ~2500) indicates that the receding limb of a 25-year event may be sufficient to propagate some of the deposited sediment downstream.

It is not unexpected that sediment is predicted to accumulate downstream of the dam under this alternative, and this may be a desirable condition. After construction of the dam, the coarse sediment supply was likely interrupted and therefore depleted. Bed scour and an armored, coarse, and tightly-interlocked bed downstream of the dam corroborates this, and could be returned to a more natural channel condition with restored longitudinal slope and sediment transport continuity.

4.3 Alternative 2: Dam Removal and Sediment Management

Alternative 2 simulates channel response to proactive sediment management in the form of a graded pilot channel through the previously impounded sediment. In comparison to the other simulations, Alt. 2 produces the least geomorphic change, with minimal deposition just downstream of the former dam where sediment supply is likely severely depleted (Figures A7 – A9). Despite selecting the pilot channel location in a topographic low on the left side of the existing meander belt, the larger 10- and 25-year flow events indicate that the thalweg would tend to migrate from the original pilot channel location toward the outer right bank where recent and active bank retreat is observed. This is unsurprising as the channel hydraulics are the main driver of the lateral migration and channel incision. If further bank erosion and lateral migration is undesirable upstream of the dam, these model results suggest the need for active management of bank stability in the case of any of the outlined dam removal alternatives.

Although not an unexpected result, these model results suggest that active management of the impounded sediment via excavation and construction of a pilot channel would cause the least amount of deposition, erosion or net sediment transport downstream of the dam. These results also provide an initial assessment of choices in designing the pilot channel slope in connection the upstream and downstream reaches.

4.4 Alternative 3: Incremental Dam Removal

After a 2-foot reduction in the dam height, impounded sediment is predicted to become mobilized in each design storm (Figures A10 – A12). The 2-year flow event would carve a new channel thalweg, but as suggested by a steep slope just upstream of the dam, this flow does not have enough hydraulic power to propagate upstream and adjust the thalweg slope to the upstream reach. Downstream, the geomorphic change is muted as compared to a complete dam removal (Alt. 1), with only 1 to 2 feet of sediment aggradation. In the 10- and 25-year flow events, the channel elevation is predicted to become less steep compared to the 2-year event, the steepened channel would still not propagate upstream throughout the model domain; a slope break still exists between the newly carved thalweg and the upstream reach. Sediment accumulated downstream is considerably less than the full dam removal scenario (Alt. 1).

After a 5-foot reduction in the dam height, we see an exaggerated geomorphic response in all design storms, compared to the 2-foot reduction in dam height (Figures A13 – A15). Interestingly, the 2-year event is sufficient to reconnect the channel elevation at the dam location by filling in the downstream scour pool and eroding the upstream impounded deposits, perhaps suggesting that lowering the dam by 5 feet could be sufficient for re-establishing longitudinal slope, sediment transport continuity, and possibly passage by salmonids. Similar to the 2-foot lowering, a 5-foot lowering produces a fairly steep channel slope in the impoundment area and maintains a slope break, with approximately 2 feet of sediment deposition in the reach immediately downstream of the dam. A 10-year event propagates the slope break observed in the 2-year model results farther upstream, but also accumulates approximately 3 to 4 feet of sediment downstream of the former dam. Model results suggest that portions of the upstream channel are relatively unimpacted by the change in dam elevation, even at 5 feet.

Modeling results of the incremental dam removal alternatives suggest that incremental lowering of the dam to an ultimate elevation that is 5 feet lower than the existing crest may limit the spatial scale of the geomorphic change, particularly regarding slope adjustment upstream of the dam. This may be a desirable alternative if geomorphic change needs to be actively managed. Conversely, there are typically extra costs and impacts associated with repeated mobilization and channel disturbance which should be weighed against other dam alternatives.

5 NEXT STEPS

5.1 Model Refinement

As the dam removal alternatives are refined, this analysis should be revised and updated. Now that the sediment transport model framework has been established, additional alternatives can be evaluated with relative efficiency. If dam removal with sediment management (Alt. 2) is selected and a "pilot channel" is constructed we recommend additional model runs to refine the placement, width, and slope of the channel.

5.2 Use of Design Storms for Understanding Geomorphic Response Times

To balance the need to explore geomorphic responses to a number of dam removal alternatives, and absent consistent high-flow gaging data, we have chosen to use design storms as input hydrology for this analysis. In reality, geomorphic response is directly dependent on the frequency and magnitude of storm events over longer periods of time than modeled, though these are difficult to predict accurately. The most accurate quantification of geomorphic timescale response would involve obtaining accurate streamflow hydrographs through streamflow gaging at this location over multiple years and modeling sediment transport dynamics over the annual hydrographs during years with low, moderate, and sustained high flow conditions. and in differing sequences. This is both resource intensive, both in terms of labor and computation resources. At this stage in the project, the design storms adequately frame the type of response that is to be expected under different alternatives and during different high flow events, both of which were selected for simplicity and clarity of results comparison. Future analysis of annual hydrographs could be completed with either modeled or measured flow data and is recommended after further alternative refinement.

5.3 Upstream Bank Stability Assessment

Alternative refinement should include additional considerations of the eroding right bank upstream of the dam. If a dam removal alternative is selected without actively reconfiguring the channel, it is likely that the adjustment of the bed (likely incision) would further destabilize the already migrating and failing bank. If that is an undesired outcome, the results of this analysis suggest that use of a pilot channel may be able to redirect flows away from the bank in the short-term channel adjustment period, but we recommend that additional design elements be included with the pilot channel configuration to reduce the risk of channel migration toward this bank. Such elements could consist of bio-engineered bank stabilization techniques.

5.4 Fish Habitat Impacts

This sediment transport modeling exercise does not include an assessment of fish passage potential or the short- or long-term impacts to fish habitat upstream and downstream of the project site. Upon further refinement, a similar analysis could be employed to evaluate the impact of bedload transport on habitat. If analysis of short-term turbidity is necessary, we would recommend further model calibration supplemented with collection of field data.

6 LIMITATIONS

This sediment transport modeling was prepared in general accordance with the accepted standard of practice existing in Northern California for projects of similar scale at the time the investigations were performed. No other warranties, expressed or implied, are made. We note that modeling is a difficult and inexact art, and a variety of physical factors can affect the results from what has been presented herein; in particular, geomorphic change, redevelopment, and bed grain size distribution. Judgments leading to conclusions and recommendations are generally made with an incomplete knowledge of the conditions present and based on data provided by others. More extensive or extended studies, including additional hydrologic or geomorphic baseline monitoring, can reduce the inherent uncertainties associated with such studies. If the client wishes to further reduce the uncertainty beyond the level associated with this study, Balance should be notified for additional consultation.

Concepts and findings contained in this report are intended for characterizing potential range of geomorphic response to dam removal alternatives in Auburn Ravine only, and should not be used for other purposes without great care, updating, review of analytical methods used, and consultation with the authors.

We have used standard environmental information such as precipitation, topographic mapping, and soil mapping, in our analyses and approaches without verification or modification, in conformance with local custom. New information or changes in regulatory guidance could influence the plans or recommendations, perhaps fundamentally. As updated information becomes available, the interpretations and recommendations contained in this report may warrant change. To aid in revisions, we ask that readers or reviewers advise us of new plans, conditions, or data of which they are aware.

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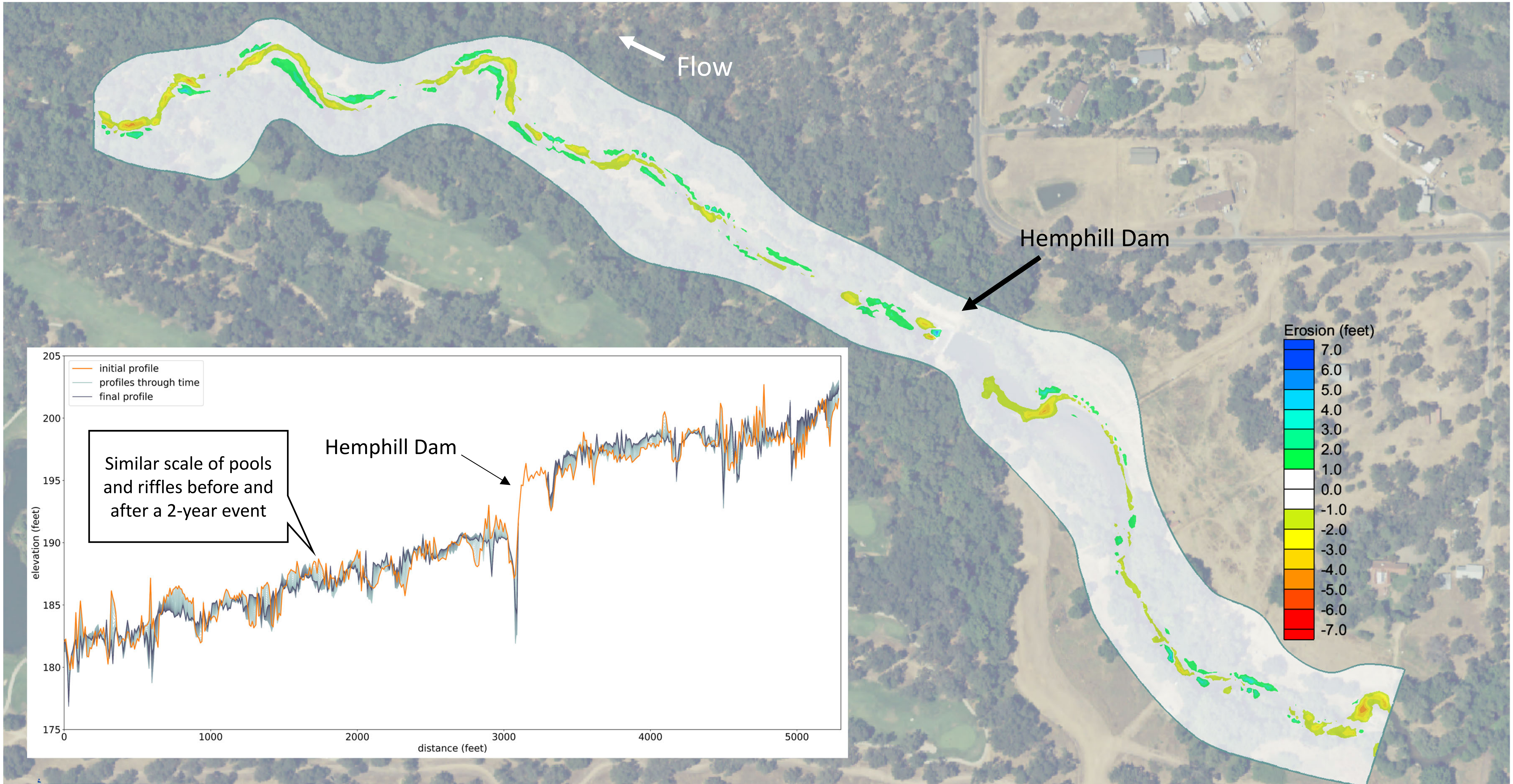
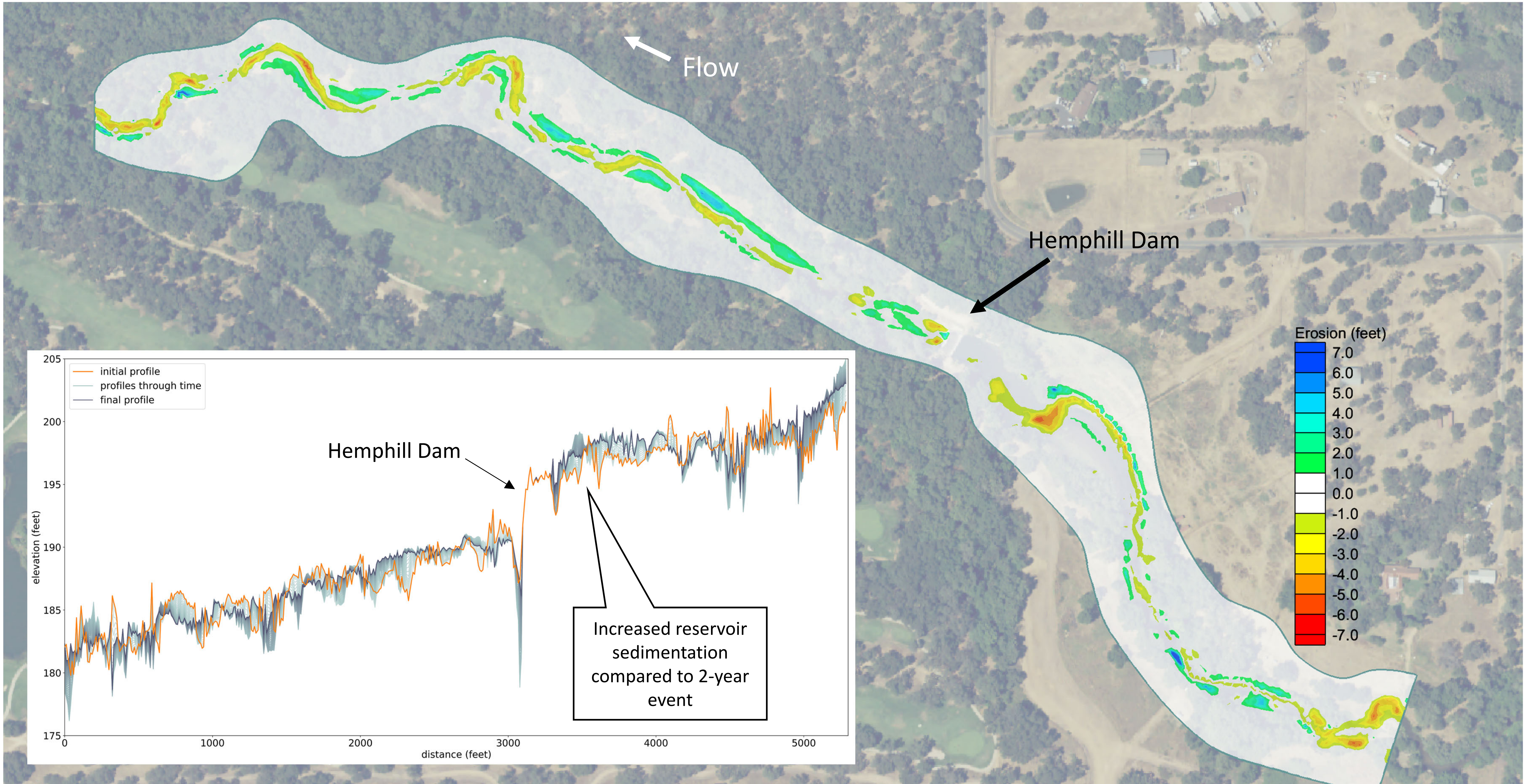
APPENDIX A

Modeling Results



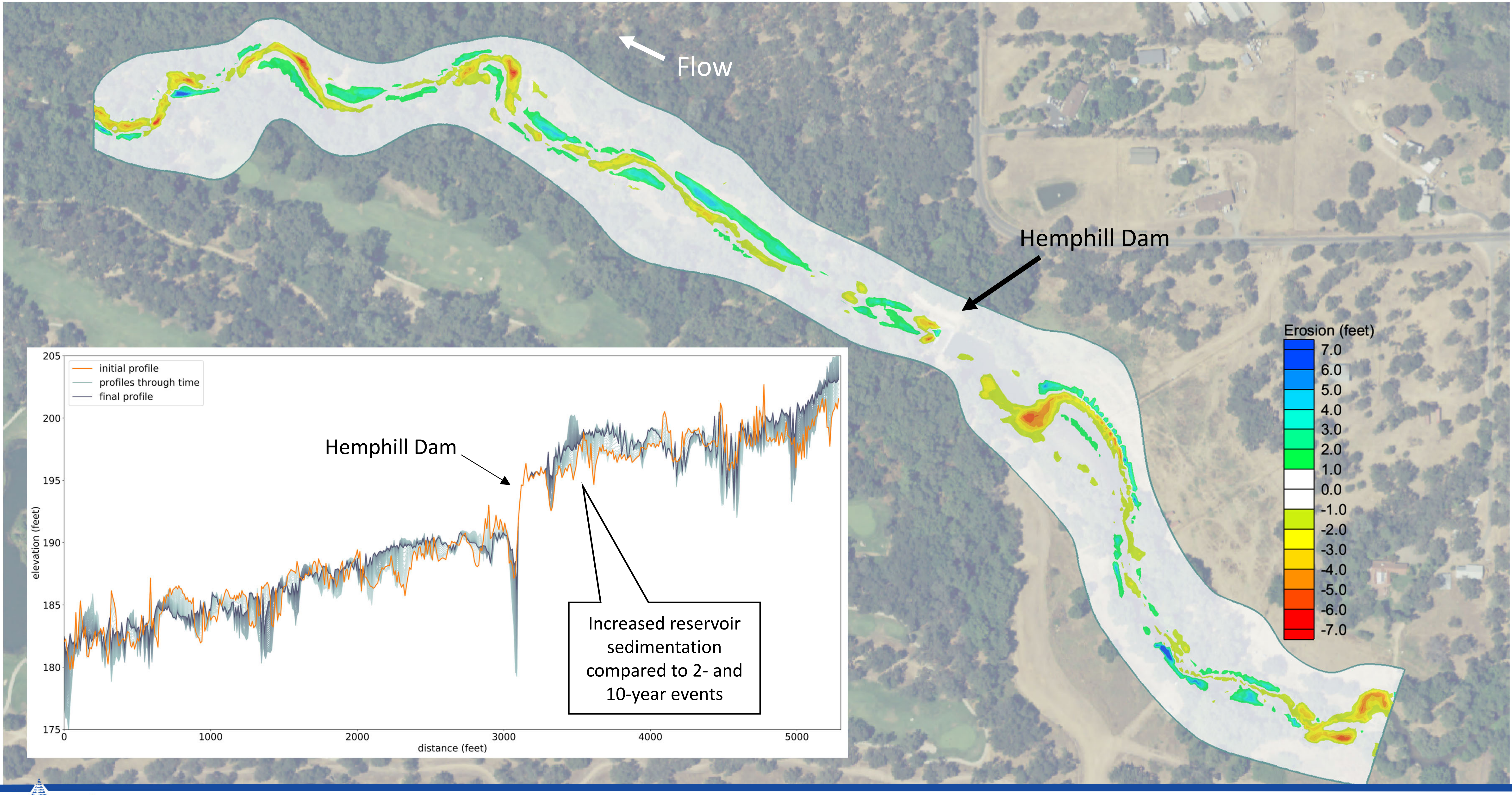
Balance Hydrologics

Figure A1. No Action Scenario, 2-year event erosion and deposition map with profile plot.



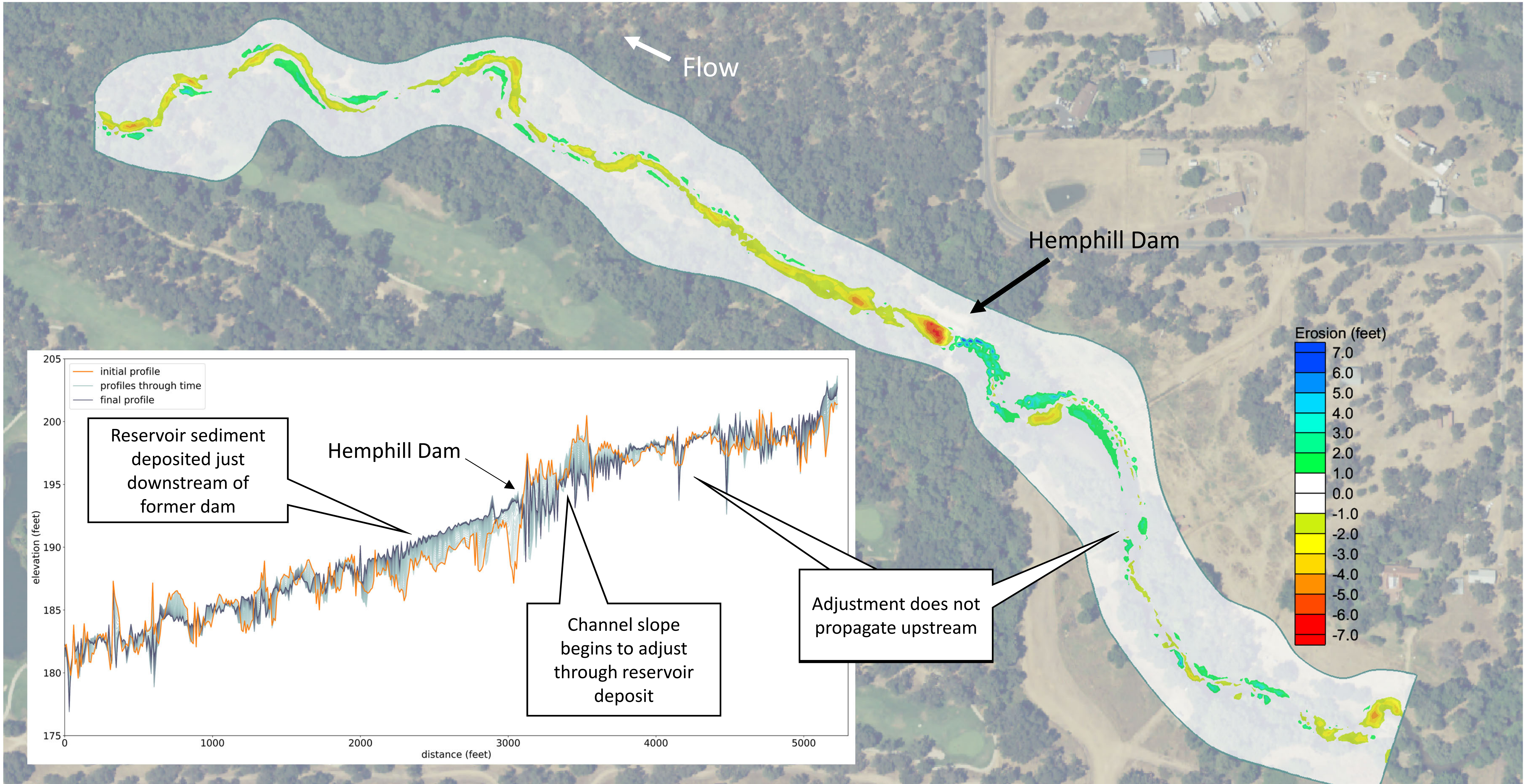
Balance Hydrologics

Figure A2. No Action Scenario, 10-year event erosion and deposition map with profile plot.



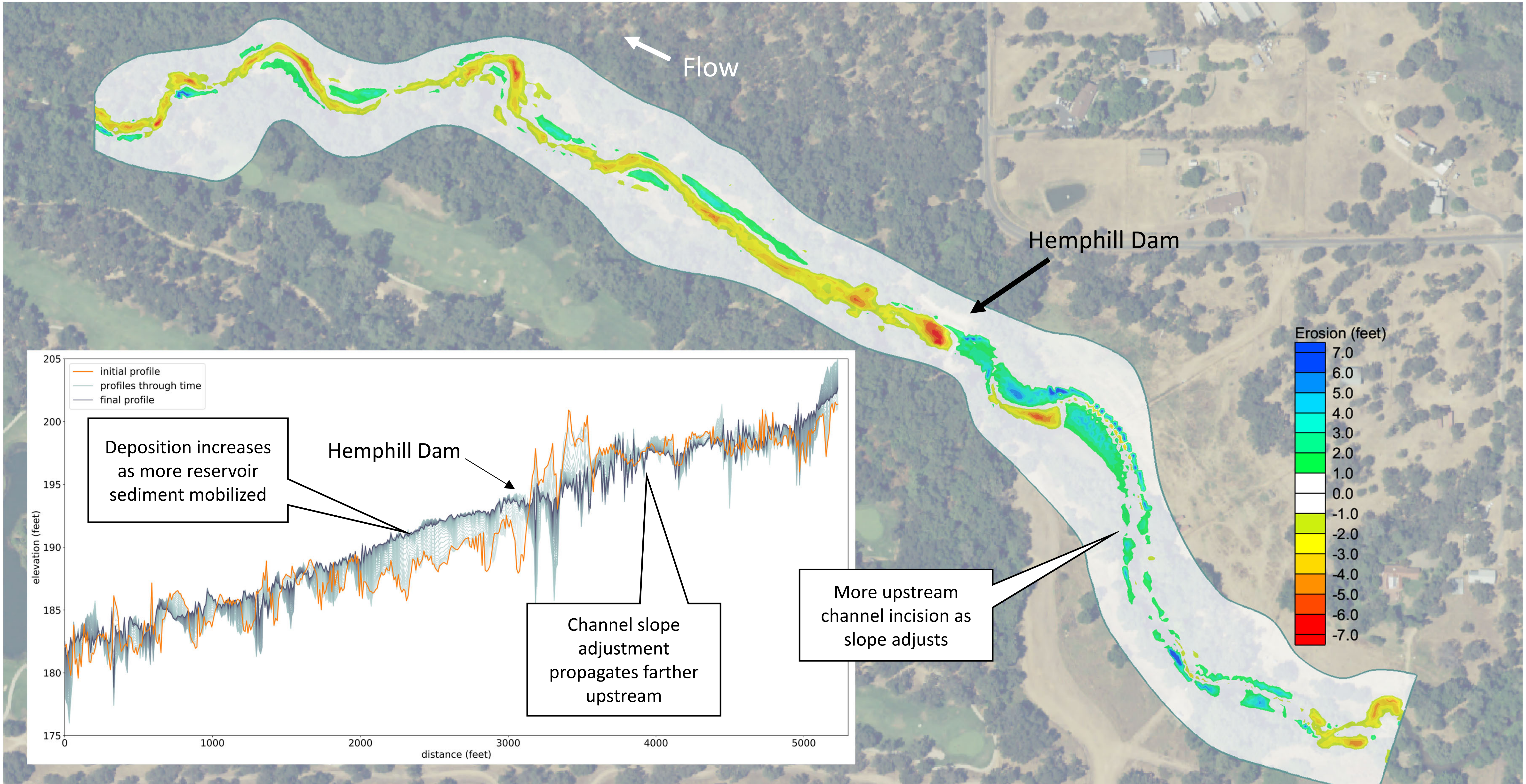
Balance Hydrologics

Figure A3. No Action Scenario, 25-year event erosion and deposition map with profile plot.



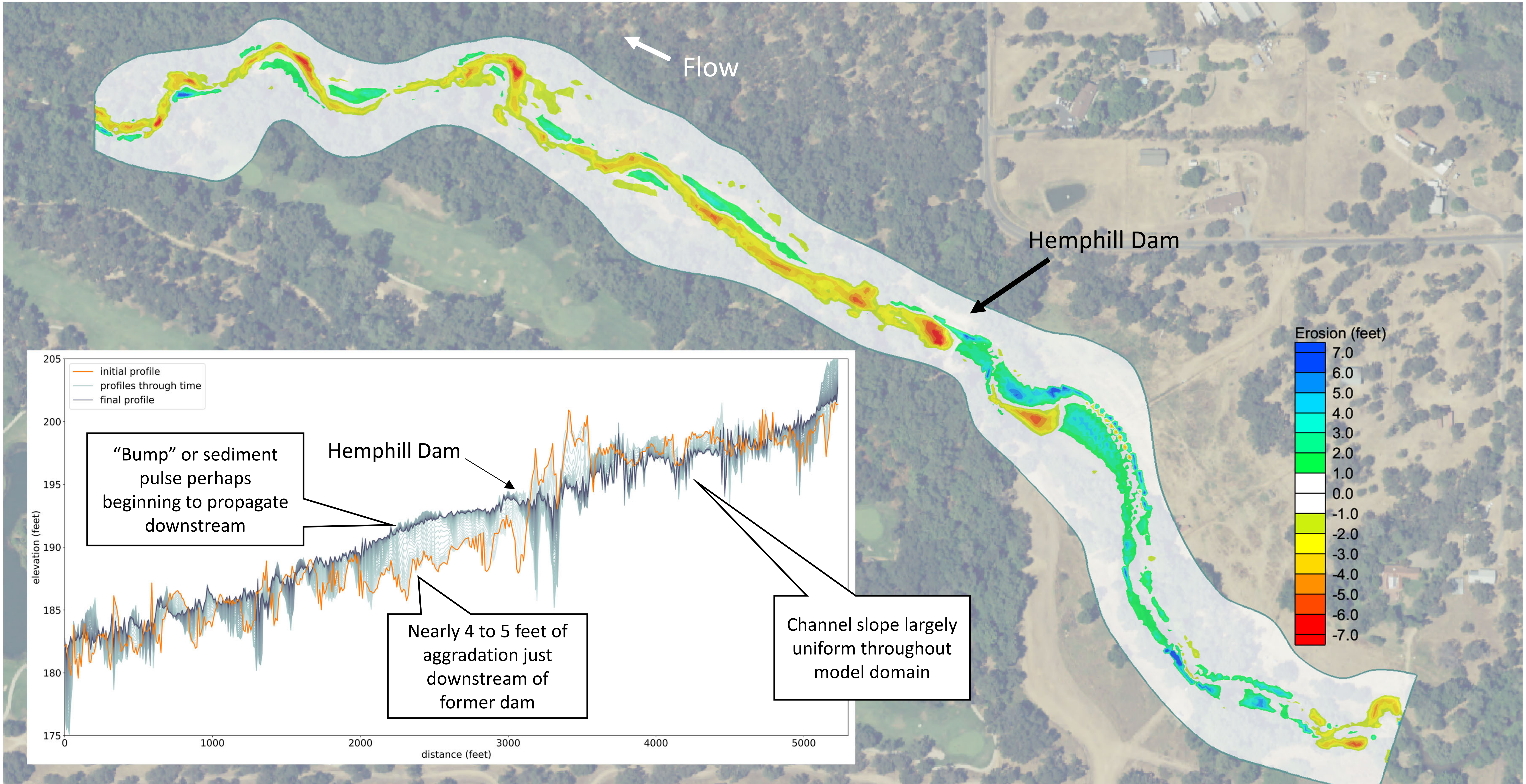
Balance Hydrologics

Figure A4. Dam Alternative 1: Dam Removal and No Sediment Management, 2-year event erosion and deposition map with profile plot.



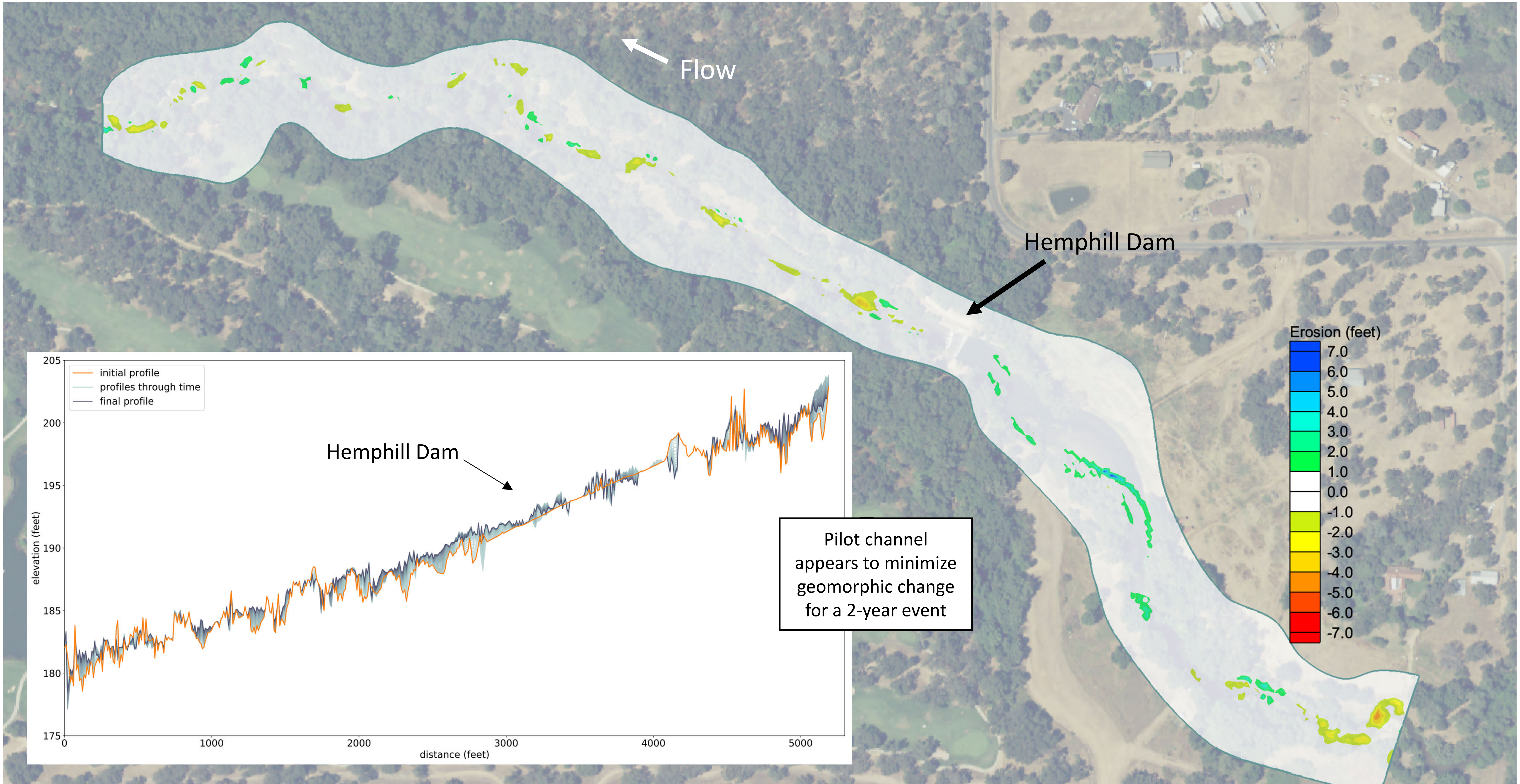
Balance Hydrologics

Figure A5. Dam Alternative 1: Dam Removal and No Sediment Management, 10-year event erosion and deposition map with profile plot.



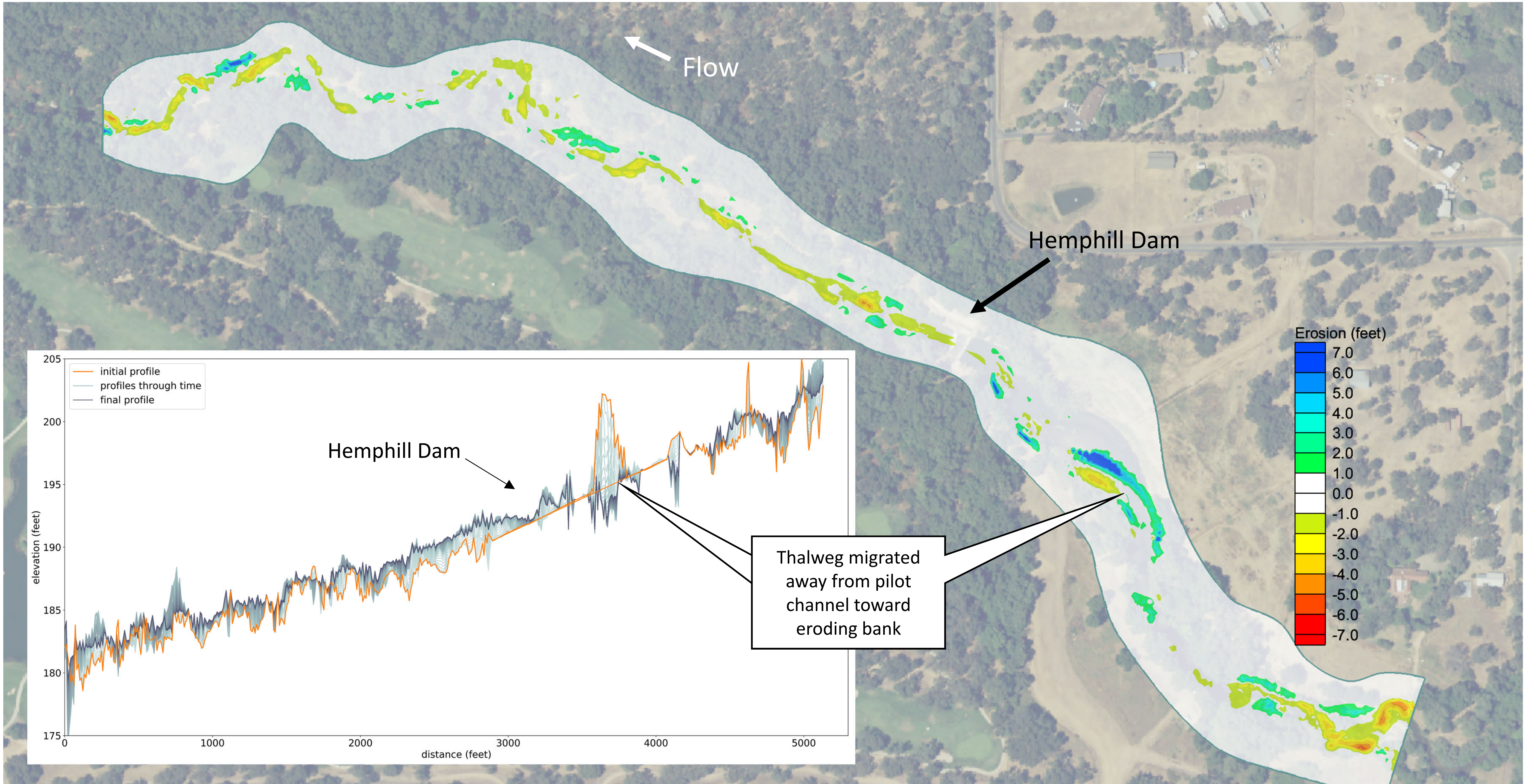
Balance Hydrologics

Figure A6. Dam Alternative 1: Dam Removal and No Sediment Management, 25-year event erosion and deposition map with profile plot.



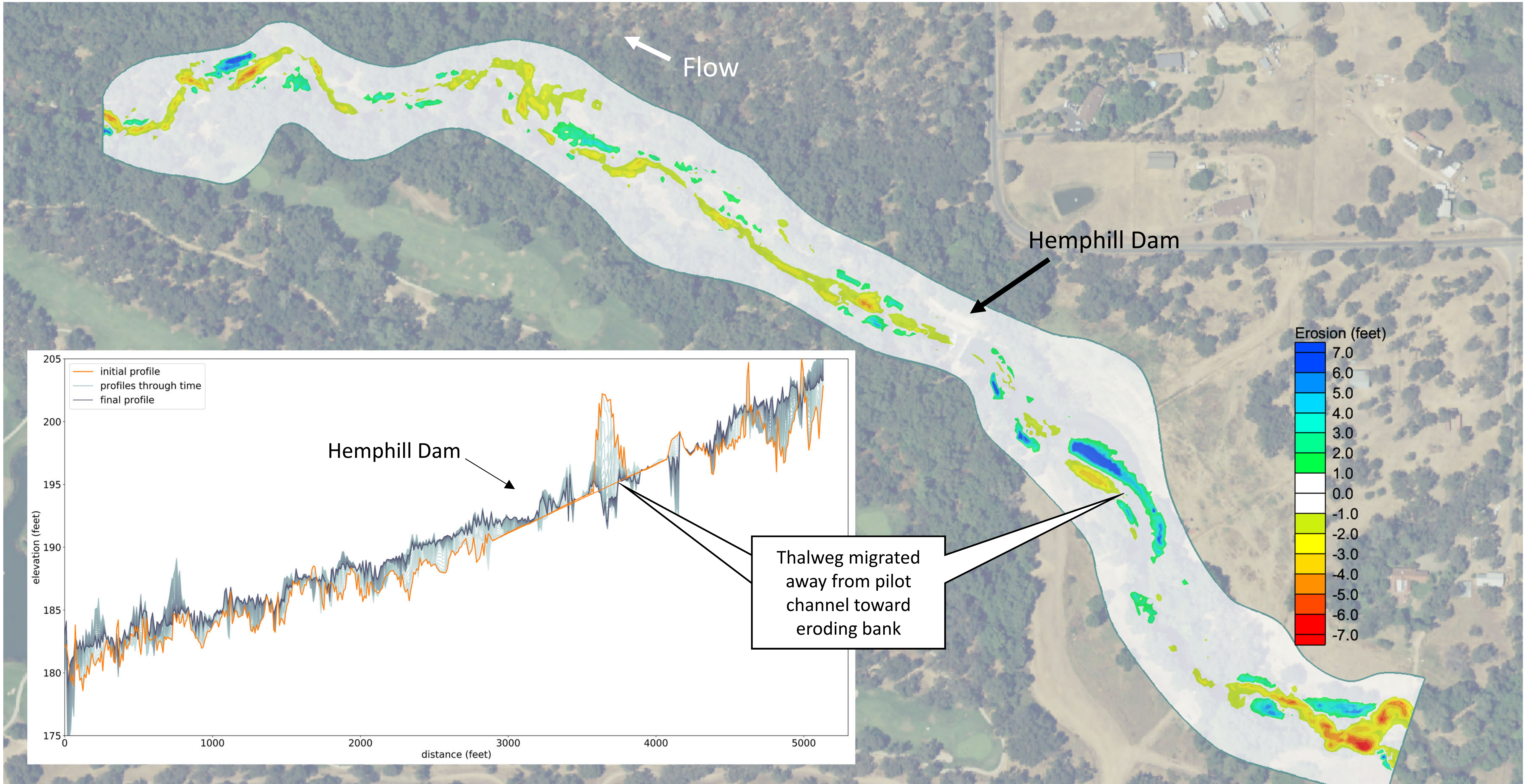
Balance Hydrologics

Figure A7. Dam Alternative 2: Dam Removal and Active Sediment Management, 2-year event erosion and deposition map with profile plot.



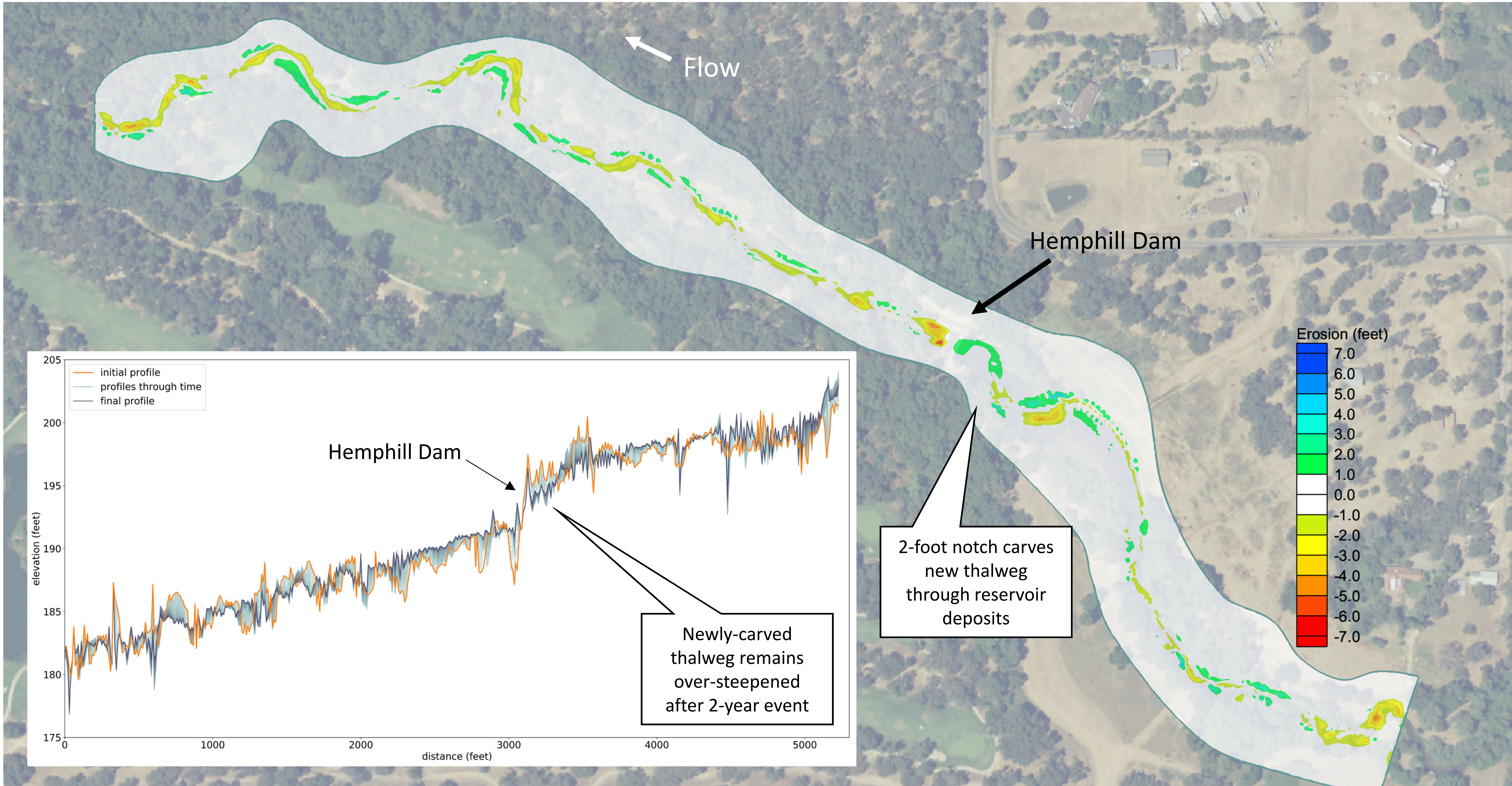
Balance Hydrologics

Figure A8. Dam Alternative 2: Dam Removal and Active Sediment Management, 10-year event erosion and deposition map with profile plot.



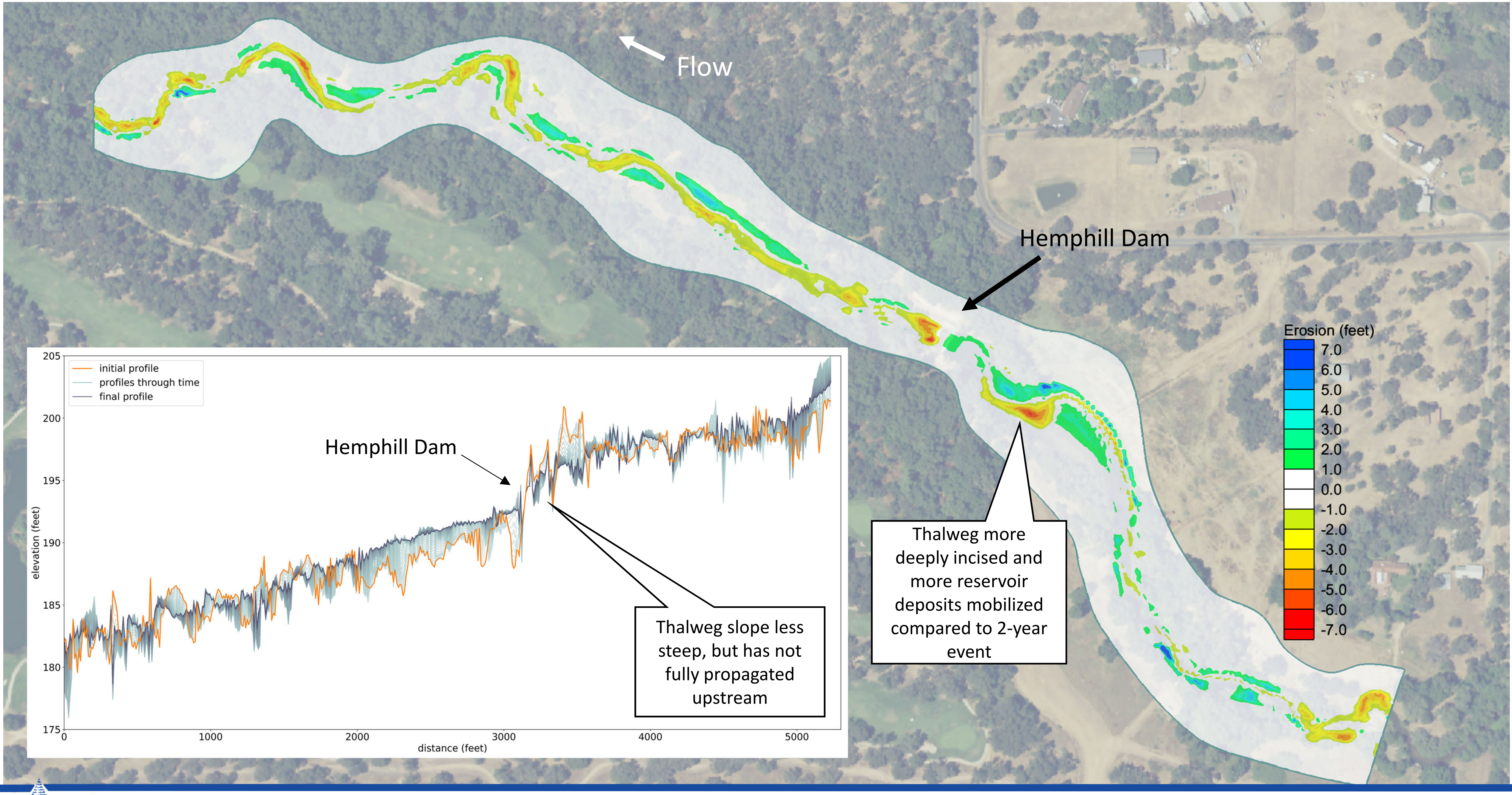
Balance Hydrologics

Figure A9. Dam Alternative 2: Dam Removal and Active Sediment Management, 25-year event erosion and deposition map with profile plot.



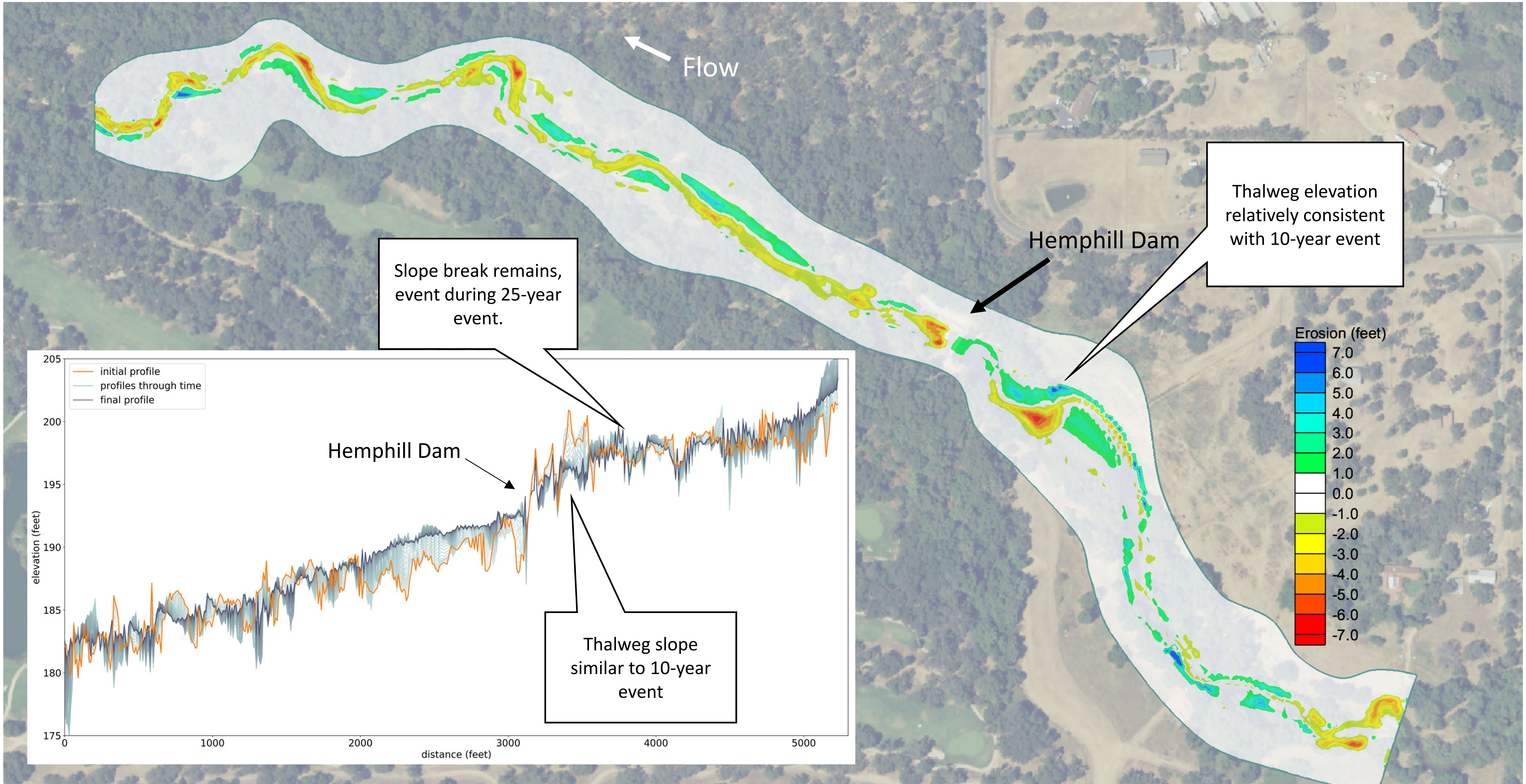
Balance Hydrologics

Figure A10. Dam Alternative 3: Incremental Dam Removal (2 feet) and No Sediment Management, 2-year event erosion and deposition map with profile plot.



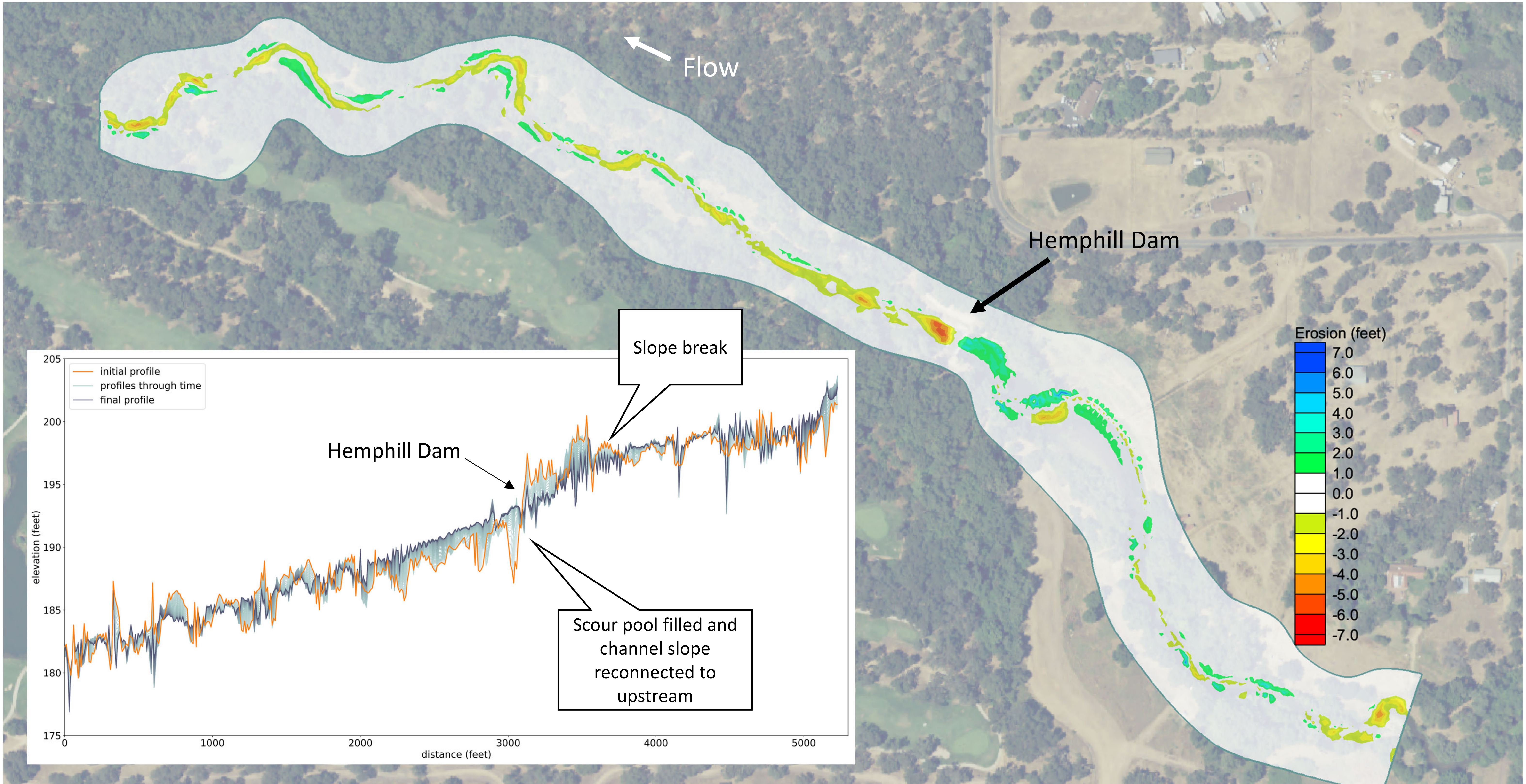
Balance Hydrologics

Figure A11.Dam Alternative 3: Incremental Dam Removal (2 feet) and No Sediment Management, 10-year event erosion and deposition map with profile plot.



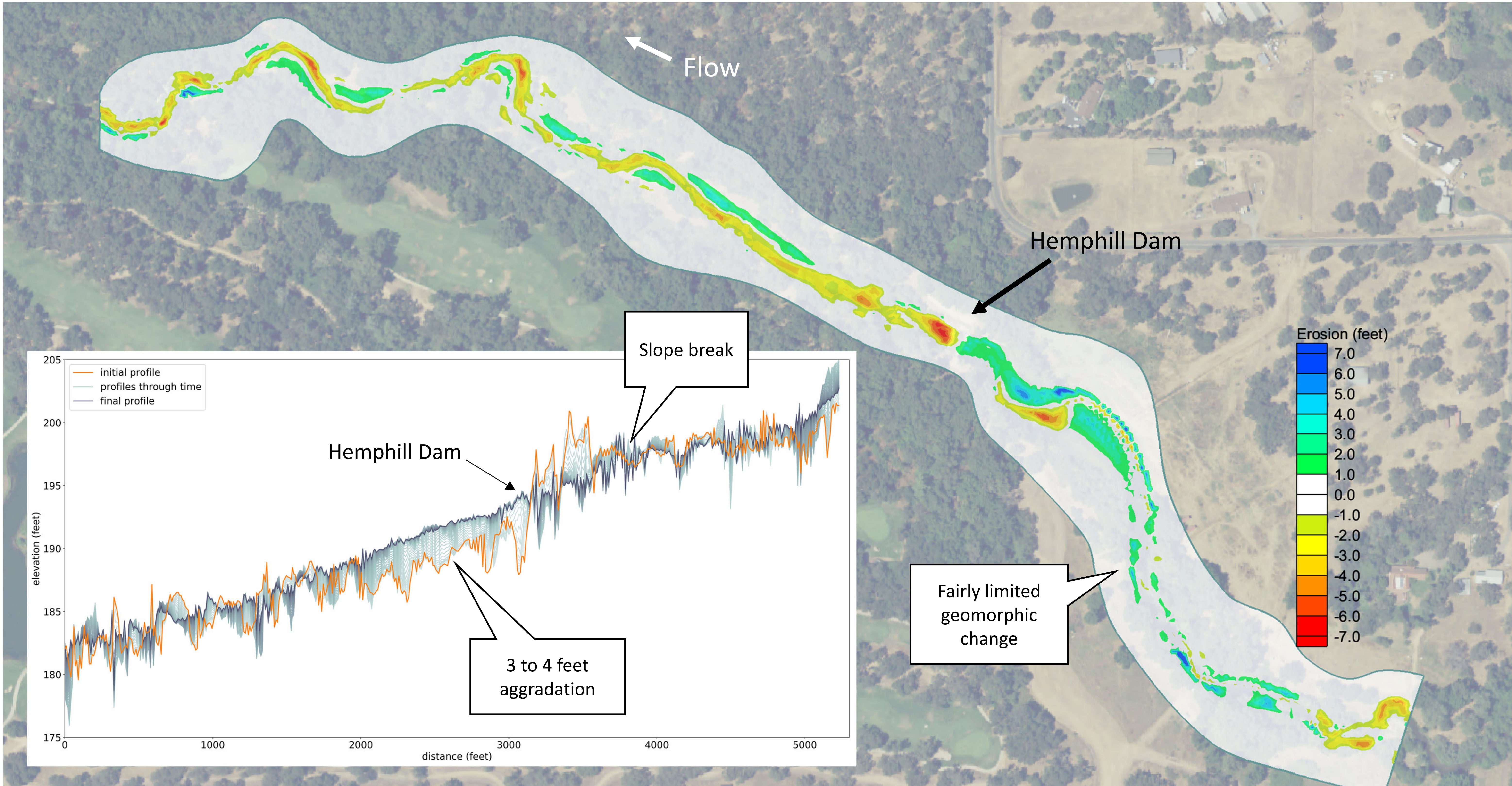
Balance Hydrologics

Figure A12.Dam Alternative 3: Incremental Dam Removal (2 feet) and No Sediment Management, 25-year event erosion and deposition map with profile plot.



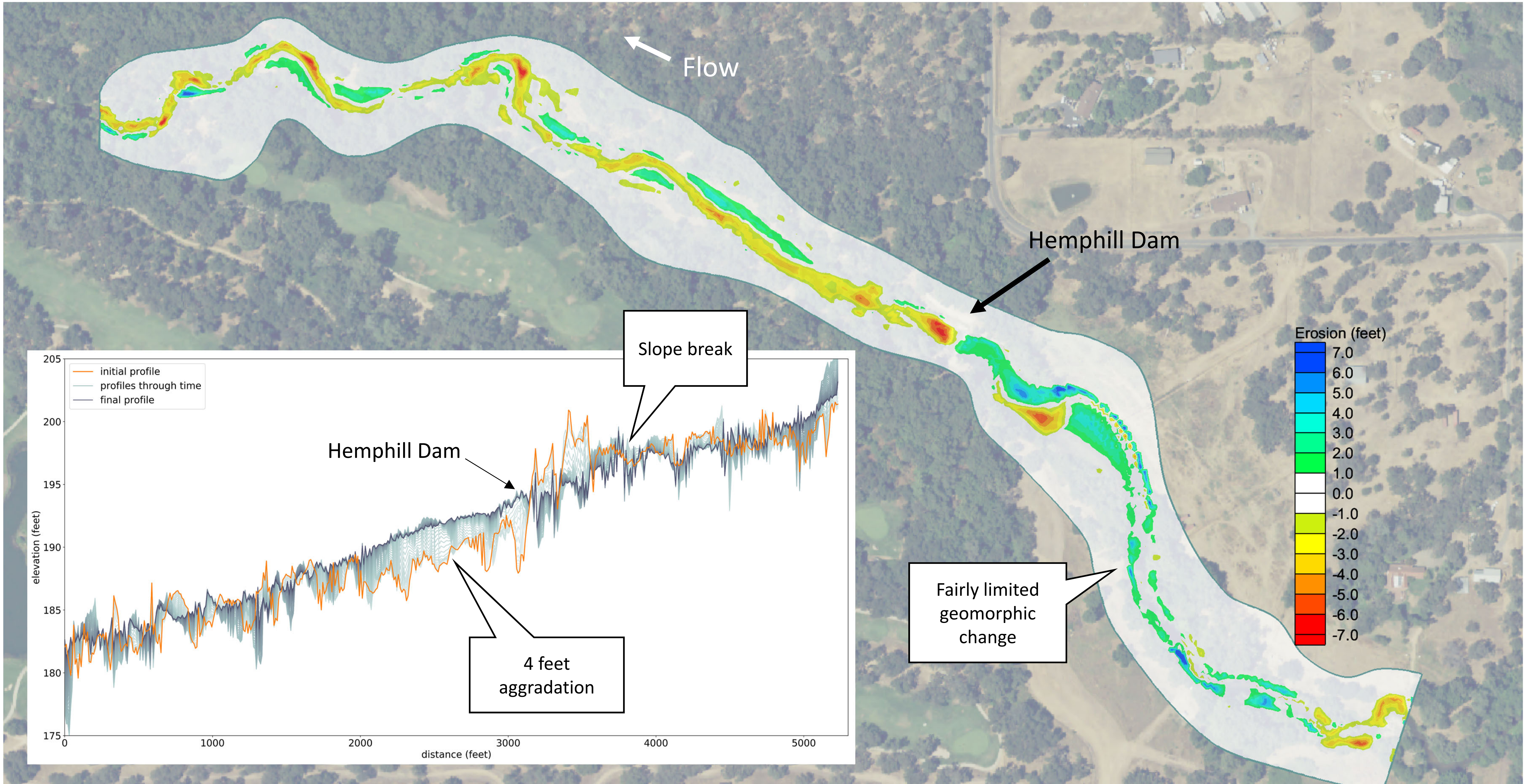
Balance Hydrologics

Figure A13. Dam Alternative 3: Incremental Dam Removal (5 feet) and No Sediment Management, 2-year event erosion and deposition map with profile plot.



Balance Hydrologics

Figure A14. Dam Alternative 3: Incremental Dam Removal (5 feet) and No Sediment Management, 10-year event erosion and deposition map with profile plot.



Balance Hydrologics

Figure A15.Dam Alternative 3: Incremental Dam Removal (5 feet) and No Sediment Management, 25-year event erosion and deposition map with profile plot.