Baseline Information for Monitoring of Floodplain Deposition

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Introduction

During the development of the scope of work for the Beehive Bend grant agreement, a stakeholder perception surfaced regarding restoration revegetation activities and the function of the Army Corps of Engineer's (ACE) Flood Control Project (FCP). In summary, the belief was that re-planting of riparian habitats would decrease water velocity and result in accelerated sediment deposition on the floodplain. The perception was that this accretion would reduce the channel and floodplain conveyance capacity to the extent that the FCP levees would no longer provide the design level of protection. We refer to recent work conducted under the ACE Sacramento and San Joaquin River Basins Comprehensive Study (Comp. Study), a number of modeling exercises, and field data collection to evaluate this perception. A brief historical context of flood control measures in the area also informs the discussion.

Investigating the complex physical process of floodplain deposition was beyond the scope of this grant agreement. However, our goal was to establish baseline information to form the foundation of a long-term adaptive management and monitoring program. Establishing baseline information and continuing long-term monitoring will inform stakeholder perceptions and help direct future floodplain management to best achieve multiple goals of flood damage reduction and ecosystem restoration.

Brief summary of Floodplain deposition

The physical process of floodplain deposition, or accretion, is a significant field of study within the discipline of fluvial geomorphology. Floodplain deposition rates are affected by many complex interactions and change over time. Examples of factors influencing floodplain deposition rates include the hydrologic regime, land use on the floodplain, tectonics, long-term climate trends, variations in floodplain topography, flood velocity and depth, floodplain roughness, and anthropogenic factors such as construction of levees and bank protection. The accretion process also occurs at many different scales from that of one single tree stem to the reach scale. A full discussion, much less a full analysis, of all of these factors is beyond the scope of this report. However, stakeholders should approach this topic with the basic understanding that floodplain deposition, or floodplain accretion, continues at large spatial scales through time indefinitely but naturally decreases to an almost imperceptible degree.

Early stages of floodplain development are relatively rapid on a geologic timescale. As the floodplain elevation continues to increase with ongoing deposition, the frequency with which floodwaters are able to access the rising floodplain typically diminishes. This reduces the frequency of depositional events and therefore the rate of floodplain accretion. However, very large floods can still in frequently access developed floodplains and continue the accretion process. Figures 1a and 1b show floodplain accretion curves for the Little Missouri River, Brandywine Creek, and the Milk River. These curves demonstrate that alluvial floodplains, such as the Sacramento River, do not continue to increase in elevation at a rapid rate. It is unlikely, therefore, that the area between the FCP levees on the Sacramento River will “fill up” due to conservation strategies in the foreseeable future, as has been suggested by some stakeholders. If this type of continued, rapid rate of deposition were possible, a deep canyon would result.

A floodplain accretion curve, similar to those in Figures 1a and 1b, has not been developed for the Sacramento River. However, Michael Singer, a researcher at UC Santa Barbara, has initiated an investigation of floodplain accretion rates on the Sacramento River. This and similar studies are focusing on quantifying current accretion rates for this system against which various impacts may be measured. More generally, the creation of a sediment budget for the Sacramento River is a research and management priority. Until this is accomplished, determining how rates of floodplain accretion are influenced by revegetation activities, or any other single influence, will remain a difficult undertaking.

Historical Context

A more complete discussion of the historic flood control efforts and changes in land use in the middle Sacramento River is included in Ayres Associates (2003). The following are summary points from that discussion, which are relevant to this issue.

The FCS was developed over approximately 120 years beginning with the discovery of gold in 1848, until substantial completion of the project in 1965 (ACE 1999). The design capacity for the FCP levees through the Beehive Bend Subreach is 150,000 cfs.

Levees such as those constructed on the Beehive Bend reach of the Sacramento River significantly decrease the likelihood of continued floodplain deposition. It is possible that stakeholders note small-scale, localized deposition near tree trunks and other obstructions on the floodplain, however. Localized deposition such as this is expected to occur. However, it is unlikely that localized deposition would elevate the overall elevation of the floodplain in a situation where large levees contain the majority of flood flows.

Floodplain accretion and other sediment transport characteristics of a river are quantified with many different sediment transport equations. Although these equations take many forms, they all include an expression of water depth as an important variable. When depth is increased in these equations, sediment transport capacity increases. The increasing “weight” of deeper water serves to increase the force that is available to move sediment. Levees increase the depth of floodwaters by containing that flood water in a smaller area, thus increasing depth. Without levees, the same amount of water spread over a larger area, thus reducing depth and sediment transport capacity. This concept, in part, drove the design of the FCP levees because as a goal of the FCP was to increase sediment transport to clear out gold mining debris (ACE 1999). The levees worked so well accomplishing this goal that in 1960 congress authorized the Sacramento River Bank Protection Project to protect the FCP levees from exacerbated bank erosion (ACE 1999).

In the 1950’s, the ACE designated a water surface profile (flood stage) that would ensure the integrity of the project levees. The ACE provided this water surface profile information to the State Reclamation Board (The Board). The Board has the authority and responsibility to maintain the function of the FCP through their floodplain encroachment permitting process and other programs.

Significant changes in land use occurred throughout the period of FCP development. Riparian forest was cleared for orchards as the FCP developed, and Shasta Dam operation began to reduce flood flows and provide irrigation. For example, approximately 9,000 acres of riparian forest was cleared between 1952 and 1972 between Keswick Dam and the town of Colusa (DWR 1987). Approximately 3,200 acres of riparian vegetation was cleared between the FCP levees in the Beehive Bend region. The rate of agricultural clearing appeared to decrease after 1972 and additional analysis suggests a slight rebound of riparian forest acreage between 1972 and 1987 (DWR 1987).

The amount of riparian forest present in the 1950's, prior to extensive clearing, has direct bearing on the present day situation. Water likely passes more slowly through riparian forest than it does through orchard land, and as a result, the water surface elevation increases. Therefore, the design water surface provided to the Board in the 1950's accounted for a greater amount of riparian forest between the project levees than exists today. All other things being equal, the design water surface for the same magnitude flood would probably be lower today than it was is the 1950's.

Other land use changes occurred within the Project levees, which also have bearing on the design water surface. These include a pronounced shift in agricultural land use practices--from row crops to orchards--between 1952 and 1987 (DWR 1987). Other changes include the construction of a network of private levees within the FCP levees, and the placement of bank protection by private landowners who were concerned about erosion.

Each of the factors discussed above (gradual clearing of riparian forest and replacement by agricultural land uses, changes in crop patterns, construction of bank protection, and perhaps most significantly, construction of a network of private levees) has altered conditions from the time the designated water surface was developed. Ensuring the function of the flood control system therefore, has become a complex issue. A true determination of the affects of one action is difficult to separate from the many other changes to the system. Perhaps the application of a common enforcement standard to all actions occurring within the Board's jurisdiction is the best course of action for ensuring the FCP function.

Recent context

Despite extensive flood control efforts in the Central Valley, large floods continue to occur. During the past two decades, the Central Valley of California has experienced several of the most devastating floods of the past century. Four recent major floods--in 1983, 1986, 1995, and 1997 (see Figures 2a, 2b, 2c, 2d in Ayres Associates [2003])--caused widespread and extensive damage in the Sacramento and San Joaquin Valleys, requiring substantial repair, replacement, and rehabilitation efforts throughout the flood management systems). In January 1997, Californians experienced one of the largest and most extensive flood disasters in the State's history, with flood damages of $524 million in the Central Valley (ACE 1999).

Effort to Address Flood Damage Reduction and Ecosystem Health

In response to an overall decline in ecosystem health and recent flooding disasters, congress directed the ACE to conduct a Comprehensive Study of the flood management systems in the Central Valley (http://www.compstudy.org/). The study was directed to address both the failing operations of the current flood control system, and the environmental degradation resulting from it. Specifically congress directed the ACE's Comprehensive Study to include:

- *(1) preparation of a comprehensive post-flood assessment for the California Central Valley (Sacramento River Basin and San Joaquin River Basin),*
- *(2) development and formulation of comprehensive plans for flood control and environmental restoration purposes, and*
- *(3) development of a hydrologic/hydraulic model of the entire system including the operation of the existing reservoirs for evaluation of the current flood control system. Not later than 18 months after the date of enactment of this Act the Secretary shall transmit an interim report describing results of the post-flood assessment and the assessment of the existing flood control system and its deficiencies.*

As one part of the Comprehensive Study the ACE completed a Post Flood Assessment in 1999. In this assessment the flood control system was newly coined as a flood damage reduction system and summary findings of the 1999 assessment of the 1983, 1986, 1995, and 1997 floods include:

- *Existing flood management systems functioned, but were clearly overtaxed.*
- *Combined damages from four recent floods exceed $1.6 billion.*
- *Another flood like those of 1986 or 1997 would likely result in similar or greater devastation.*
- *Storms greater than those of January 1997 are possible, and the resulting flooding could be catastrophic.*

And most importantly,

- *The flood management system is in desperate need of upgrade and modification.*

Modeling

The background information above makes it clear that floodplain accretion is affected by many factors other than conservation activities. The deteriorated condition of the FCP should be considered before a lack of function of the system is assigned to conservation actions. For example, the Comprehensive Study found that the project levees have settled over time and no longer provide their original design capacity (ACE, 1999).

Regardless, due diligence of potential conservation actions should include attempts to quantify the likely affects of all proposed projects. A due diligence sensitivity analysis was conducted to evaluate hypothetical future conditions in the Beehive Bend Subreach (Ayres Associates 2003). This analysis can be used to inform the stakeholder perception that such activities would lead to accelerated floodplain deposition. The Ayres Associates (2003) analysis shows the current condition of the FCS in this reach relative to hypothetical future conditions. Hydraulic modeling in this area determined that under current conditions, minimum levee freeboard is approximately 5 feet, and on average is between 5-6 feet (Plate 2, Ayres Associates 2003). The analysis also depicts a restoration strategy that does not decrease the FCP levee freeboard, but rather increases it in some locations.

Changes in the amount of FCP levee freeboard affect the levee's probability of failure. A recent ACE report (ACE 2000) contains a levee failure analysis, which produced generic conditional probability of failure curves. Figure 2 shows the Beehive Bend area levee failure curve. More specifically, the "S2" curve is the stability ranking assigned to levees in this area. The range of freeboard determined in the Ayres Associates (2003) hydraulic modeling exercise corresponds to a 15-25% probability of failure, according to the ACE failure curves. Thus, the restoration strategy in this reach does not increase this probability of failure, and in some cases reduces this probability.

Flood water velocity affects sediment erosion and deposition (Wolman and Leopold 1957). The Ayres engineers used best professional judgement to determine that a velocity change of 0.5 ft/sec should not be exceeded in an effort to maintain current conditions in average floodwater velocity. Although localized changes occurred as a result of the modeled hypothetical conservation strategy, the study determined that no significant changes would result in changes to these physical processes (Plate 3, Ayres Associates 2003). Based on this large scale this analysis, restoration strategies do not appear to reduce the level of protection from the FCP levees as perceived by some stakeholders.

Other researchers are utilizing different types of modeling to improve our understanding of floodplain accretion on the Sacramento River system. Singer and Dunne (2001) characterized reaches of the river as net erosional or depositional by analyzing hydrologic and suspended sediment records. Their model predicted that, for the years of their analyses, the top end of the Beehive Bend should have experienced net erosion, and the bottom end net deposition (Figure 3). Although this is an excellent first step in formulating a sediment budget for the Sacramento River, the analysis is limited by the need to define study reaches using stream gages locations. Additional study is needed that defines reaches based on geomorphic characteristics and is less dependent on stream gauge locations.

Baseline field data collection

Although quantifying long-term rates of sediment deposition is not possible within a 3-year grant period, field-collected data may provide a useful baseline of information to inform stakeholders perceptions and aid in the evaluation of future floodplain management activities. Our original intent with this study was to compare floodplain deposition in neighboring restoration and agricultural sites in the Beehive Bend Subreach. However, conservation ownership parcels within the Beehive Bend selected for monitoring were not inundated, and consequently no deposition occurred during the grant period. Therefore a comparison of deposition within differing land uses was not possible. However baseline data collected in this study should permit this comparisons to be made at some future date.

We collected floodplain topographic data at selected conservation ownership parcels in the vicinity of the Butte City Bridge. Hydraulic modeling revealed this area as the most sensitive area of the FCP within the subreach. Floodplain topography was characterized with a rod and level both upstream and downstream of the bridge location (Figure 4). Topographic data was related to an established benchmark at the east end of the Butte City Bridge. The extent of cross section A was limited by the height of restored vegetation blocking line of site surveying with a rod a level (Figure 5). Ideally, future data collection will utilize total station survey technology which is less limited by height of vegetation on the floodplain. The extent of cross section B was limited due to private land ownership at the east end of the survey (Figure 5). This information can now form the foundation of a future long term monitoring program.

Future Information Needs

Creation of a sediment budget for the Sacramento River is a research and management priority. We also suggest a number of monitoring guidelines to further inform perceptions regarding land use changes, floodplain accretion rates, and the function of the FCP.

- Floodplain roughness values need to be better determined with field data collection. Hydraulic variables, such as water depth and velocity, should be measured during flood events within different land uses.
- Vegetation monitoring should be tailored to attempt to quantify what vegetation variables affect floodplain roughness. This information could guide conservation strategies, which accomplish multiple objectives of ecosystem restoration and flood damage reduction.
- Additional high water mark data should be collected to improve hydraulic modeling calibration efforts.
- A system of stream reference sites, with permanent benchmarks and full floodplain cross sections, should be established and raw topographic data from these sites made available to researchers. These sites should be resurveyed every 3-5 years or after large flood events.
- Existing historic topographic data should be evaluated for long-term changes in channel and floodplain dynamics.

Literature Cited

Army Corps of Engineers. 1999. Post-Flood Assessment for 1983, 1986, 1995, and 1997 in the Central Valley, California. The Army Corps of Engineers' Sacramento and San Joaquin River Basins Comprehensive Study, Sacramento District. March 1999.

Army Corps of Engineers. 2000. In-Progress Review Document. The Army Corps of Engineers' Sacramento and San Joaquin River Basins Comprehensive Study, Sacramento District. October 2000.

Ayres Associates. 2003. Hydraulic Analysis of Riparian Habitat on the Sacramento River from Princeton to Beehive Bend (RM 163-176). Final Report to The Nature Conservancy. Available at: http://www.sacramentoriverportal.org

Bradley, C. E. and D. G. Smith. 1986. Plains cottonwood recruitment and survival on a prairie meandering river flood plain, milk river, southern Alberta and northern Montana. Canadian Journal of Botany 64:1433-1442.

Everett, B.L. 1968. Use of cottonwoods in an investigation of recent history of a floodplain. American Journal of Science 266:417-439.

Department of Water Resources. 1987. Land Use Changes in the Sacramento River Riparian Zone, Redding to Colusa. Third Update 1982 to 1987. State of California Resources Agency, Dept of Water Resources, Northern District.

Singer, M. B., and T. Dunne, 2001. Identifying eroding and depositional reaches of valley by analysis of suspended sediment transport in the Sacramento River, California. Water Resources Research, Vol. 37, No. 12:3371–3381.

Wolman, M. G., and L. B. Leopold. 1957. River floodplains; some observations on their formation. U.S. Geological Survey Prof. Paper 282-C.