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AN ENVIRONMENTAL ALTERNATIVE FOR THE PÁJARO RIVER FLOOD PLAN

FINAL REPORT

Prepared for

The Sierra Club

Prepared by

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1. INTRODUCTION AND STATEMENT OF PROBLEM

Flooding on the Pájaro River in 1995 and 1998 caused extensive flood damage to the cities of Watsonville and Pájaro, and to the levees of the existing federal flood control project. In response the US Army Corps of Engineers (USACE), San Francisco District, is developing a new Pájaro River Flood Plan that is intended to offer greater flood protection both in the urban and downstream agricultural areas. The proposed alternatives (as of the May 12th 2003 USACE stakeholder presentation) are designed to offer protection against the 100-year flood (assumed to be 40,100 cfs at Murphy's Crossing and 45,500 downstream of the confluence with Salsipuedes Creek), and employ a combination of levee setbacks and raises, and maintenance of a hydraulically-smooth channel with a composite Manning's roughness coefficient (or n-value) of approximately 0.04. These alternatives assume hydraulic roughnesses so low that, in practice, they would not permit a properly functioning riparian corridor to develop – indeed, would require removal of most riparian vegetation within the flood corridor, with detrimental consequences for aquatic habitat, water quality and other environmental processes. We find that these alternatives would also perpetuate the current instability of the channel (as described in Section 4) as a result of which maintenance of the assumed hydraulic roughness may require vegetation and possibly sediment management over the project life. For these reasons, the alternatives fall short of the performance standards that the Resource Agencies -- California Regional Water Quality Control Board (RWQCB), California Department of Fish and Game, and National Marine Fisheries Service -- have reportedly laid out in letters and meetings with the USACE and local sponsors as necessary to comply with the Clean Water Act, Endangered Species Act, and other laws they administer to protect environmental quality. We have reviewed a letter from the RWQCB, dated February 10, 2003 and spoken with members of the staff of these agencies to better understand the nature of their concerns.

Philip Williams & Associates, Ltd. (PWA) has been retained to assess the potential for developing alternatives for modification of the existing project that meet two fundamental standards: first, the same level of flood protection as proposed by the USACE; and second, establishment and maintenance of channel conditions that promote geomorphic sustainability, a wider, more dense riparian corridor, and a more extensive range of ecologically-useful channel-floodplain interactions. We evaluated alternatives that would provide the desired capacity (100-year flood flow) within the existing project footprint, upstream detention storage to reduce that peak flood flow in Watsonville, and omission of downstream levee improvements or downstream flood corridor widening.

In this study we have developed and simulated a series of different approaches to achieve flood control with greater environmental benefits than the current proposals. We have used the different scenarios to assess the sensitivity of the Pájaro River system to different types of channel modification, and to highlight approaches that will lead to a true multi-objective flood plan.

2. CONCLUSIONS AND RECOMMENDATIONS

1. The plans proposed by the USACE as of May 12, 2003 will not allow the development of a geomorphically-stable channel and will require considerable and expensive long-term maintenance of the flood channel, including sediment and vegetation management and/or removal. We have not located any assessment to date by the USACE to quantify how vegetation and sediment would be managed on a long-term basis to maintain the assumed hydraulic roughness and design conveyance.

2. If USACE Alternative 2A is modified to include a more realistic hydraulic roughness (n=0.12) and riparian corridor width (minimum of 200 feet total), the water surface elevation would rise by approximately 2.0 feet, on average, during the design event (100-year).

3. Lowering the floodplain between the existing levees to a geomorphically stable elevation, as described in PWA Scenarios 2, 3, 4, and 6, will significantly lower flood flow stage, allow the development of a significant riparian corridor, and reduce long-term maintenance (sediment and vegetation removal after initial construction). It may reduce or even eliminate required increases in current levee elevations proposed by the USACE in Alternative 2A for most of the channel length. It will require the removal of significant quantities of sediment and existing vegetation in the short term. Based on this initial investigation the approach taken in PWA Scenario 4 appears to be the most promising of these scenarios.

4. There is an opportunity to refine the scenarios tested in this preliminary effort to develop a specific project alternative that will interact with the floodplain on a more appropriate recurrence interval (e.g., a 2-year flood), will minimize soil excavation and vegetation removal by limiting floodplain excavation to one side of the channel, and will require levee increases similar to or less than those proposed by the USACE in Alternative 2A. Such a refinement should include Corralitos and Salsipuedes Creeks, which are not discussed in this report due to time constraints.

5. We have calculated the relationship between the volume of upstream storage and the resulting reduction in downstream peak flow rate in Watsonville. Subsequent development of a relationship between upstream storage and flood elevation will allow the USACE, Resource Agencies, or other interested stakeholders to evaluate the feasibility of upstream storage as a feature of one or more alternatives which modify the levees or channel within the existing footprint.

6. Replacement of the Main Street Bridge or elimination of downstream levee improvements is not expected to have a large or extended effect on expected water surface elevations within the reach of the river by Watsonville.

This report has assessed several different approaches, and identified opportunities and constraints with each. It does not propose a fully developed alternative, though it assesses the potential to develop a geomorphically-stable channel with significant habitat benefits with footprints that are similar to those proposed by the USACE. Additional analysis is needed to achieve this and should include the following:

1. Further assessments of hydraulics, sediment transport, and cost-effectiveness, as appropriate to (A) evaluate the comparative geomorphic stability of each of the USACE and PWA alternatives; (B) quantify the comparative maintenance burden (including sediment and vegetation removal) required under each alternative to maintain the desired capacity over project life; and (C) evaluate the disposal alternatives (including potential beneficial uses) for any sediment.
2. Additional work to refine the design (e.g. refine excavation plans to optimize floodplain inundation frequencies, assessment of saline riparian conditions downstream of Thurwatcher Bridge, potential to create wetland habitat in tidal zone).
3. More detailed assessment of upstream flood detention storage. Upstream storage could potentially remove the need for levee raises in the project reach. Such further assessment should take into account the separate efforts now underway by RMC (Raines-Melton Consulting) and Professor Robert Curry (UC Santa Cruz) to evaluate the feasibility and location of specific storage sites.

3. LIMITATIONS WITH THE CURRENT ALTERNATIVE PLANS

As of the May 12th Stakeholder meeting, the USACE alternatives have the following limitations that our planning approach seeks to address:

- The hydraulic roughness simulated is too low to allow a sustainable riparian corridor to develop.
- The hydraulic roughness simulated is probably too low to allow form roughness from a riffle-pool sequence in the channel bed. The Resource Agencies have stated that such channel form is important to the quality of habitat for steelhead and other fish and wildlife species.
- As a result of the low hydraulic roughness built into the design, the channel will require frequent maintenance in the form of riparian vegetation removal and mowing, removal of channel vegetation and woody debris, and potentially channel bedform (riffle and pool) flattening.
- Such recurrent maintenance will have detrimental effects on both the ecology and the cost-effectiveness of the flood plan.
- Since the flood plan relies on maintaining a smooth channel, any future failure to remove vegetation could result in flooding.
- The channel as designed appears to be incised, disconnected from its floodplain and geomorphically unstable. Continuing incision, including head-cutting above Murphy's Crossing, appears to be likely.
- The flood plan will exacerbate such instability by raising levee heights while maintaining a steep, straight incised channel.

4. GEOMORPHIC INSTABILITY OF THE PÁJARO RIVER

The Pájaro River has been straightened and confined between levees over the last two centuries, with the greatest changes occurring following the construction of the flood plan in the late 1940s. Sinuosity (the ratio of channel length to valley length) was reduced from between 2.0 and 3.0 in 1885 to between 1.0 and 1.6 in 1995 (*source*: USACE San Francisco District, Pajaro River Stable River Planform Study, April 2003), associated with flood control, land drainage and consolidation of agricultural land. In the late 1940s, the current flood control project was constructed, placing levees along both sides of the channel. The flood control plan had the effect of increasing channel gradient (by maintaining a low sinuosity planform), increasing flow depth during floods (by introducing levees and preventing the river from discharging excess flows on to its floodplain) and increasing flow velocities (by removing vegetation cover from the channel bed and margin). In response the channel has degraded (eroded its channel vertically) by 3-5 feet between 1969 and 1995 (USACE). It is likely that erosion started before this time, and that this figure is an underestimation. We expect that channel erosion is a significant source of suspended sediment in the river, and may contribute to the Pájaro River's status as impaired due to sediment.

5. INVESTIGATION APPROACH AND METHODS

This report presents a series of channel scenarios that have been simulated in a hydraulic model and provisionally evaluated as potential alternatives to the existing USACE plans (as they were outlined in the May 12th 2003 USACE Stakeholder presentation). The plans have been developed after discussions with the Sierra Club and members of the Resource Agencies working with USACE, and have been tested using the 1D hydraulic model HEC-RAS Version 3.1.1. We have then provisionally evaluated the alternatives for their feasibility as multi-objective channels that combined geomorphic, habitat and flood defense value and sustainability. We have compared our alternatives with the USACE Alternative 2A to ensure that we achieve at least the same degree of flood protection in Watsonville, primarily by keeping the predicted water surface elevation at or below 35.8 feet NGVD at the Main Street Bridge. Several of the scenarios have been developed to assess the sensitivity of the Pájaro River to different flood design approaches, rather than as stand-alone alternatives.

All elevation references provided in this document refer to the National Geodetic Vertical Datum of 1929, or NGVD. The acronym will be omitted in subsequent elevation references for conciseness.

5.1 FEATURES OF THE ALTERNATIVE PWA SCENARIOS

5.1.1 Sustainable and High Value Riparian Corridor

A common feature to all our channel configurations is the development of a continuous dense riparian corridor of at least 100 feet on both sides of the river (we assume a roughness or n-value of 0.12), and a sufficiently rough channel bed to have riffle-pool sequences (n=0.04). After consultation with resource agency staff we have selected a 100-foot wide riparian corridor on both sides of the channel, with the exception of the Watsonville reach where land use constraints preclude such options. One hundred feet is a minimum buffer width to avoid excessive edge effects and to provide high value habitat. Designing the system around a high roughness allows the corridor to fully develop with minimal need for ongoing management and removes the need for periodic cutting. Vegetation clearance greatly reduces habitat value and increases recurrent maintenance costs, as well as creating a risk that if vegetation management stops flooding may occur, as happened in 1995.

5.1.2 Stable Geomorphic Channel Connected to the Floodplain

We developed a series of alternatives that are based around a geomorphically-stable channel that is connected to the floodplain (i.e. that experiences floodplain flows approximately every one to two years). This feature will result in reduced maintenance requirements and improved riverine habitat. The designs were based on consultation with resource agency and USACE staff. The design steps were as follows (Ann Riley, personal communication June 23rd 2003):

- Calculate the channel forming discharge based on flow recurrence data and a sediment transport curve (*source*: USACE San Francisco District, Pajaro River Stable River Planform Study, April 2003).
- Use Santa Clara Valley Water District isohyetal maps to calculate mean annual rainfall for the Pájaro basin.
- Use San Francisco Bay Area regional curves developed by Waterways Restoration Institute relating drainage basin area and mean annual rainfall to channel cross section area.
- Use 1858 topographical maps to measure channel meander wavelength and sinuosity.
- Use San Francisco Bay Area regional relationships between Rosgen 'C' type channel wavelength and bankfull width to calculate channel width.
- Use predicted width and cross section to estimate channel bankfull depth.
- Use cross section area and bankfull discharge to calculate velocity and ensure it is within the range of allowable velocities for this type of channel.

The dimensions of the geomorphically based channel design are shown in Table 1. Although further hydraulic and sediment transport analysis is needed to ensure that this empirically-designed channel is geomorphically stable, our experience suggests that this approach is more promising than using the current channel geometry and planform, which are recognized as being unstable (*source*: USACE San Francisco District, Pajaro River Stable River Planform Study, April 2003) and we have used these guidelines as the basis for our initial assessment and feasibility study. In scenarios where we increased sinuosity to a value greater than 1.2 we also made an additional increase in channel and floodplain roughness to account for additional turbulence and form roughness. For channel reaches with a sinuosity between 1.2 and 1.5 we added 10% to all Manning's n values, while for channel reaches with a sinuosity greater than 1.5 we added 20%.

5.1.3 Upstream Flood Storage

An additional aspect of our analysis has been to look into the feasibility of using additional upstream storage on the San Benito and Upper Pájaro rivers to supplement the downstream flood defense, thereby reducing flood flows at Watsonville. There is a historical precedent for greater upstream storage on both the San Benito and Upper Pájaro systems; the San Benito has a large floodplain that appears to have been abandoned after the channel incised, reducing flood detention storage and increasing flood peaks in the lower Pájaro River, while on the Upper Pájaro the construction of Miller Canal, incision of the Upper Pájaro and reduced roughness of Soap Lake has had a similar effect. *Both these locations represent situations where historic upstream channel and floodplain modification has increased flood hazard downstream, and it is therefore reasonable to look upstream to rectify some of the flood problems in Watsonville and Pajaro*. While it is beyond the scope of this report to identify locations and methods of mobilizing historic or supplemental flood storage, we have used a sensitivity analysis of flood storage versus flood elevation at Watsonville to identify how much storage would be required to achieve flood control in a more environmentally sustainable channel, and to provisionally assess whether such volumes are likely to be achievable. For the sensitivity analysis we ran flows at 5,000 cfs increments through the model. To account for flow inputs at Salsipuedes Creek we developed a regression curve relating inflow proportions from Murphy's Crossing and Salsipuedes Creek at different total flow levels, and partitioned the totals between the two inflows. In addition we used hydrograph analysis techniques to estimate the relationship between upstream storage and downstream flood peak reduction, based on the RMC 100-year hydrograph for the vicinity of Chittenden Pass (RMC HEC-1 model for the Phase 1 Study for the Pajaro River Watershed Flood Prevention Authority Study, July 2002). This topic is addressed in greater detail in Section 7.

5.1.4 Sensitivity Analyses

We have simulated two alternatives that test the sensitivity of flow levels upstream to levee raises downstream of Watsonville (PWA Scenarios 5 and 6). In these scenarios we left the levees at their existing height (rather than raise them by 4 feet as the USACE 2A Alternative proposes). The results of these simulations are discussed in the following section.

We also performed a sensitivity analysis of the effect of the Main Street Bridge on estimated water surface elevations by modifying the USACE Alternative 2A to remove the hydraulic effect of the bridge; it had little influence on estimated upstream water surface elevations. The bridge increases simulated water surface elevations just upstream by less than 0.1 feet. We therefore assumed no change in the Main Street Bridge in our scenarios.

6. SCENARIOS SIMULATED

In all of the PWA Scenarios discussed, the channel through Watsonville is left as outlined in USACE Alternative 2A. In the discussion we focus on the 100-year flood, taken as 40,400 cfs at Murphy's Crossing and 45,900 below Salsipuedes Creek. We have included a brief assessment of likely geomorphic evolution for each scenario, based on our experience in similar situations. However, more investigation is needed (including sediment transport analysis and further geomorphic studies) to enable more rigorous assessments to be made. Figure 1 shows the layout of the channel features modeled in the different scenarios. Figures 2 through 8 show flood elevations at key points in the channel for all scenarios simulated, while Figures 9 through 32 show individual cross sections and water surface elevations as referred to in the sections below.

6.1 USACE SCENARIO 2A

(100-ft levee setback geometry with no riparian corridor (n=0.04) and smooth form channel bed (n=0.03); see Figures 2 – 9, 15, 21, and 27)

This Scenario is the USACE-favored alternative (as of May 12th 2003). The hydraulic model was supplied by USACE (Bill Firth, June 23rd 2003).

6.1.1 Hydraulic Analysis

During the 100-year flood, flow elevation at the upstream face of Main Street Bridge was 35.8 feet, while at the Highway 1 Bridge it was 27.0 feet.

6.1.2 Advantages

This alternative probably represents the least amount of initial construction and disturbance to the channel, and lowest initial cost.

6.1.3 Disadvantages

This design has the highest maintenance costs and the greatest recurrent environmental impact (associated with repeated removal of the riparian corridor and clearing of the active channel). It has the lowest environmental value of the proposals considered in this report. The channel is geomorphically unstable and disconnected from the floodplain. Grade control would be required to prevent headward migration of the incised channel in Reach 4. There is minimal riparian corridor function due to the low roughness requirement.

6.2 PWA SCENARIO 1

(100-ft levee setback geometry with 100-ft riparian corridor on both sides (n=0.12) and rough form channel bed (n=0.04); see Figures 2 – 9, 15, 21, and 27)

This Scenario is based on the USACE Scenario 2A for underlying geometry (100-foot levee setback and existing channel geometry) with the addition of 100-foot wide high roughness riparian corridors and a rougher bed to allow for riffle-pool development. This Scenario was modeled primarily to assess the sensitivity of the flood plan to increases in channel and riparian corridor roughness.

6.2.1 Hydraulic Analysis

Under PWA Scenario 1 during the 100-year flood, flow elevation at the upstream face of Main Street Bridge was 38.7 feet, approximately 3 feet higher than the USACE Alternative 2A (35.8 feet). At Highway 1 Bridge the flood level was 29.3 feet, approximately 2 feet higher than the USACE alternative 2A (27.0 feet). The increase in stage is due to an increase in channel roughness from vegetation and channel form. Achieving the same flood elevation at Main Street Bridge as the USACE Alternative 2A in this channel would require a reduction in peak flow of approximately 11,000 cfs to 29,500 cfs. This equates to an upstream storage volume of approximately 24,000 acre-feet.

6.2.2 Advantages

This alternative represents no additional construction and disturbance to the channel beyond the USACE alternatives. The riparian corridor would be allowed to grow naturally, with some initial control of non-native species to give native species a competitive advantage, and the channel would be allowed to develop riffles and pools. Once established no additional vegetation or channel maintenance would be required, lowering recurrent costs and enhancing environmental value.

6.2.3 Disadvantages

This alternative does not have sufficient capacity to hold the design flow on its own, and relies upon new upstream flood storage. A further disadvantage is that the existing channel design is geomorphically unstable due to reduced sinuosity and flow confinement, and starts from a condition where historic incision has disconnected the channel from the floodplain. This design would not create a fully functioning river corridor with 'natural' river-riparian corridor interactions. Grade control would be needed upstream of Watsonville in Reach 4 to prevent headward migration of incision, while the floodplain benches would remain largely disconnected. Flow would only reach the benches during the 4 to 5-year events, rather than every one to two years, as we would expect in an equilibrium channel.

6.3 PWA SCENARIO 2

(100-ft levee setback geometry with 100-ft riparian corridor on both sides (n=0.12) and rough form channel bed (n=0.04), stable channel geometry, lowered terraces, current sinuosity; see Figures 2 – 8, 10, 16, 22, and 28)

In PWA Scenario 2 we have kept the channel invert (lowest point) at its present location, but have lowered the benches (areas within the levees) on both sides to a level where they form a new floodplain an appropriate height above the channel, based on the geomorphic channel design (Section 5.1.2). This would involve excavating the current benches on average 3-5 feet down below their current elevation and 100-150 feet wide to form a floodplain. The channel planform has been left in its current configuration, with the existing sinuosity.

6.3.1 Hydraulic Analysis

Under PWA Scenario 2 during the 100-year flood, flow elevation at the upstream face of Main Street Bridge was 30.0 feet, approximately 6 feet lower than the USACE Alternative 2A (35.8 feet). The decrease in stage is due to a large increase in flood storage area on the newly reconnected lower floodplain within the levees, which more than offsets the increase in channel roughness from vegetation and channel form. Flows greater than approximately 6,000 to 9,000 cfs escape from the low flow channel and disperse onto the lower floodplain. This option would not require upstream storage. This option would require less overall levee height increases to the project reach than what is proposed by the USACE in Alternative 2A.

6.3.2 Advantages

This design would have a higher flood capacity than the USACE 2A Alternative, is more geomorphically-stable (subject to more detailed analysis) than the current conditions, and would have a high degree of natural function. Flow inundation of the new, connected floodplain and dense riparian corridor would occur at similar frequencies as in an unmodified river, and we would expect to see a good range of complex ecological interactions between river and corridor. This option would have low or zero channel maintenance costs as the design tolerates a high roughness of both channel and riparian corridor.

6.3.3 Disadvantages

This design is quite invasive, involving the excavation of a large volume of sediment to lower the terraces to the new floodplain. As an initial estimate, approximately 11 million cubic yards would have to be excavated and disposed of. There would also be great disruption to the riparian corridor during and immediately after construction.

6.4 PWA SCENARIO 3

(100-ft levee setback geometry with 100-ft riparian corridor on both sides (n=0.12) and rough form channel bed (n=0.04), stable channel geometry, lowered terraces, 1858 sinuosity; see Figures 2 – 8, 11, 17, 23, and 29)

This Scenario is identical to PWA Scenario 2 but with increased channel length in Reaches 4 and 2 to restore the sinuosity at 1858 (assumed pre-disturbance) levels. The increase in sinuosity could be achieved within the USACE right-of-way footprint, though realignment and lengthening would be required. In Reach 2 this configuration takes advantage of the abandoned meander bend. For purposes of initial modeling, we did not assume any aggradation of the current channel profile under this alternative, though some aggradation is likely to result from the reduced shear stresses provided by the increased roughness and sinuosity of this alternative. Thus, actual reductions in water surface elevations are likely to be somewhat less than suggested by our initial analysis. This issue would need to be examined in greater detail if this design concept is pursued.

6.4.1 Hydraulic Analysis

Hydraulically this scenario performs in a very similar manner to PWA Scenario 2 in the critical reaches. Flood elevation during the 100-year event is slightly higher due to a lower gradient channel (30.2 feet at the upstream face of Main Street Bridge, compared with 30.0 feet under PWA Scenario 2 and 35.8 feet under the USACE 2A Alternative). At the Highway 1 Bridge flood level is 25.9 feet, compared with 27.0 feet for the USACE 2A Alternative. In Reach 4 the meandering creates a much more noticeable increase in flood level (approximately 3 feet higher than PWA Scenario 2) but this is still approximately 3 feet lower than the USACE 2A Alternative.

6.4.2 Advantages

This design would have higher flood capacity than the USACE 2A Alternative, is significantly more geomorphically stable (subject to more detailed analysis) than the current conditions, and would have a high degree of natural function. Flow inundation of the new floodplain and dense riparian corridor would occur at similar frequencies as in an unmodified river, and we would expect to see a good range of complex ecological interactions between river and corridor. Recurrent channel maintenance costs would be low to zero. This option would require less overall levee height increases to the project reach than what is proposed by the USACE in Alternative 2A.

6.4.3 Disadvantages

This design is quite invasive, involving the excavation of a large volume of sediment to lower the terraces to the new floodplain, and additional excavation in the relocated channel meanders. As an initial estimate, approximately 13 million cubic yards of material would have to be excavated and disposed of. There would also be great disruption to the riparian corridor during and immediately after construction.

6.5 PWA SCENARIO 4

(100-ft levee setback geometry with 100-ft riparian corridor on both sides (n=0.12) and rough form channel bed (n=0.04), stable channel geometry, selectively lowered terraces, 1858 sinuosity; see Figures 2 – 8, 12, 18, 24, and 30)

This Scenario is a less invasive version of PWA Scenario 3 that lowers the floodplain to the geomorphically-designed channel with less floodplain excavation, generally by lowering only one side bench. The floodplain is typically 100-150 feet wide, encompassing the riparian corridor on one side. The result would be a channel that had access to the floodplain and riparian corridor on one side during the mean annual flood, with the other side only being inundated at lower frequency events. For purposes of initial modeling, we assumed 2 feet of aggradation of the current channel profile outside of Watsonville under this alternative as a result of the reduced shear stresses provided by the increased roughness and sinuosity of this alternative.

6.5.1 Hydraulic Analysis

This Scenario has a slightly lower flood elevation than the USACE 2A Alternative, with a peak stage of 34.6 feet at the upstream face of the Main Street Bridge, compared with 35.8 feet under USACE 2A. At the Highway 1 Bridge the flood elevation is slightly higher under this Scenario (28.5 feet compared with 27.0 feet under USACE 2A). However, flow elevation is well below the bridge deck.

6.5.2 Advantages

This Scenario achieves a stable channel with a high degree of channel-riparian floodplain interaction while maintaining USACE 2A flood levels and minimizing the amount of excavation and disruption. Although the degree of river-floodplain interaction is less than PWA Scenarios 2 and 3, it is still very high, and the slightly raised riparian corridor on one side adds a more terrestrial habitat that increases ecotype diversity. This Scenario would have low or non-existent channel maintenance requirements, and associated environmental benefits.

6.5.3 Disadvantage

This Scenario involves the excavation of approximately 8 million cubic yards of sediment, and attendant disruption to the riparian corridor.

6.6 PWA SCENARIO 5

(As PWA Scenario 1 upstream of Watsonville, with no levee improvements downstream; see Figures 2 – 8, 13, 19, 25, and 31)

This Scenario was tested to determine the effect that downstream levee improvements have on upstream stages. It uses the PWA Scenario 1 channel and vegetation pattern upstream of Watsonville (USACE 2A geometry with full vegetation cover), and does not raise the levees downstream (with a guide levee to prevent water from flowing back up to Watsonville or Pájaro). On the north side the floodplain would be extended to Riverside Road, drawn south of the Highway 1 interchange and would then follow Beach Rd to Watsonville Slough. On the south side the floodplain would extend to Trafton Road (shown in Figure 1). Additional culverts would be needed under Highway 1 to achieve flood conveyance in this Scenario. This Scenario uses increased flood capacity downstream to reduce flood levels upstream. Further studies would be needed to evaluate flow levels relative to infrastructure on the floodplain.

6.6.1 Hydraulic Analysis

This Scenario has little effect upstream of Main Street Bridge, but significantly lowers flood levels from this point to the mouth of the river compared with PWA Scenario 1 even when Beach Road is assumed to be the northern limit of the active flow path. However, the increase in flood conveyance downstream of Watsonville does not significantly offset the increase in flood stage through Watsonville over USACE 2A due to increased channel roughness. At Main Street Bridge the 100-year flood level is reduced relative to Scenario 1 by 1.5 feet to 37.3 feet (compared with 35.8 feet under USACE 2A and 38.7 under PWA Scenario 1). At the Highway 1 Bridge the flood level is lowered almost 10 feet to 19.6 feet compared with 27.0 feet under USACE 2A and 29.3 feet under PWA Scenario 1. For this Scenario to pass the peak flow at the Main Street Bridge, at a stage equivalent to that of USACE 2A, a reduction of approximately 6,900 cfs, equivalent to approximately 12,000 acre-feet of upstream storage, would be necessary. Further analysis would be required to ensure that the channel was stable downstream of the Main Street Bridge, where the hydraulic gradient would become steeper under this scenario. With this flow reduction, levee raises similar to those of USACE 2A would be required.

6.6.2 Advantages

This Scenario has the advantages of PWA Scenario 1 (little additional change to the channel upstream) with the addition of lower flood levels. Costs would be reduced over the USACE 2A given the omission of downstream levee improvements. Upstream flood detention storage would still be necessary under this scenario, but maintaining current levee heights rather than raising the levees would reduce the amount of storage required from 24,000 to 12,000 acre-feet, making it a more viable option.

6.6.3 Disadvantage

This Scenario has the disadvantages of PWA Scenario 1 (channel is not geomorphically stable, and is poorly connected to its floodplain and riparian corridor) and would not, on its own, achieve the desired level of flood control without upstream storage. Unlike the USACE 2A Alternative, it would not reduce the frequency of flooding downstream of Watsonville and Pajaro.

6.7 PWA SCENARIO 6

(As PWA Scenario 4 upstream of Watsonville, with no levee improvements downstream; see Figures 2 – 8, 14, 20, 26, and 32)

This Scenario combines a geomorphically-stable channel connected to its floodplain on one side (layout as for PWA Scenario 4) with omission of downstream levee improvements from the project (layout as for PWA Scenario 5).

6.7.1 Hydraulic Analysis

As for Scenario 5, this Scenario has little effect upstream of Main Street Bridge, but significantly lowers flood levels from this point to the mouth of the river compared with PWA Scenario 4. Effects downstream of Watsonville are similar to those of Scenario 5. Further analysis would be required to ensure that the channel was stable downstream of the Main Street Bridge where the hydraulic gradient would become steeper under this Scenario.

6.7.2 Advantages

Upstream of Watsonville, this Scenario has the advantages of PWA Scenario 4 (a stable channel with a high degree of channel-riparian floodplain interaction while maintaining USACE 2A flood levels and minimizing the amount of excavation and disruption) with still lower flood levels at the lower end of the reach through Watsonville. Costs would be reduced over the USACE 2A Alternative, given the omission of downstream levee improvements and the reduced need for levee improvements in some reaches.

6.7.3 Disadvantage

This Scenario involves the excavation of approximately 8 million cubic yards of sediment, and attendant disruption to the riparian corridor. Unlike the USACE 2A Alternative, it would not reduce the frequency of flooding downstream of Watsonville and Pajaro.

7. RELATIONSHIP BETWEEN UPSTREAM FLOOD WATER STORAGE AND DOWNSTREAM FLOOD PEAK REDUCTION

PWA Scenarios 1 and 5 generated higher flood stages than the USACE Alternative 2A, indicating that additional upstream flood storage would probably be needed for these alternatives to be viable as flood plans. To calculate the volume of upstream storage required we measured the difference in allowable peak flow (assuming the same peak stage for both scenarios at the Main Street Bridge) between the PWA alternative and the USACE Alternative 2A (see Figure 4, red dotted line). We then took an approximation of the USACE 100-year design hydrograph based on an existing conditions hydrology model developed by others (RMC, Phase 1 Study, July 2002) (see Figure 33) and compared this with the channel capacity to give the volume of excess water that would need to be stored at the peak of a flood event. Figure 34 shows the estimated relationship between upstream flood storage and discharge at Murphy's Crossing. While this approach may understate actual storage requirements due to the assumption that water is stored only during a flood peak, it is a reasonable first approximation of upstream storage requirements.

To provide some context to these figures, the Phase 2 report of the Pajaro River Watershed Flood Prevention Authority Study (RMC, April 2003) identified potential increases in flood storage (obtained by raising the existing Pájaro tributary dams) of between 16,000 and 31,000 acre-feet (page 3-17). An estimated 21,000 acre-feet of storage could be obtained by inducing channel aggradation and reconnecting the floodplain along the San Benito River (R. Curry, personal communication, June 25, 2003). There may also be potential for increasing flood detention in Soap Lake by increasing floodplain roughness (for example by planting trees), restoring the Upper Pájaro channel, and by inducing greater flooding either with in-channel roughness, structures, or through selective floodplain lowering.

Upstream flood storage is not proposed as a stand-alone alternative for modification of the existing project. However, it may be used as a feature of any alternative to reduce peak flow and provide additional benefits, such as increased groundwater recharge.

8. SUMMARY OF THE DIFFERENT SCENARIOS

USACE Scenario 2A – initially a lower cost and non-destructive alternative but no environmental benefits, geomorphically-unstable channel, disconnected floodplain, requires repeated costly and environmentally damaging maintenance;

PWA Scenario 1 – initially a lower cost and non-destructive alternative but only partial environmental benefits (disconnected riparian corridor), unstable channel, requires significant amounts of upstream flood storage to be viable;

PWA Scenario 2 – significant environmental benefits and additional flood control, at a high initial cost due to substantial excavation requirements; lower long-term maintenance;

PWA Scenario 3 – very significant environmental benefits and additional flood control, at a very high initial cost due to substantial excavation requirements and new meander construction; lower long-term maintenance;

PWA Scenario 4 – significant environmental benefits and flood control, at a moderate cost, including lower long-term maintenance;

PWA Scenario 5 – lower cost and non-destructive through Watsonville and Pajaro and upstream, but only partial flood benefits, no flood benefit downstream, unstable channel, still needs storage upstream;

PWA Scenario 6 – significant environmental benefits as for Scenario 4, and lower cost than Scenario 4, but leaving downstream levees at present levels doesn't increase benefits through Watsonville and Pajaro and upstream, no flood benefit downstream.

Based on an initial assessment it appears that the approach taken in PWA Scenario 4 is the most advantageous alternative, and should be further developed and assessed. This approach combines creating a vibrant and fully functioning riparian corridor well connected to a geomorphically-stable river channel with the least possible amount of floodplain excavation, while maintaining flood control. The approach has low maintenance requirements and recurrent costs after completion.

Table 1. Channel Properties of the Different Scenarios Simulated

PWA Scenario	Geometry	Channel roughness	Riparian corridor roughness	*Reach 1*		*Reach 2*		*Reach 3*		*Reach 4*		Stage (ft) at Main Street Bridge (100-year)
				Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	
USACE Alternative 2A	100 ft levee setback, existing channel geometry	0.03 – 0.075	0.04 – 0.1	~140	~14	~100	~17	~100	~14	~120	~14	35.8
PWA Scenario 1	100 ft levee setback, existing channel geometry	0.04	0.12	~140	~14	~100	~17	~100	~14	~120	~14	38.7
PWA Scenario 2	Geomorphic cross section, current planform	0.04	0.12	170	12	200	10	200	10	220	9	30.2
PWA Scenario 3	Geomorphic cross section, planform based on 1858 sinuosity	0.04	0.12	170	12	200	10	200	10	220	9	30.2

PWA Scenario	Geometry	Channel roughness	Riparian corridor roughness	*Reach 1*		*Reach 2*		*Reach 3*		*Reach 4*		Stage (ft) at Main Street Bridge (100-year)
				Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	Channel width (ft)	Bankfull depth (ft)	
PWA Scenario 4	Modified geomorphic cross section, 1858 sinuosity	0.04	0.12	170	12	200	10	~100	~14	~160	~12	34.7
PWA Scenario 5	100 ft levee setback, existing channel geometry, removed d/s levees	0.04	0.12	~140	~14	~100	~17	~100	~14	~120	~14	37.3
PWA Scenario 6	Modified geomorphic cross section, 1858 sinuosity, removed d/s levees	0.04	0.12	170	12	200	10	~100	~14	~160	~12	32.6

9. LIST OF PREPARERS

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10. FIGURES