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Sediment Transport Model of the San Benito River Between Hollister and the Pajaro River Confluence

Prepared for

RMC Water and Environment

and

Pajaro River Watershed Flood Prevention Authority

Prepared by

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1. INTRODUCTION

This report presents the findings of an assessment conducted by Philip Williams & Associates (PWA) of the sediment transport characteristics of the San Benito River between its confluence with the Pajaro River and Hollister, CA. The study was carried out as one of three studies for the Joint Powers Authority to assess sediment loads into the Pajaro River from this source, and to identify aggradational and degradational trends on the San Benito River.

1.1 BACKGROUND TO THE CURRENT REPORT

The San Benito River is the main tributary to the Pajaro River, with a watershed area of 607-square miles above Hospital Road, which is at the upstream end of the current study (Figure 1). The Pajaro River flooded in 1995 and again in 1998, causing damages and one fatality in the towns of Watsonville and Pajaro. One factor in the flooding was an increase in vegetation that had grown in the channel, reducing flood capacity below the original level of the 1940s flood control project. Associated with vegetation growth, there is believed to have been sediment deposition in both the channel and on the floodplain within the levees, though the exact balance between sediment deposition and removal is not clear. In response, the U. S. Army Corps of Engineers (USACE) developed a flood plan for the lower 12 miles of the Pajaro River. The preferred project plan (USACE 2A) involves setting back the existing project levees by 100 feet on both sides of the river and raising them by 4 feet. It also involves a vegetation management plan, and a plan for periodic sediment removal from the channel.

The resource agencies (Regional Water Quality Control, Board [RWQCB], California Department of Fish & Game [DFG], National Oceanic and Atmosphere Administration – Fisheries [NOAA]) and several stakeholders objected to the vegetation clearance requirement of the USACE plan, and the agencies developed a set of performance criteria as a condition for issuing a permit to the project. Among other elements, the performance criteria call for minimal channel maintenance, including sediment removal from the channel. Where possible, there is a desire to reduce sediment at the source rather than remove sediment from the flood project area.

The issue of sediment transport was investigated by the Action Pajaro Valley-sponsored Stream Team. The Stream Team found that sediment accumulation was a potential problem in terms of both project performance (loss of conveyance over time) and the associated difficulties obtaining permits and winning agency and stakeholder support for in-channel sediment removal. The mainstem Pajaro River is a steelhead migration zone, and channel clearing activities pose problems due to habitat destruction, sediment loading and loss of riparian vegetation. Most of the sediment in the Pajaro River is believed to originate in the San Benito River.

In response to the 2003 PWA report and the Stream Team sediment findings, the Stream Team called for more detailed study of both the bench concept and sediment transport issues. This led to three follow-on studies, the third of which is the topic of this report: 1) a 2D hydrodynamic and sediment transport model to assess the bench concept and assess its impact on sediment transport, 2) evaluation of a sediment trap in the upper project reach to prevent sediment accumulation in the flood-prone area, and 3) a sediment model of the San Benito River to assess inputs from this source.

The San Benito River is believed to be the main source of sediment in the Pajaro River. Though a sediment transport model of the San Benito River was previously developed, work by PWA (PWA, 2005) showed that the river has widened by an average of 277 feet since 1986, the date of the topographic survey used in the former model. There is thus a need to update the model to account for the changed geometry and sediment transport capacity.

2. INVESTIGATION METHODS

This investigation used the HEC-6T sediment transport model to estimate sediment transport capacity, erosion and deposition between the Pajaro River confluence and Hollister. The model geometry and inputs were updated using more recent topographic survey data, sediment data from several previous studies, and a field assessment of channel sediment, hydraulic and geomorphic characteristics.

2.1 PROJECT SETTING

The San Benito watershed has relatively high relief, and is largely rural, dominated by agriculture and ranching. The San Benito River drains a 607-square mile watershed upstream of Hollister that lies parallel with, and slightly north, of the San Andreas Rift Zone for a length of approximately 60 miles. The model study reach extends approximately 8 miles upstream from the mouth, representing about ten percent of the total river length.

2.2 HISTORIC CHANGES IN CHANNEL FORM

The San Benito River has undergone dramatic changes in channel morphology over the last 50 years, many related to gravel mining activities. Figure 2 shows the change in long profile between 1955 and 2000. The 1955, 1974, and 1989 profiles are from Golder Associates (1997). Between 1955 and 1974 the channel incised by up to 40 feet downstream of the new State Hwy 156 Bridge, with much of the channel between Hwy 195 and Hollister degrading by more than 25 feet. The PWA (2005) assessment of channel changes in the San Benito showed that between 1987 and 2000 the river, in the same location as the current study, widened by an average of 277 feet and incised by an average of 2.4 feet. This change in channel geometry increased channel capacity by 5.2 million cubic yards due to a mixture of gravel extraction and erosion. These changes are likely to have changed the river's sediment transport characteristics, providing the impetus for this study.

2.3 SITE RECONNAISSANCE

Through the town of Hollister, the San Benito is bordered on both sides by low relief agricultural fields (Figure 1). Approximately 5000 feet downstream of the old Highway 156 Bridge, the channel turns directly west and the steep Flint Hills form a sharp border close to the northern, or right bank. In this reach the southern or left bank is bordered by low relief agricultural fields separated from the river by a levee. Along both banks, there are abundant bank failures contributing sediment directly to the channel. Numerous landslides along the river also contribute sediment directly to the channel, particularly in the Flint Hills area. Landslides were documented by Ayres Associates (1999) as a dominant feature throughout the San Benito watershed, and were considered more prevalent in the San Benito portion of the Lower Pajaro watershed than the area below the confluence of the San Benito River and the Lower Pajaro River, in part due to the surrounding relief and geology.

PWA identified eight characteristic reaches (labeled reaches 100 to 800; Figure 1), using HEC-RAS profiles, a DEM provided by the Granite Rock mining company, and aerial photography. Reach 100 included the confluence of the San Benito and the Pajaro River, as well as approximately one mile of the Lower Pajaro River, and is located outside the limits of the high resolution Granite Rock DEM. Reach was 100 was subsequently removed from the model because of problems tying together topography at two different resolutions. The results for the reach downstream of the limits of the high resolution topographic data were appeared numerically unstable. Reach 800 also was excluded from our model because it extends upstream from Union Road, the location of a USGS gage which we considered a good upstream boundary.

During February and March of 2005, PWA collected field observations of each reach to better parameterize the model and to characterize results.

2.3.1 Reach 200

The channel in this 1.55-mile reach is straight and narrow, confined by levees with thick willow growth (Figure 1). The channel appeared to be approximately 15-20 feet wide with no braiding and limited sinuosity. The channel was submerged during our field reconnaissance, and no channel bars were observable. Downstream from the gravel mine, near sample 201, we observed some instream willow growth, likely occurring on channel bars that were submerged.

2.3.2 Reach 300

Reach 300 is 2.83-miles long, and has the widest and most densely vegetated channel within the study area, particularly in the downstream portion (Figure 1). The main channel was submerged during our field reconnaissance, but appeared to be approximately 150 feet wide with a thick band of willows (approximately 100 feet wide) along the sides of the channel at its widest locations. Channel roughness along this portion of the reach was assessed to be very high. During our field reconnaissance, all gravel and sand bars were submerged but their presence could be inferred from aerial photos and the location of willow tops in the flow.

2.3.3 Reach 400

The channel in this 1.16-mile long reach is relatively straight, and considerably narrower than Reach 300 (Figure 1). The channel is partly sinuous with alternating cut banks and meanders. The main channel varies in width from 20-30 feet. During our reconnaissance, the floodplain was inundated and sediment was settling out on the left overbank area (viewed facing downstream). Vegetation along the banks consists of grasses and willows. In the upstream portion of the reach, willow growth is dense on the right bank and slightly elevated from the main channel, whereas the downstream portion of the reach is sparsely vegetated. In the sparsely vegetated areas, the cut banks are steep and contribute sediment directly to the channel (Figure 3).

2.3.4 Reach 500

The active floodplain widens to nearly 800 feet within in this 2.64-mile long reach. The drainage consists of a braided network of channels across a larger active channel corridor. Willow growth is widespread on the floodplain where short grasses provide a protective cover. The right bank is consistently near vertical and is topped by an abandoned floodplain terrace, while the left bank grades down to the river, allowing the floodplain to widen up to a levee protecting the adjacent sod farm. Sediment deposition was observed on the vegetated areas of the floodplain left of the channel.

2.3.5 Reach 600

The channel in this 1.37-mile long reach has a widening, active channel with moderately dense willows on the floodplain (Figure 1). During our reconnaissance, sediment appeared to be settling out during inundation of the right bank and floodplain. The flow appeared to be cutting additional side channels, with a braiding channel morphology within a larger active channel corridor.

2.3.6 Reach 700

The channel in this 1.54-mile long reach shows evidence of historic incision. Old willow growth on the 15 foot-high banks suggests that the former floodplain has been abandoned as a terrace as the channel incised. The channel corridor is wide and appears active from bank to bank. The channel corridor width is roughly 200-300 feet wide throughout the reach, and has a braided form. Willows are continuous along the toe of slope. There is minimal vegetation on semi-stable sand bars.

2.4 DESCRIPTION OF HEC-6T MODEL

PWA utilized the HEC-6T model developed by Mobile Boundary Hydraulics to simulate sediment transport in the San Benito River. HEC-6T is a one-dimensional open channel flow and sediment transport model that simulates erosion and deposition of river channels based on varying flow events. It is an upgraded version of the USACE sediment transport model HEC-6. The upgrades include a wider range of sediment transport modules, better representation of split flows, and the ability to model bank erosion. It is compatible with HEC-RAS in that river channel geometry can be visualized, adjusted and directly exported to the HEC-6T model. Upstream inflowing hydrology and downstream water surface elevations also can be developed in HEC-RAS. HEC-6T takes these geometry and hydrology inputs and calculates a water surface profile providing energy slope, depth, velocity, and other necessary parameters at each cross section. HEC-6T allows definition of movable bed and erosion limits which define where each cross section can change volumetrically over the duration of the modeled flows. Sediment transport rates are computed using a variety of sediment transport functions, and each cross section is then adjusted during the simulation, accounting for bed and bank change.

Selection of appropriate sediment transport functions is critical to this study, and must be appropriate the appropriate for the observed San Benito particle size range. Selection of multiple appropriate functions provides a range of channel change and transport rates to bracket the contribution of sediment from the San Benito to the Pajaro. Yang and Huang (2001) compared 13 sediment transport formulae under different flow and sediment conditions to develop a comparative index of applicability of each method for use in modeling different size ranges. Based on their results, PWA identified three appropriate sediment transport functions, included in HEC-6T, for application on the San Benito: Yang; Ackers & White; and Toffaleti. These functions were most applicable for the size range identified in PWA's sediment sampling (see below).

2.4.1 Hydrology and Geometry Inputs to the HEC-6T Model

The study reach includes approximately 11.5 miles along the San Benito River from the town of Hollister, CA to the confluence with the Pajaro River (Figure 1). River Miles are from the confluence of the Pajaro River with the San Benito. The upstream boundary is defined at the crossing of Lane Road in south Hollister, and the downstream boundary is located at River Mile 0.70 (Figure 1). These limits were taken from the HEC-RAS model developed by PWA in 2004, defined by a high resolution (2 foot contour) AutoCAD DEM of the San Benito River created by the Granite Rock mining company in 2000.

The previously developed HEC-RAS model simulated several flow conditions, including a 100 cfs flow that approximates the 1.5 year recurrence interval bankfull condition, as well as the 10-, 25-, 50-, and 100-year floods (Figure 4). We utilized these flow hydrographs as our upstream inflow boundary condition for HEC-6T. We extracted water surface elevations for each corresponding time step in the hydrographs at River Mile 0.70 forming our HEC-6T model boundary. These elevations were used as the downstream boundary condition for HEC-6T.

2.4.2 Sediment Inputs to the HEC-6T Model

Two sets of sediment input data are needed for sediment transport modeling: the concentration and distribution of inflowing sediment (sediment rating curve) and the particle size distribution of the bed material. Observed sediment concentrations and size distributions were not available for the upstream boundary, so these data were synthesized using empirical relationships between flow and sediment load. PWA collected bed samples during the reconnaissance and carried out particle size distribution assessment.

Wherever possible we collected two samples per reach, one near the downstream end and one near the upstream end. Based on the technical literature associated with HEC-6T, we collected samples at locations which satisfied the following criteria: a relatively straight reach; at the upstream end of grade breaks or riffles; in the middle of dry, depositional areas; approximately 6-10 inches below the armored layer wherever present.

PWA obtained 12 sediment samples (Figures 1 to 3). Because of high flows and, in some cases, lack of access to private land, we collected only one sample from reaches 100, 300, 600, and 800. All of the samples were distributed primarily between coarse sand and fine silt (Figure 5). Three samples (601, 501, and 301) were taken from bank locations that did not meet all the specified criteria, and were excluded for use in developing HEC-6T model inputs due to an increase in the amount of fine silts and clays, typical of bank material.

While collecting samples, PWA qualitatively assessed bed gradations and suspended sediment concentrations. Fine-grained material was observed in suspension during the period of high flows coincident with our sampling initiative. The bed was characterized by coarse sand intermixed with fine-grained material. PWA developed an average distribution from the representative sediment samples collected in the field as the bed gradation input for the HEC-6T model (Figure 5). The average distribution which formed the bed gradation model input is predominantly fine to coarse sand, but also contains significant percentages of medium silts and fine gravels (Figure 5).

The sediment inflow boundary condition for the upstream end of the study reach was developed from the equation used in the Golder Associates (1997) study of sediment transport in the San Benito River. Their equation is in turn based on the empirical relationship:

$$V = \alpha\, Q^{b}$$

where:

- V = daily mass of incoming sediments;
- α = an empirically derived coefficient;
- Q = daily discharge; and
- b = an empirically derived exponent.

The coefficient b was assumed at a value of 3 based on values presented in Gregory and Walling (1973), while α was calculated based on estimated watershed sediment yield and daily discharge data.

The Golder study reported the sediment discharge for flows up to 1,500 cfs. This analysis was conducted for 100-year recurrence interval discharge rates, upwards of 25,000 cfs. In the absence of suitable data from the San Benito River we used analog channels in the vicinity to extend the Golder study curve for higher flows. While we selected channels that have similar climatic and geological characters, extrapolating from one watershed to another clearly introduces uncertainty into the model as landuse and historic conditions may be different. The Corralitos River Sediment Assessment Study (PWA, 1994) was used for estimating the increased sediment load beyond 1,500 cfs. Corralitos Creek is a downstream tributary to the Pajaro River. PWA projected the San Benito inflow sediment rating curve up to 25,000 cfs based on the results of the 1994 PWA study of Corralitos Creek (Figure 6).

HEC-6T allows the user to represent a gradation for the incoming sediment load for each defined flow rate. PWA used a distribution that was representative of larger flow events across the range of values given on the rating curve. Upon successful trials using the sediment transport model the distribution of the inflow sediment load was revised to mimic load conditions in the center of the study area where it was estimated that the model had equilibrated and was no longer responding to its upstream boundary condition. Each discharge plotted on the inflowing sediment rating curve was assigned its own grain size distribution based on previous model run results for each flow event. These distributions change as the flow rate increases. Typically, the lower discharges carried more fines and less sand as a percentage of total load than higher discharge events, which carried more coarse material within the sediment load. The total load for this analysis includes wash load.

3. SEDIMENT TRANSPORT IN THE SAN BENITO

PWA analyzed two primary outputs from the HEC-6T model, channel bed volume change at each station throughout the reach, and sediment load throughout the study reach. The first of these outputs provides a spatial framework to evaluate locations of consistent bed erosion or deposition, and the latter is an overall measure of the sediment being delivered to the Pajaro River.

For almost all flow conditions, model results suggest that the San Benito River is predominantly erosional between Hollister and the Pajaro River, (Figures 7-11). The three different sediment transport methods (Yang, Toffaleti, Ackers & White), produce results with local differences in the magnitude and spatial location of channel bed erosion and deposition. However, at the reach scale identified by PWA in our site reconnaissance, there are consistent sediment transport trends. Channel bed erosion increases from the bankfull flow to the 100-year flow, and sediment load increases from the bankfull flow to the 50-year flow, with some reduction in sediment load between the 50- and 100-year flows.

3.1 SPATIAL PATTERNS OF BED EROSION AND DEPOSITION

Spatial patterns of bed erosion and deposition are consistent between all flow events (Figures 7-11) though the magnitude of erosion and deposition changes between events. The pattern of erosion and deposition is discussed from upstream to downstream.

The channel bed in Reach 700 erodes increasingly with distance downstream, with maximum depths of approximately 1 foot below the existing elevation during the 100-year event. There is a large depositional zone in the upstream half of Reach 600, elevating the bed up to 0.5-feet above the existing elevation during the 100-year event. At this location in the reach, the channel crosses the Old Highway 156 Bridge, which may slow flow upstream of the bridge, raising water levels and allowing sediment to deposit on the floodplain. Immediately downstream of this depositional zone, the bed erodes by over 1-foot during the 100-year event. Golder Associates (1997) reported erosion in this area, noting the threat of exposing a buried pipeline.

The channel bed is relatively stable at the downstream end of Reach 600. By contrast, Reach 500 is much less stable. The channel bed alternates between erosion and deposition by as much as 3-feet during the 100-year event. Historical profiles show aggradation, or bed deposition in the same location as Reach 500 between 1974 and the current study profile (Figure 2). This bed aggradation took place just downstream of the New Highway 156 bridge, located at River Mile 8.48 (Figures 1 and 2), and historical aggradation may reflect floodplain stabilization efforts associated with the bridge. During our field reconnaissance, PWA observed dense willow growth below the New Highway 156 Bridge, which appeared to be planted vegetation along the floodplain areas in between the main channel, which may have been designed to trap sediment.

Because we used the channel geometry and roughness coefficients from the previously developed HEC-RAS model, the roughness values used in this analysis may have been lower than those observed in the field in reaches 200 and 500. We performed a sensitivity analysis with higher roughness values, and found similar patterns of erosion and deposition, but with a lower magnitude of value.

Bed erosion decreases through Reach 400, except in the 50- and 100-year events which cause approximately 1 foot of bed incision. PWA observed the channel in these reaches to be narrow and sparsely vegetated, with numerous cut banks and large bank failures (Figure 3). For all flows simulated except the 50- and 100-year, the upstream half of Reach 300 shows some areas of stability as well as deposition (Figures 7-11). These results are consistent with our observations of a wide channel with dense willow growth, which was actively depositing sediment on the floodplain. The channel narrows in the downstream half of Reach 300, and for all the flow conditions the bed incises, lowering approximately 2 feet during the 100-year event. For all flow events, Reach 200 begins, at the upstream end, with a large depositional zone (Figures 7-11) elevating up to 3 feet during the 100 year event. Immediately downstream of this depositional zone, the channel bed erodes by as much as 3 feet during the 100 year event. The downstream end of Reach 200 marks the largest depositional zone, elevating the bed over 3 feet during the 100 year event (Figures 7-11).

3.2 SEDIMENT LOSS FROM SAN BENITO RIVER STUDY REACH

We attempted to simulate flows from reach 200 through the confluence with the Pajaro River, to develop sediment delivery values to the USGS gage at Chittenden, but were unable to develop a realistic model output due to the transition from the high resolution to low resolution topographic data. Thus, the data presented here reflect sediment delivery to the end of the San Benito River at the limit of the Granite Rock DEM (Figure 1).

The bed volume change within the limits of the Granite Rock DEM accounts for a large volume of material delivered to the Lower Pajaro River (Table 1). Of the three sediment transport models used, the Yang equation generally results in the greatest predicted sediment delivery for all simulated flood events except the 25-year, with a maximum delivery of 576,188 tons of sediment in the 100-year event. The 100-year event is estimated to deliver the most sediment using all three models, with an average delivery of 524,398 tons of sediment. By comparison, the bankfull event, which represents conditions similar to an average flood event, delivered an average of 3,405 tons of sediment to the Lower Pajaro River.

Table 1. Estimated Sediment Loss from the San Benito River in the Study Reach to the DEM Limit

Return Interval (years)	Sediment Transport Function: Yang — Total Sediment Loss (tons)	Toffaleti — Total Sediment Loss (tons)	Ackers & White — Total Sediment Loss (tons)	Average — Total Sediment Loss (tons)	Min — Total Sediment Loss (tons)	Max — Total Sediment Loss (tons)
BANKFULL	3,726	2,463	4,026	3,405	2,463	4,026
10	125,192	119,605	102,927	115,908	102,927	125,192
25	238,318	246,747	204,672	229,912	204,672	246,747
50	420,360	364,746	411,875	398,994	364,746	420,360
100	576,188	447,416	549,590	524,398	447,416	576,188

3.3 SEDIMENT LOAD IN THE SAN BENITO RIVER STUDY REACH

Similar to bed volume change, sediment outflow from the simulated reach also indicates that a large volume of material is delivered to the Lower Pajaro River from the San Benito River (Table 2). Aside from the bankfull and 25-year events, Yang predicts the most sediment discharge within the limits of the study reach, with the maximum capacity for all events being 576,188 tons/day. By contrast, the bankfull event delivered a maximum of 4,026 tons/day to the Lower Pajaro River. Sediment load shown in Table 2 represents the sediment concentration, calculated as milligrams per liter in HEC-6T, which has been converted to tons per day. The sediment rates shown in Table 2 were calculated for the peak flow condition during the given event (Return Interval).

Table 2. Maximum Sediment Load Passing out of the Study Reach (Granite Rock DEM Limit)

Return Interval (years)	Sediment Transport Function: Yang — Sediment Load (tons/day)	Toffaleti — Sediment Load (tons/day)	Ackers & White — Sediment Load (tons/day)	Average — Sediment Load (tons/day)	Maximum — Sediment Load (tons/day)	Minimum — Sediment Load (tons/day)
BANKFULL	3,618	3,544	3,643	3,602	3,643	3,544
10	224,717	168,079	153,925	182,240	224,717	153,925
25	316,124	356,500	297,865	323,496	356,500	297,865
50	480,711	337,346	344,322	387,460	480,711	337,346
100	418,121	342,041	471,285	410,482	471,285	342,041

Average sediment discharge values were plotted against their respective flow rates, and compared to the inflowing sediment rating curve at the USGS Chittenden gage on the Pajaro River developed for the concurrent PWA study (Figure 12). While there is potential error associated in comparisons between predicted sediment outputs (the San Benito River sediment transport model) and observed sediment inflows (the Pajaro River rating curve at Chittenden) such comparisons do give a general idea of the relative sediment budgets between the two.

Our modeling shows a relatively close fit between predicted outflow of sediment from the San Benito River and observed sediment inflow to the Upper Pajaro River at the Chittenden gage (see Figure 12). For example, during a 10,000 cfs event on the San Benito River approximately 217,000 tons of sediment per day leaves the San Benito and enters the Pajaro River. Based on the observation that, during high flows, half the Lower Pajaro River's water flow comes from the San Benito and half from the Upper Pajaro River, a flood of 10,000 cfs on the San Benito River would be associated with a total flood of 20,000 cfs at Chittenden. From the Chittenden gage data we would expect such an event to carry approximately 303,000 tons of sediment. Thus 72% of the Lower Pajaro River's sediment in a 20,000 cfs event appears to be contributed by the San Benito River. In theory the additional 86,000 tons (28%) represents sediment inflow from the Upper Pajaro River, plus or minus deposition or erosion from the Pajaro River between its confluence with the San Benito River and Chittenden. At lower flows the difference between the San Benito River outflow curve and the Pajaro River inflow curve are greater, suggesting deposition of material from the San Benito River in the Pajaro River upstream of Chittenden in these conditions. For example, during a 1,000 cfs event on the San Benito River we would expect to see 9,500 tons of sediment flow into the Lower Pajaro. However, the observed sediment load at Chittenden under the equivalent 2,000 cfs flow of the Pajaro River is only 7,400 tons, implying that the excess sediment plus inflows from the Upper Pajaro River are deposited between the San Benito River confluence and Chittenden. Extrapolating from the relative shapes of the inflow and outflow curves, we might hypothesize that during medium flows the San Benito River contributes sediment that is stored between the confluence and Chittenden, but that during high flows some of this excess is transported into the Pajaro River as the two systems sediment transport capacities converge.

4. CONCLUSIONS

The HEC-6T model output is in agreement with field observations that show that the San Benito is slightly erosive between Hollister and the confluence with the Pajaro River. This trend is shown regardless of the sediment transport function used in the model.

Comparing our results with the historic and current long profiles shows that the lower reaches of the San Benito River have remained at a constant grade and are now relatively stable, but that the focus of erosion appears to have moved upstream from previous studies. This is consistent with the concept of an equilibrium channel gradient and upstream migrating knickzone, suggesting that in the future more upstream reaches will experience greater erosion and those in the central reaches will stabilize.

Compared to historic channel incision rates between 1955 and 1974, the predicted rate of future channel incision is relatively small, suggesting that as the river has widened it has lowered its sediment transport capacity below levels in the last 50 years, come closer to reaching a new equilibrium.

Sediment delivery and discharge output shows that the San Benito is a significant source of sediment for the lower Pajaro River, with an average total sediment load of 410,482 tons per day being delivered at the peak of the 100-year flood, and 3,602 tons per day being delivered during bankfull events. Comparing the sediment outflow from the San Benito with the sediment inflow to the Pajaro River suggests that during high flows two thirds of the Lower Pajaro River's sediment load comes from the San Benito River. At low flows the proportion is greater, but the excess may be stored between the San Benito and Chittenden, mobilizing only during larger events.

This study suggests that, while the river will continue to erode and generate sediment to the Pajaro River, the rate of vertical erosion may be similar to the last 20 years and lower than rates observed between the 1950s and the 1970s. We would thus expect sediment delivery rates to be similar to those observed during the last 20 years.

4.1 RECOMMENDED ADDITIONAL WORK

This study has identified reaches of the San Benito River that are likely to erode in the future. Erosion-induced problems, such as local threats to infrastructure and sediment delivery to the Pajaro River, can be reduced by addressing San Benito River erosion issues. We recommend that an opportunities and constraints assessment for erosion reduction be carried out on the lower San Benito (between Hollister and the confluence with the Pajaro River). The project should focus on arresting potential knickpoints that may migrate upstream, and on stabilizing the banks and bed of the San Benito River.

Calculating, and if necessary managing, sediment load from the upper watershed into the lower Pajaro River is important to the success of the Pajaro River Flood Plan. We have outlined several additional projects that will assist in this. A key data gap can be filled by initiating sediment data measurement and setting up and calibrating a sediment transport model of the full lower San Benito River so that any follow-on studies are based on measured rather than inferred data. We recommend a program to collect sediment concentration and flow data on both the Pajaro River and the San Benito River above their confluence, so that an accurate sediment budget for the two systems can be developed. This will allow more precise determination of the relative roles of each system in supplying sediment to the lower river, leading to well-targeted sediment management actions.

In the immediate term, calibration of the sediment transport model can be conducted based on observed erosion between 1987 and 2000. The analysis would involve running a sediment transport model with the 1987 FEMA geometry and the observed flows between 1987 and 2000, and then comparing the predicted changes in bed geometry with the observed changes. This would enable us to select or calibrate an appropriate sediment transport model that would then be used to make future predictions. Once additional data are collected, re-calibration should take place to better represent current conditions.

Because of the recent changes in the channel geometry of the San Benito River it is necessary to continue collecting sediment data at the Chittenden gage and to re-analyze the sediment rating curve to see how it has shifted over time as erosion has slowed. These data will allow more up to date assessments of sediment input to the lower river and will help assess the effects of changes in river management upstream. In addition, analysis may be conducted using the annual daily discharge data measured from USGS gage at Chittenden to estimate total mass delivered to the Pajaro River from the San Benito River.

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7. REFERENCES

Ayres Associates. 1999. Geomorphic and Sediment Delivery Assessment San Benito River and Tres Pinos Creek Watersheds. Prepared for San Benito Supply, Inc. August 31.

Golder Associates. 1997. Qualitative and Quantitative Analyses of Degradation of the San Benito River. Prepared for the City of Hollister, CA. August 27.

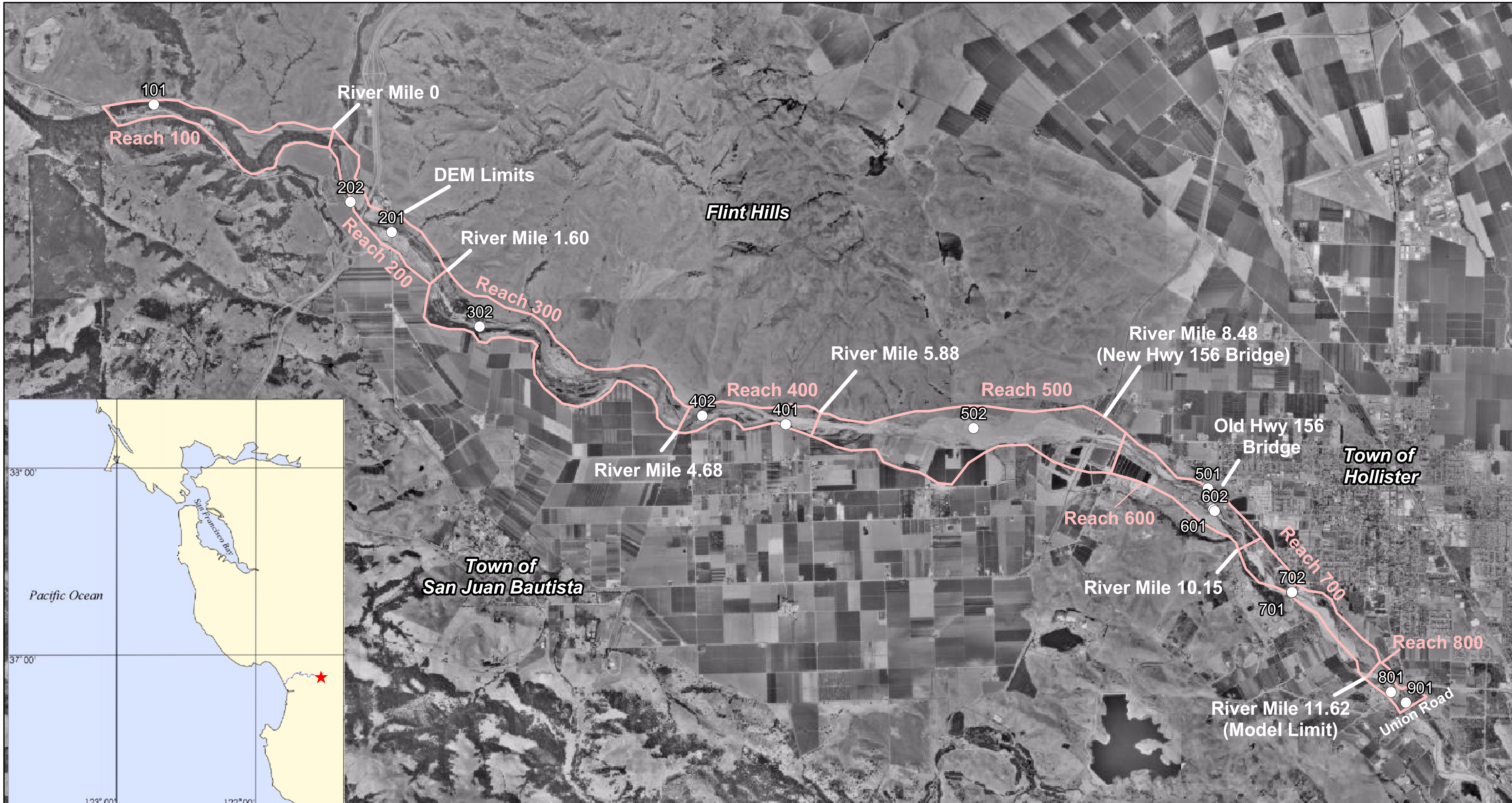
Gregory, K.J., and Walling, D.E. 1973. Drainage basin form and process: New York, John Wiley, 456 p.

Philip Williams & Associates, Ltd. (PWA). 1994. Corralitos and Salsipuedes Creeks: Reconnaissance Level Sediment Assessment Study. Prepared for the U.S. Army Corps of Engineers, San Francisco District. July.

Philip Williams & Associates Ltd. (PWA). 2005. Pajaro River Study. Prepared for The Resources Legacy Fund, and The Natural Heritage Institute. February 28.

Yang, C.T., and Huang, C. 2001. Applicability of Sediment Transport Formulas. International Journal of Sediment Research 16 (3): 335-353.

8. FIGURES



Source: USGS (San Juan, Chittenden, Hollister, San Felipe Quads)

N

0 0.5 1 2 Miles

Sediment Sampling Reaches
Sediment Sample Locations

figure 1

San Benito Sediment Transport Study

Site Map

Proj. 1768

PWA

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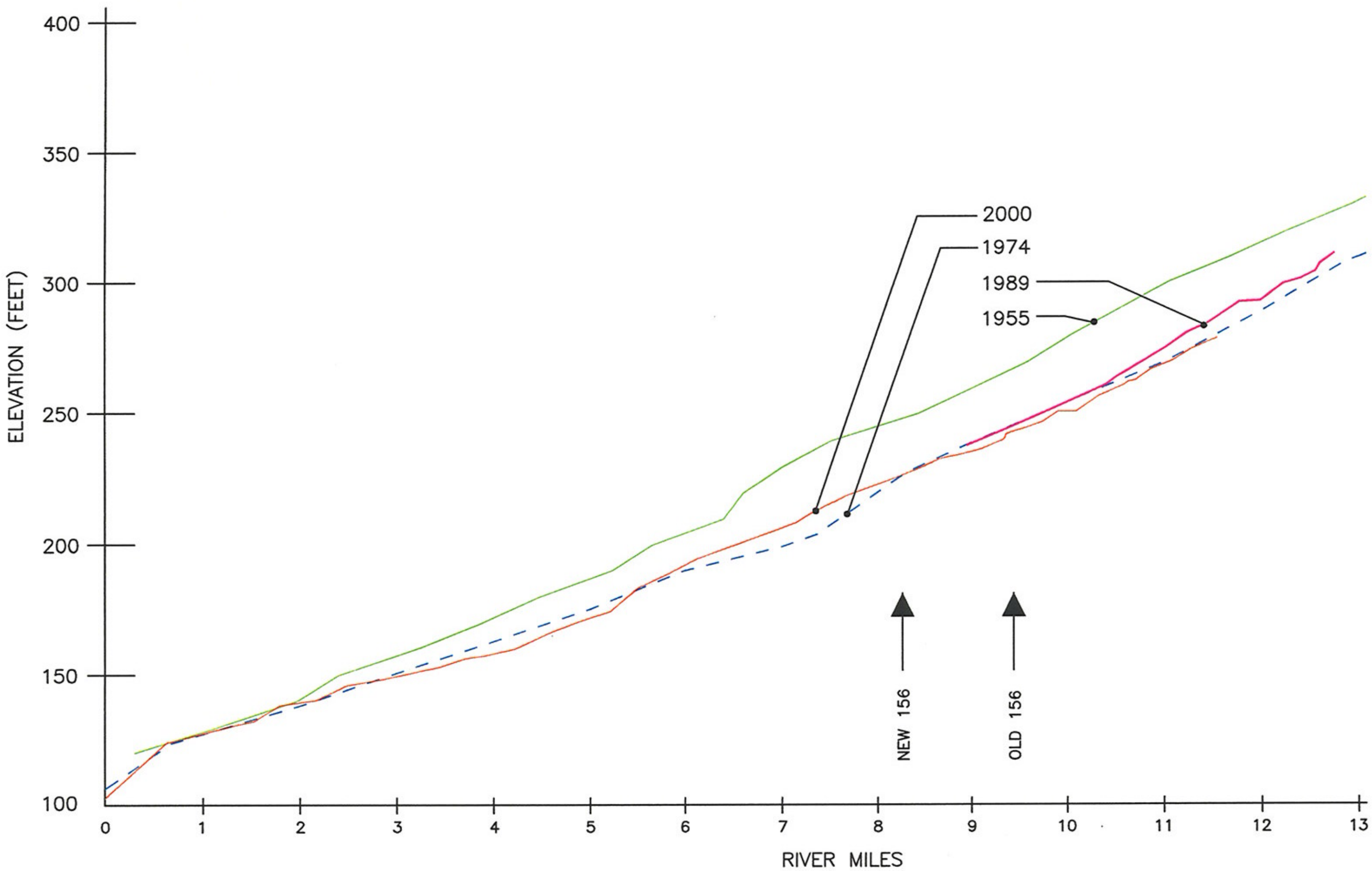


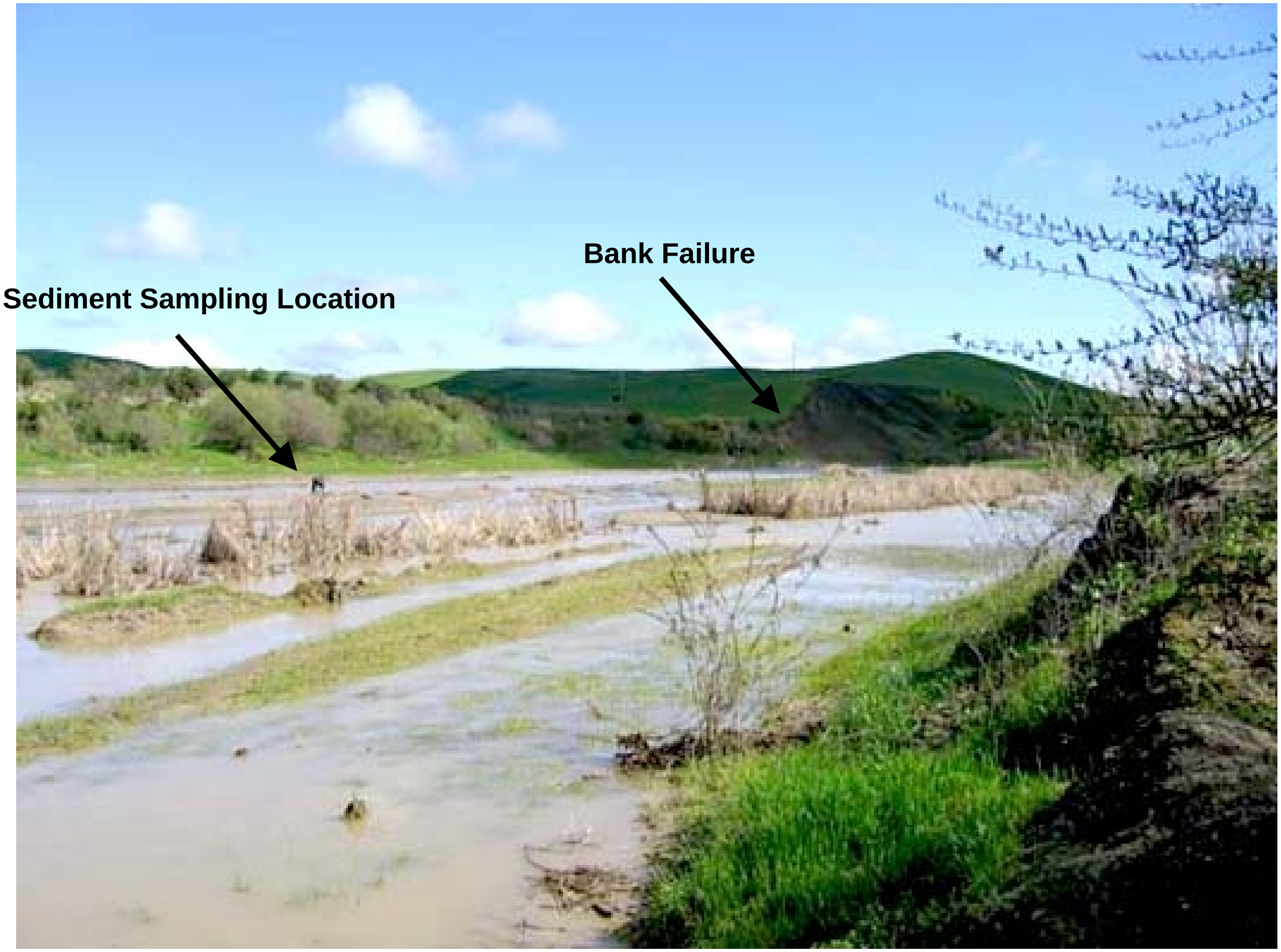
figure **2**

San Benito Sediment Transport Study

Historic Profile Analysis

PWA Ref 1768

PWA



Note: Photo taken March 2, 2005. This photo was taken while collecting sample 402 on the downstream end of Reach 400, between river stations 24,713 and 31,072. This reach is a characterized by a narrow river corridor with steep cut banks like the one shown in the photograph. These cut banks contribute sediment directly to the channel.

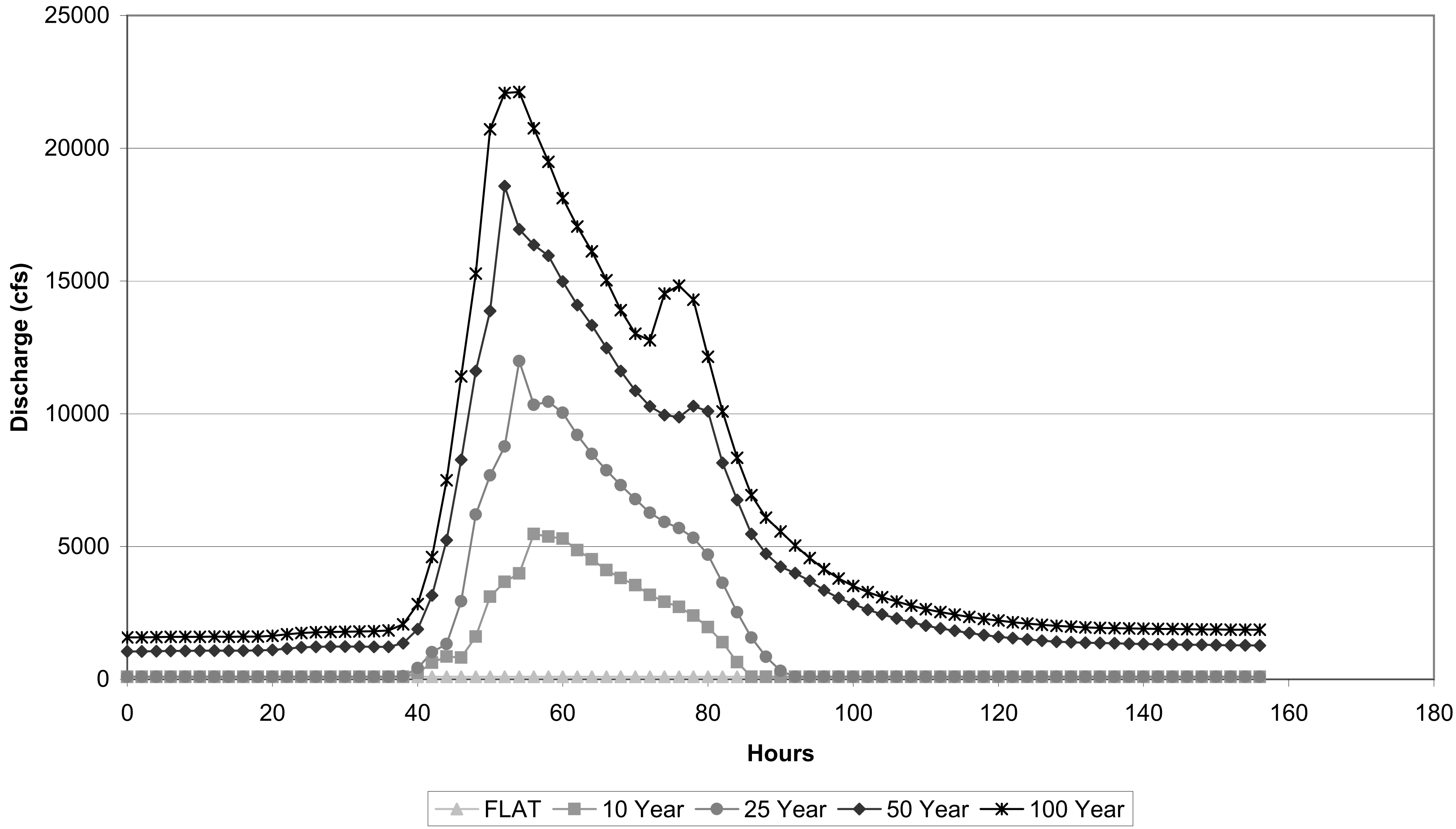
figure 3

San Benito Sediment Transport Study

Sediment Sampling in an Erosive Reach

PWA Ref 1768

PWA



Source: PWA (2004)

Note: The "FLAT" condition is set at 100 cfs for the duration of the model run, and closely approximates a bankfull, or 1.5-2 year flow.

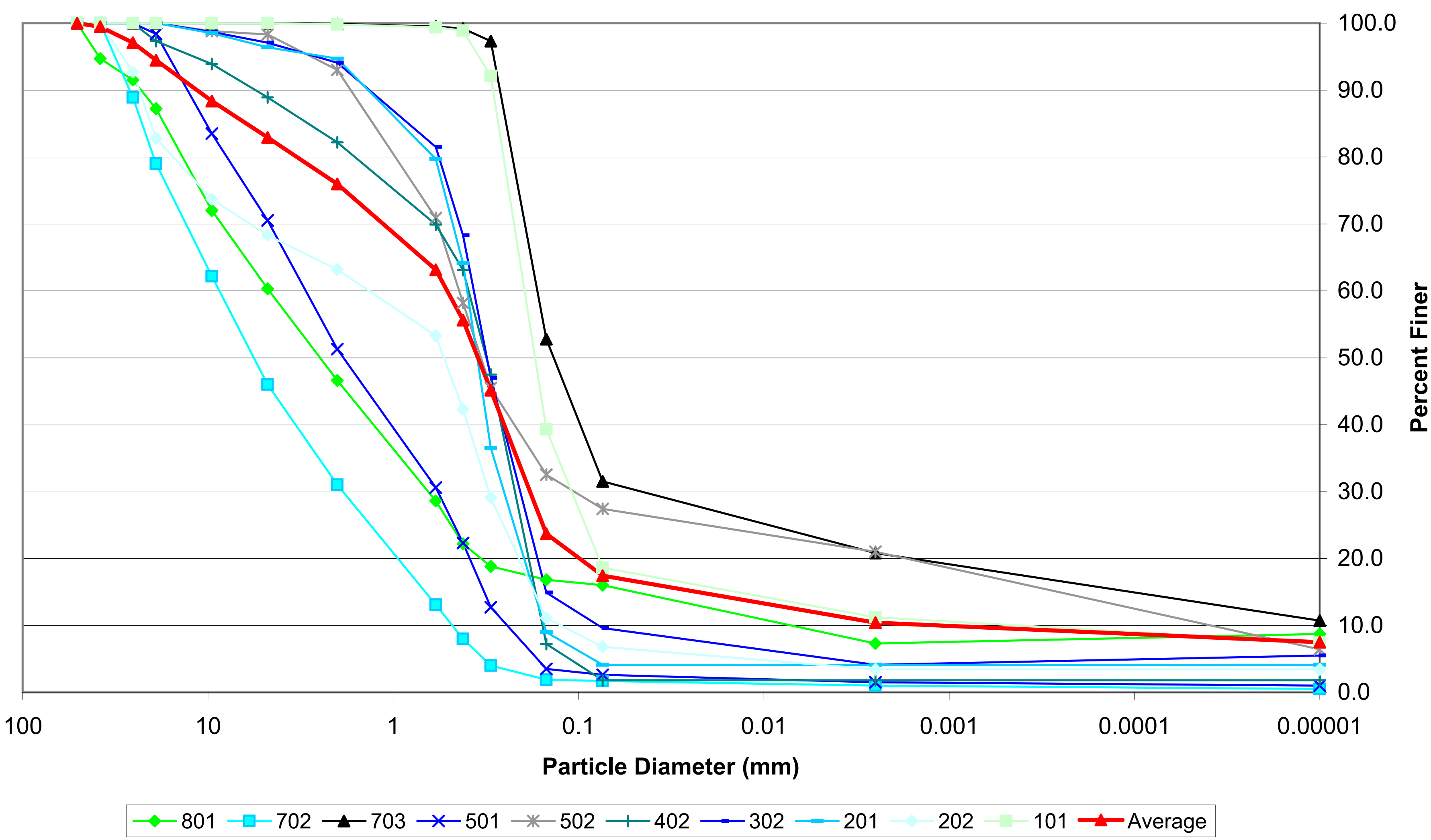
figure 4

San Benito Sediment Transport Study

Flow Conditions for Sediment Transport Model

PWA Ref 1768

PWA



Notes: Fourteen samples were collected from the San Benito river (101, 201, 202, 302, 401, 402, 501, 502, 601, 602, 701, 702, 801, and 901). An average of the ten samples selected was considered respresentative, and was used in the model (see Section 2.4.2).

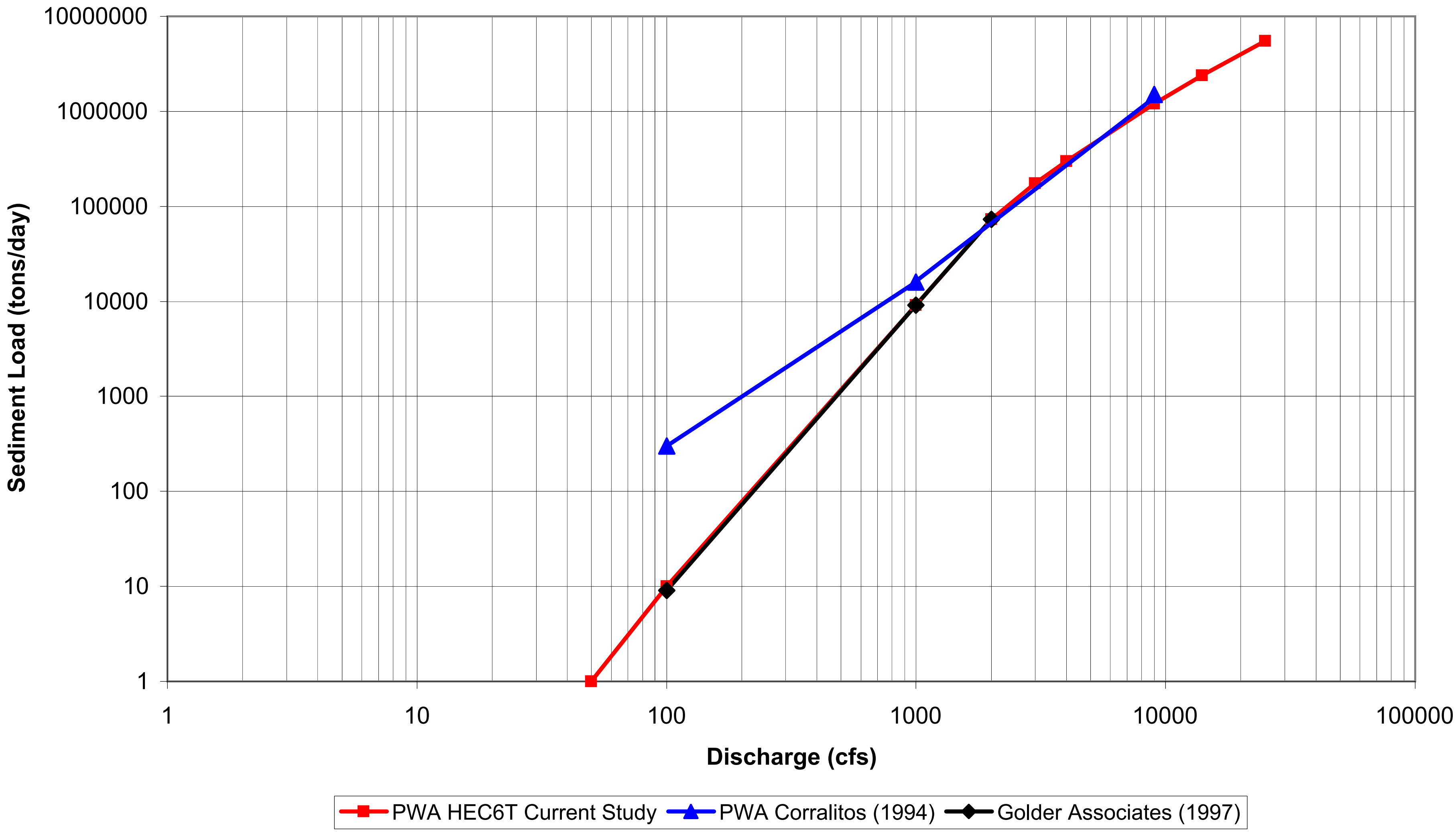
figure 5

San Benito Sediment Transport Study

Bed Gradation Particle Size Distributions

PWA Ref 1768

PWA



Note: The equation for the Golder Rating Curve is

Sediment Load (tons/day) = (9.12*10^-6) x (Q^3)

figure 6

San Benito Sediment Transport Study

Inflowing Sediment Rating Curve

PWA Ref 1768

PWA

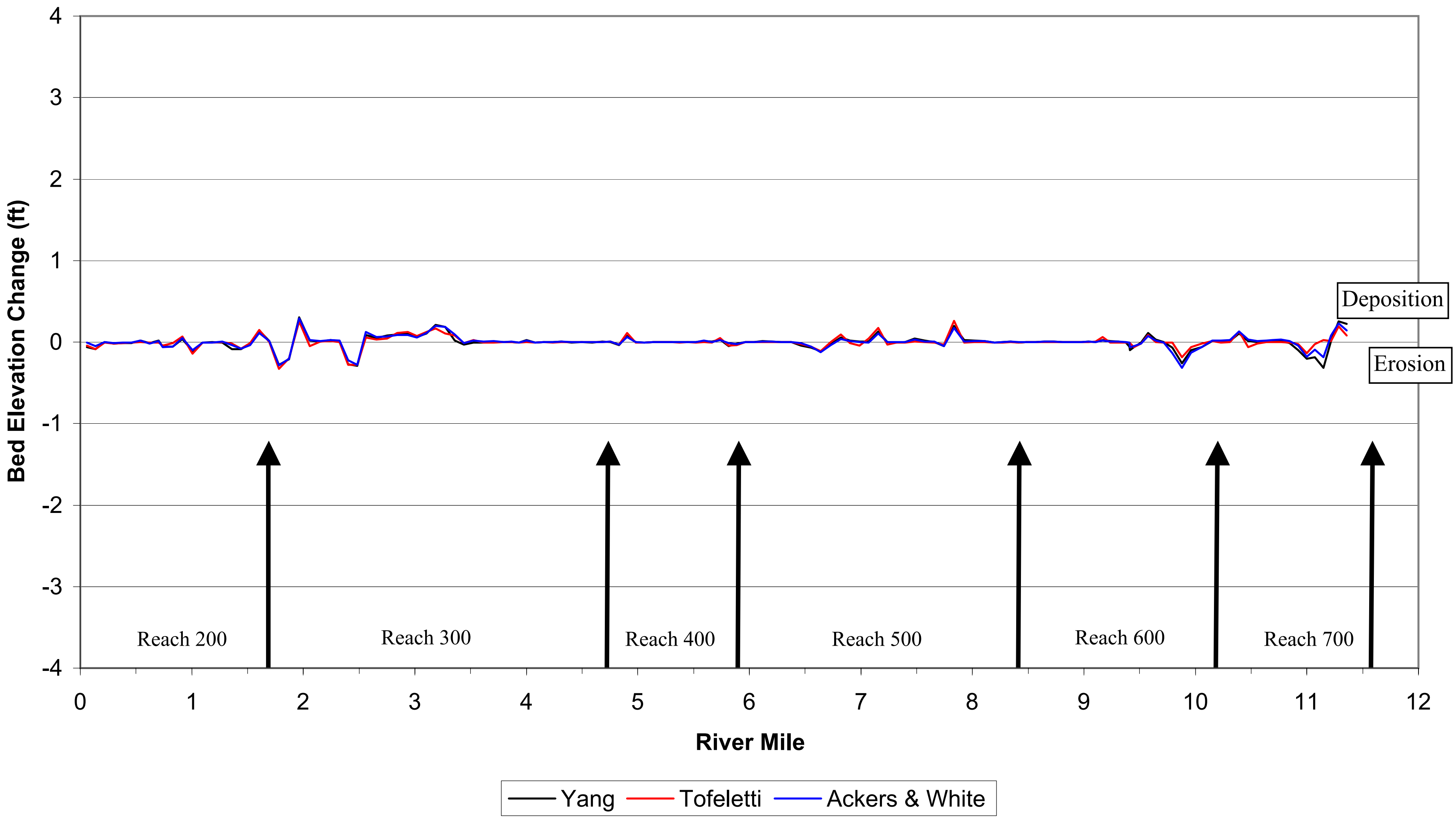


figure 7

San Benito Sediment Transport Study

Channel Bed Change in Study Reach (Bankfull)

PWA Ref 1768

PWA

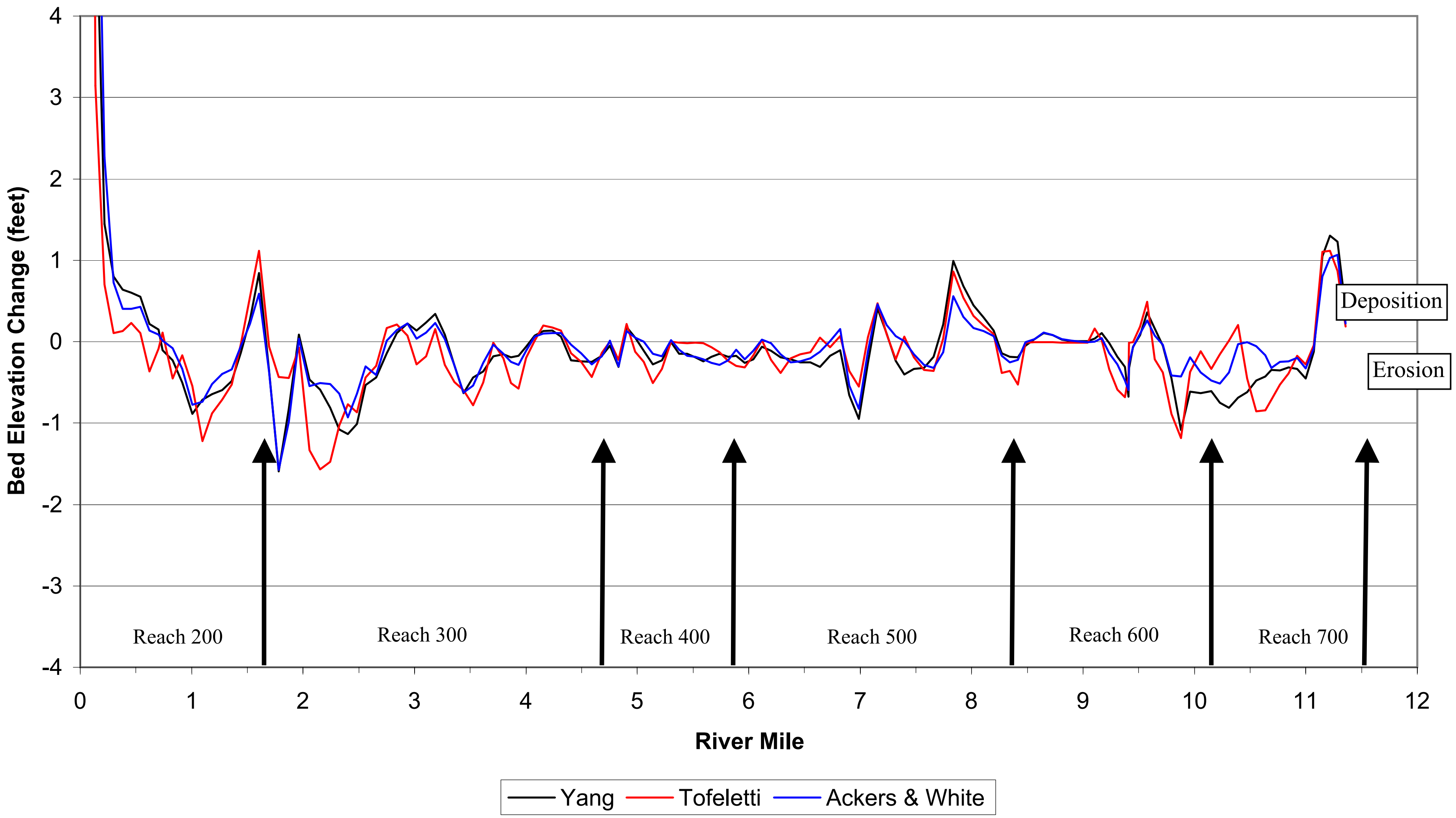


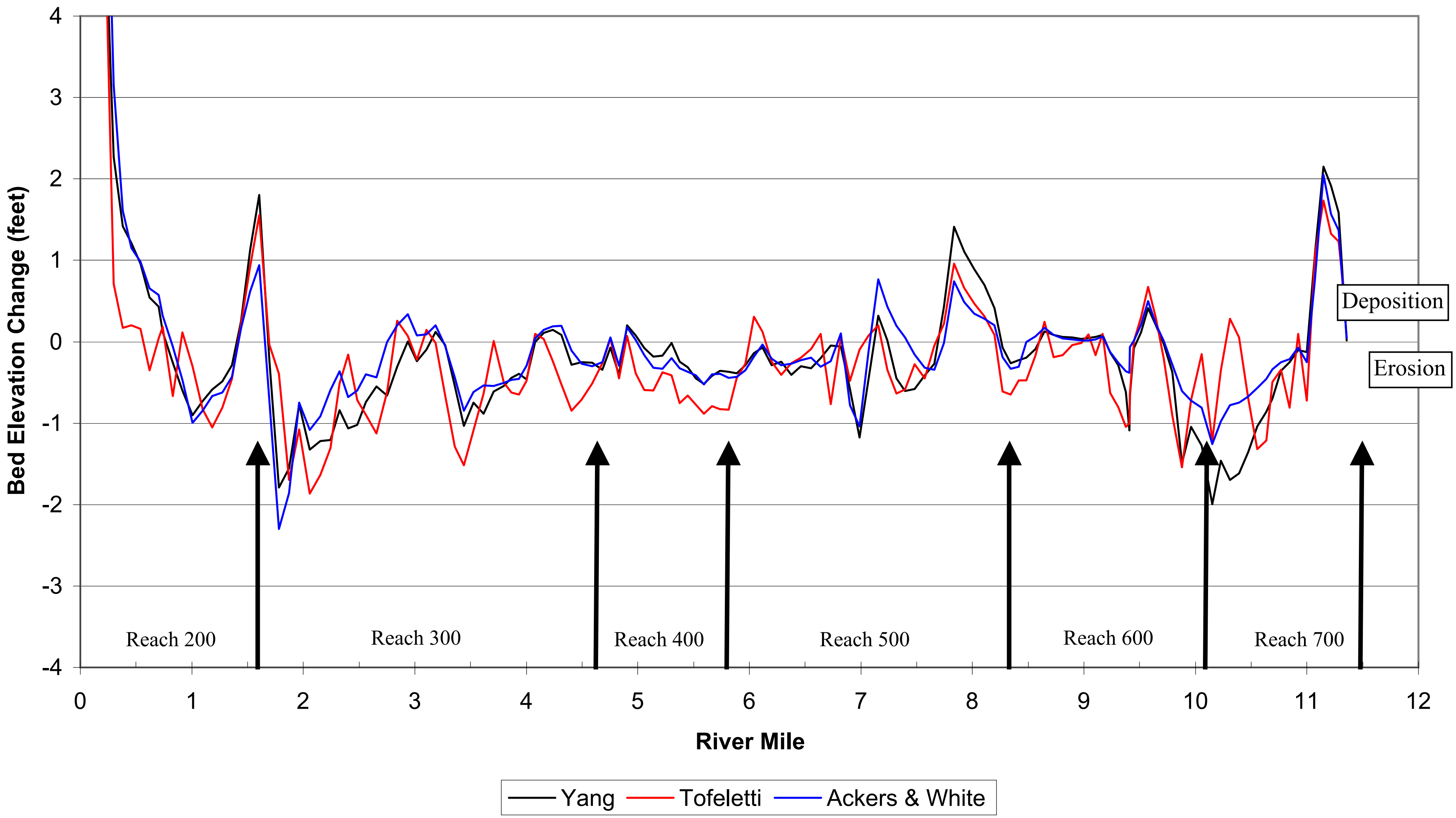
figure 8

San Benito Sediment Transport Study

Channel Bed Change in Study Reach (10yr)

PWA Ref 1768

PWA



Notes: The high values shown near River Statior 60,000 are a result of the model adjusting to the boundary condition.

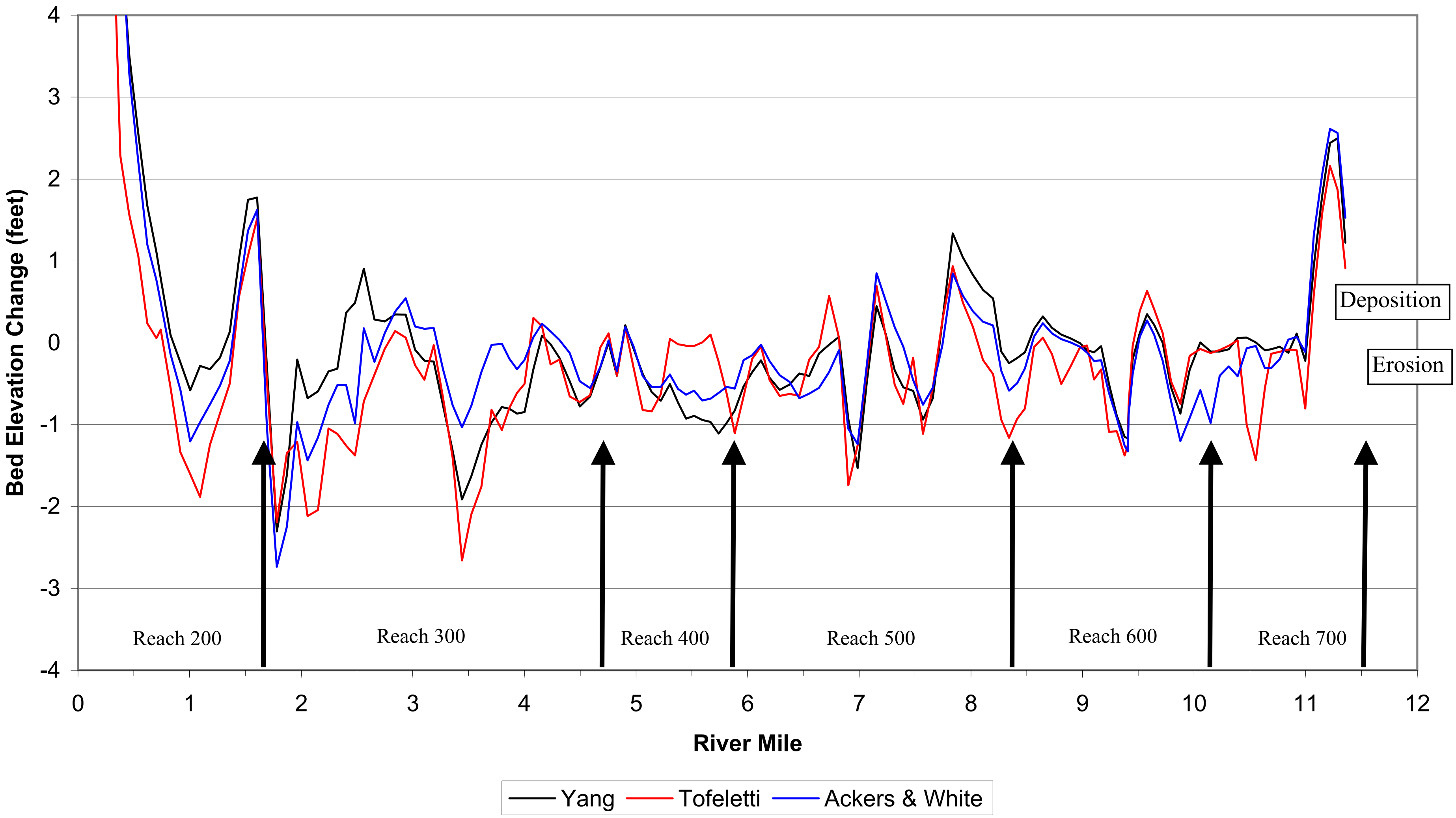
figure 9

San Benito Sediment Transport Study

Channel Bed Change in Study Reach (25yr)

PWA Ref 1768

PWA



Notes: The high values shown near River Station 60,000 are a result of the model adjusting to the boundary condition.

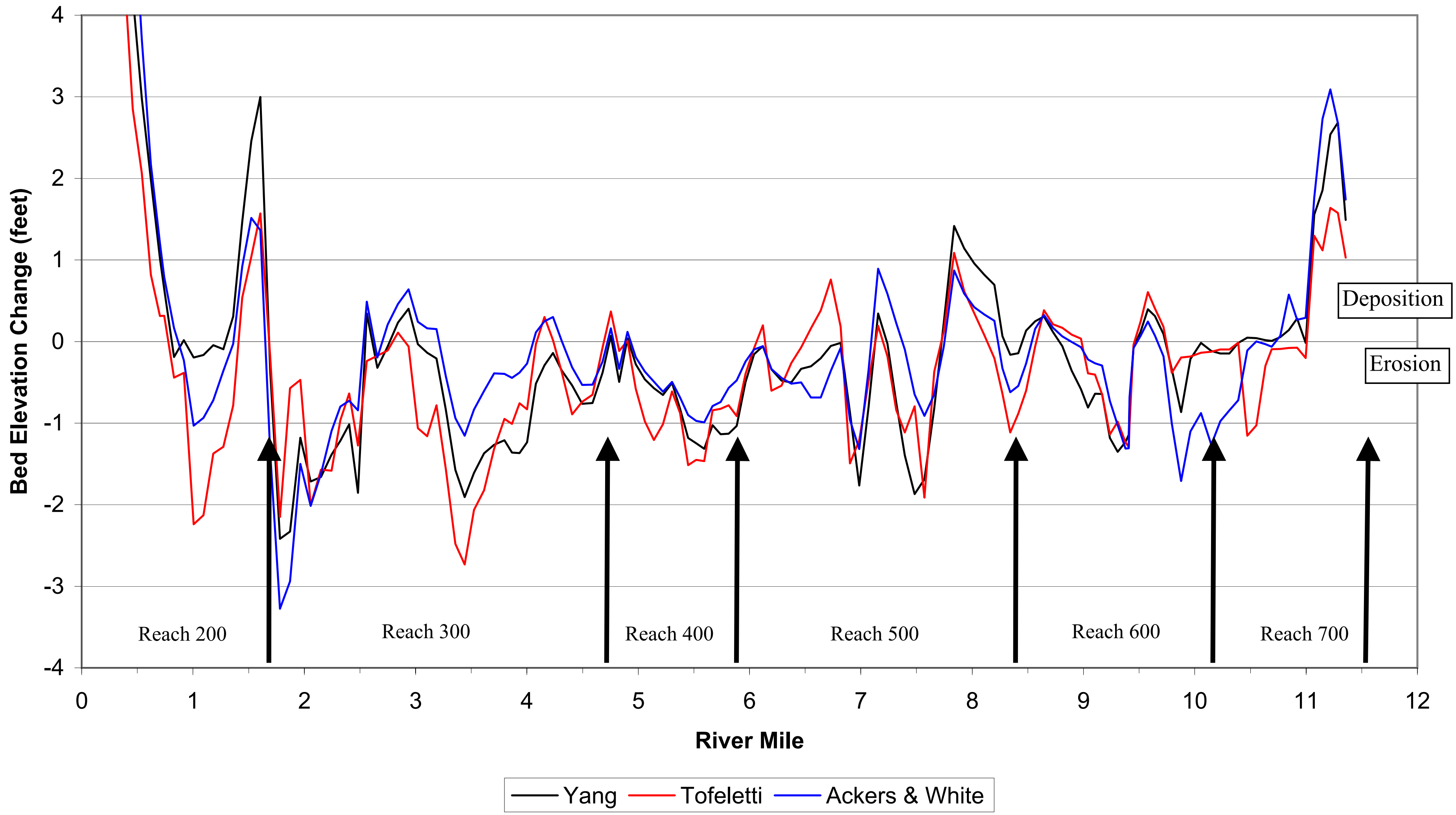
figure 10

San Benito Sediment Transport Study

Channel Bed Change in Study Reach (50yr)

PWA Ref 1768

PWA



Notes: The high values shown near River Station 60,000 are a result of the model adjusting to the boundary condition.

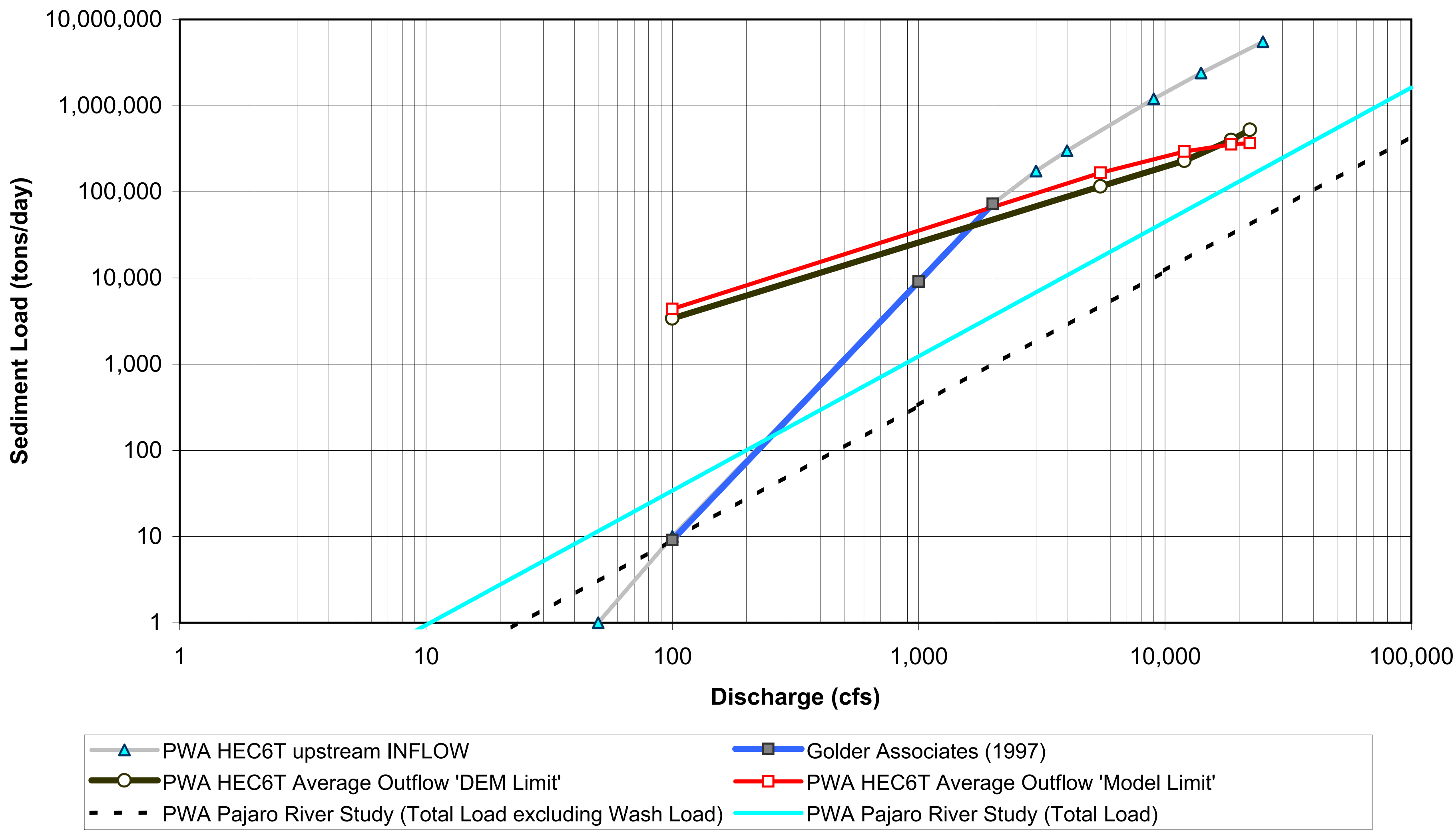
figure 11

San Benito Sediment Transport Study

Channel Bed Change in Study Reach (100yr)

PWA Ref 1768

PWA



Note: The equation for the Golder Rating Curve is:

Sediment Load (tons/day) = (9.12*10^-6) x (Q^3)

figure 12

San Benito Sediment Transport Study

Outflow Sediment Rating Curve

PWA Ref 1768

PWA