GEOMORPHIC INVESTIGATION OF SACRAMENTO RIVER MIGRATION AND BAR SEDIMENTATION AT THE PROPOSED CITY OF CHICO POLLUTION CONTROL PLANT OUTFALL DIFFUSER

1. Background

The City of Chico Water Pollution Control Plant (WPCP) discharges treated wastewater to the Sacramento River via an existing outfall diffuser located in the river near the left (east) bank at approximately River Mile (RM) 192.8 (**Figure 1**). The confluence of Big Chico Creek is located at RM 193. Recent growth and migration of the gravel bar extending downstream along the left bank from just upstream of the confluence of Big Chico Creek suggests that the current location of the outfall may not be the optimal location for installation of an additional or replacement diffuser. In addition, historic river meandering and bankline migration would indicate that the existing or proposed designs be adaptable to future channel migration of both the river and Big Chico Creek.

The following tasks were required to accomplish the geomorphic investigation:

1. Perform a literature search and review of historic meander migration patterns.
2. Perform a field review of conditions at the existing and proposed outfall sites and develop an inventory of current erosion and deposition patterns in surrounding reaches of the river.
3. Develop a draft and final report summarizing the findings and recommendations for the proposed diffuser location and design to minimize the impacts of potential sedimentation and channel migration.

2. Literature Review

A search of existing literature on the morphology and behavior of the Sacramento River within the project reach was conducted. However, much of the literature pertains to the general behavior of the river and many of the discussions focus on relatively long reaches of the river. Previous studies of meander migration on this reach of the river include work conducted by Brice (1977), California DWR (1984), USACE (1986), Buer et al. (1989), WET (1990), Stillwater Sciences (2001), Larsen et al. (2002), and Ayres Associates (2003).

The study conducted by Larsen et al. (2002) deals with historic assessments of historic channel migration and computer modeling to predict future channel behavior under different scenarios for the reach from RM 201 to RM 185. However, the Larsen et al. study does not appear to accurately reflect historic patterns nor predict future behavior satisfactorily in the outfall reach. Because of the inherent complexities of the fluvial system, care should be taken when using empirical or analytical models to predict stream channel behavior. Lagasse et al. (2003a) provides a detailed discussion as to the limitations of these types of models.

Although the study by Ayres Associates (2003) is focused primarily on the impacts of levee modifications on the reach from RM 192 to RM 201, the study does provide an analysis of meander migration in the study reach. The analysis of historic meander migration in the study reach was used in this report.

The study conducted by Stillwater Sciences (2001) focuses specifically on the reach of the river containing the M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility intake, which is located immediately upstream of the City's wastewater outfall. Many of the resources

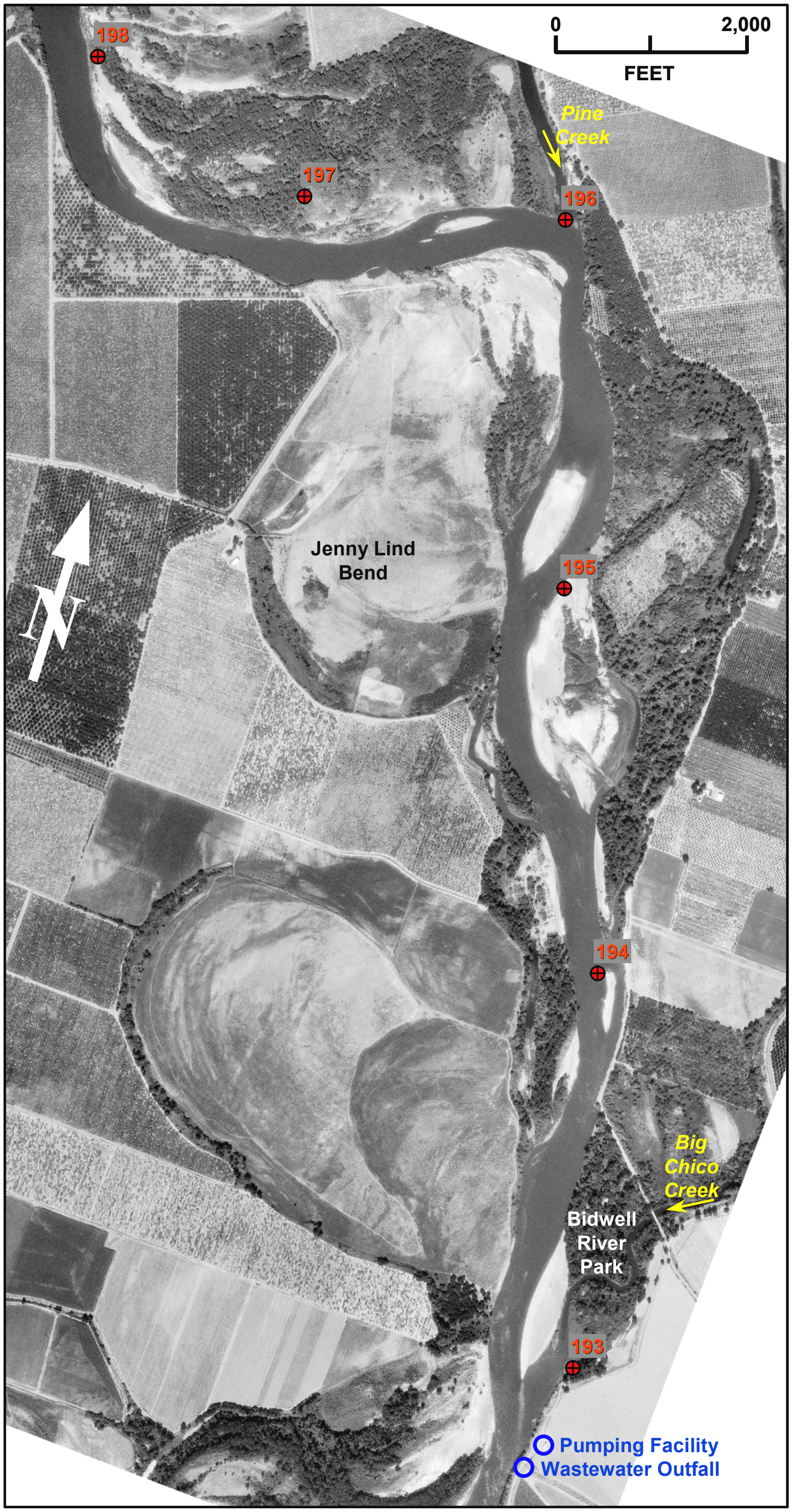

Figure 1. Aerial photo (1998) of the Sacramento River from RM 192.5 to RM 198 showing the location of the Chico WPCP wastewater outfall, the M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility, Pine Creek, Big Chico Creek, and Bidwell River Park.

used in preparation of this report were used by Stillwater Sciences in their study. The Stillwater Sciences report is generally accurate, but there are some discrepancies in the bar migration values that are attributable to incorrect scaling. An examination of the mapped historic bar positions on the accompanying aerial photos reveals that the bar migration distances discussed in the text of the report are approximately twice that shown on the photos.

The Stillwater Sciences report does provide an accurate discussion of historical changes in channel pattern and bar sedimentation, but does not provide a detailed analysis as to the potential causes of local channel migration and bar sedimentation nor does the report characterize the potential behavior of the river in the future. Any recommendations on the siting and design of new facilities or modification to existing facilities should account for the conditions that exist in the reach as well as an understanding of the causes of those conditions and the potential future behavior of the river.

3. Site Reconnaissance

Mr. Thomas Smith, P.E. and Mr. William Spitz, P.G. of Ayres Associates, Inc. conducted a field visit at the site on 28 January, 2004, in order to assess existing geomorphic conditions at the outfall site and to identify and evaluate current erosion and sedimentation patterns within the project reach. The site was observed from both the landward side and from the river via boat. Existing conditions on both sides of the river as well as upstream and downstream of the site were documented and digital photos were obtained during the field visit.

Figure 2 shows the levee near the City of Chico's wastewater outfall location and the M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility intake, which is located just upstream. **Figure 3** shows the river and the eroding right (west) bank just upstream of the intake and across from the confluence of Big Chico Creek. The portion of the right bank that is eroding fastest is composed of predominantly sand and silt (**Figure 4**). Immediately upstream and downstream of the more rapidly eroding bank, coarser grained horizons composed predominantly of gravel to cobble size material (bar deposits) are providing some erosion resistance to the lower bank and is slowing retreat of the bank. **Figure 5** shows the bar at the mouth of Big Chico Creek that is migrating downstream and threatening the M&T intake and the Chico outfall.

4. Historic Channel Behavior

The Sacramento River is a highly dynamic river with active areas of erosion, sedimentation, and meander migration occurring along much of its length upstream of Colusa. The historic behavior of the river in the reach between RM 192 and RM 198 (Figure 1) was examined by compiling and comparing bankline positions and evaluating planform adjustments over time using the methodologies described by Lagasse et al. (2003b). **Table 1** provides a list of the resources used in conducting the historic channel migration assessment.

Prior to the 1930s, the river between RM 192 and RM 199 was extremely sinuous with several large recumbent meander bends located within the reach. Two such bends, one of which is Jenny Lind Bend, were located between RM 194.5 and RM 196 and formed a tightly compressed S-shaped planform. Sometime between 1923 and 1935, these bends were cutoff resulting in a shortening of the river by about 3.75 miles. This would have resulted in an oversteepening of the river and probably initiated significant channel degradation upstream and may have initiated much more rapid migration of the upstream bends. This cutoff reach remained relatively straight until about the 1970s, when it began to develop large radius meanders in response to the rapid migration and the cutoff of the meander bend located just upstream after 1976.

Figure 2. View looking upstream along the left bank levee of the Sacramento River at RM 192.8 showing the location of the M&T intake and Chico wastewater outfall.

Figure 3. View looking upstream toward the eroding right bank of the Sacramento River at RM 192.8 across from the location of the M&T intake and Big Chico Creek.

Figure 4. View of the eroding right bank of the Sacramento River at RM 193.

Figure 5. View looking upstream along the left bank of the Sacramento River at RM 192.9 showing the location of the M&T intake and the bar at the confluence of Big Chico Creek.

Prior to the cutoffs between RM 194.5 and RM 196, the 2 bends located upstream near Pine Creek (RM 196 – 198.5) were slowly migrating downstream. Once the cutoffs occurred, the Pine Creek bends began migrating more rapidly downstream. By 1975, the west (right) bank between RM 196.5 and RM 198 was riprapped in response to this rapid migration and bank erosion. The low radius bend at Pine Creek (RM 196 – 196.5) had become tightly compressed against the erosion resistant east (left) bank by 1976. A neck cutoff occurred on this bend sometime between 1976 and 1981 resulting in a shortening of the river by about a mile. This cutoff likely resulted in significant channel changes upstream, including an increase in upstream erosion and concomitant sedimentation and increased meandering downstream.

Table 1. Map and aerial photo resources used in the historic channel migration assessment.

Agency/Resource	Media	Bankline Dates
U.S. Army Corps of Engineers (USACE)	Blueline topographic survey maps (Colusa to Chico Landing) dated March, 1937	1937 with hand drawn bankline positions from 1896, 1908, 1937, 1946, 1955, 1956, 1960, 1964
California Department of Water Resources (DWR)	Middle Sacramento River Spawning Gravel Study Atlas (1984)	1896, 1908, 1923, 1935, 1937, 1946, 1955, 1956, 1960, 1964, 1969, and 1981 plotted on 1976 aerial photo base.
U.S. Geological Survey (USGS)	Ord Ferry, California 7.5 Minute Topographic Quadrangle Map	1941 base map photo-revised in 1969 from 1969 aerial photos
U.S. Army Corps of Engineers (USACE)	Blueline aerial photos (scale 1" = 400') of existing revetments	1986
U.S. Army Corps of Engineers (USACE)	Sacramento River, Sloughs, and Tributaries, California 1991 Aerial Atlas	1991
California Department of Water Resources (DWR)	1997 Sacramento River Aerial Atlas	1997
U.S. Geological Survey (USGS) and MSN TerraServer	Georeferenced Digital Aerial Photos	1998
California Department of Water Resources (DWR)	1999 Sacramento River Aerial Atlas	1999
U.S. Army Corps of Engineers (USACE)	Georeferenced Digital Aerial Photos	2002

Large meander scars on the floodplain immediately west of the study reach (RM 192.5 – 194) also indicate that significant meandering occurred in the study reach. The river has occupied all or a portion of the riparian land within Bidwell River Park until the early 1960s. By 1969, the river had shifted westward, creating the riparian land that is now encompassed by the park. The confluence of Big Chico Creek is also located at the park. The river has also meandered back and forth within a 3,000-foot wide zone between RM 192 and RM 193, with the existing left bank and levee being the maximum eastward extent of the meander belt. The east (left) bank between RM 192.5 and RM 193 is composed of erosion resistant materials and is presently protected by rock riprap, both of which have limited eastward migration.

From RM 192.5 and RM 196, the river developed a series of long, large radius meanders with small point bars after 1969 (Figure 1). The study area is located in one of these long, large radius bends and point bars. **Figure 6** shows the bankline and bar positions within the study reach over time. The left bank gravel bar and riparian land of Bidwell River Park comprise the point bar of the study reach bend. These bends have slowly extended outward and migrated in the downstream direction over the last 30 years. For example, the right (west) bank across from the park has shifted westward nearly 600 feet since 1976. The bulk of the movement occurred between 1976 and 1986 (350 feet), most of which was likely in response to the 1986 flood. From 1986 to 1998, the bank shifted 150 feet further westward and shifted an additional 70 feet between 1998 and 2002.

As the meander bend at Bidwell River Park has developed through bank retreat and extension, the left bank point bar area has grown in size and length, with the bar growing westward and extending in the downstream direction (Figure 6). The growth of this bar and it's extension downstream are creating sedimentation problems at the existing M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility intake and the Chico WPCP wastewater outfall. **Figure 7** shows the growth and downstream extension of the bar with time. The bar appears to have developed between 1969 and 1976. Stillwater Sciences (2001) indicates that the bar was not present on 1964 aerial photos and suggests that the bar developed during the 1964 flood. However, the 1969 USGS topographic of the reach does show significant change in the area, but a bar does not appear to have developed at the site in 1969 either. The first appearance of the bar on available aerial photography is in 1976 and the bar is fairly well developed by then. The development of this bar and the other bars between RM 194 and 196 is likely the result of upstream cutoffs, which have resulted in degradation and bank erosion, and the initiation of an incipient meandering planform between RM 193 and RM 196.

Growth of the rate of the bar has varied greatly. Between 1976 and 1986, the bar increased in size by about 25% and the downstream end of the bar migrated about 1,160 feet downstream. This results in a downstream migration rate of about 116 feet per year for that period. From 1986 to 1998, the downstream end of the bar extended downstream an additional 560 feet and increased in size by another 15 to 20%. This results in a migration rate of about 47 feet per year. It should be noted that the slower rate was probably a result, in large part, of the low flow conditions associated with the drought that occurred in the valley from 1986 to 1993. The average rate for the period from 1976 to 1998 is 78 feet per year. By 2002, the bar had grown an additional 25 to 30% and extended another 775 feet downstream resulting in a migration rate of 194 feet per year. This results in an overall average migration rate of 92 feet per year for the 26-year period of record for the bar growth.

As shown in Figure 6, a channel had been dredged through the bar just prior to the 2002 photo. Based on comparisons with the 1998 aerial photos and the extent of the remaining bar in the 2002 photo, it is apparent that the bar had extended down to and was silting in the area around the M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility intake by the time the 2002 photo was taken.

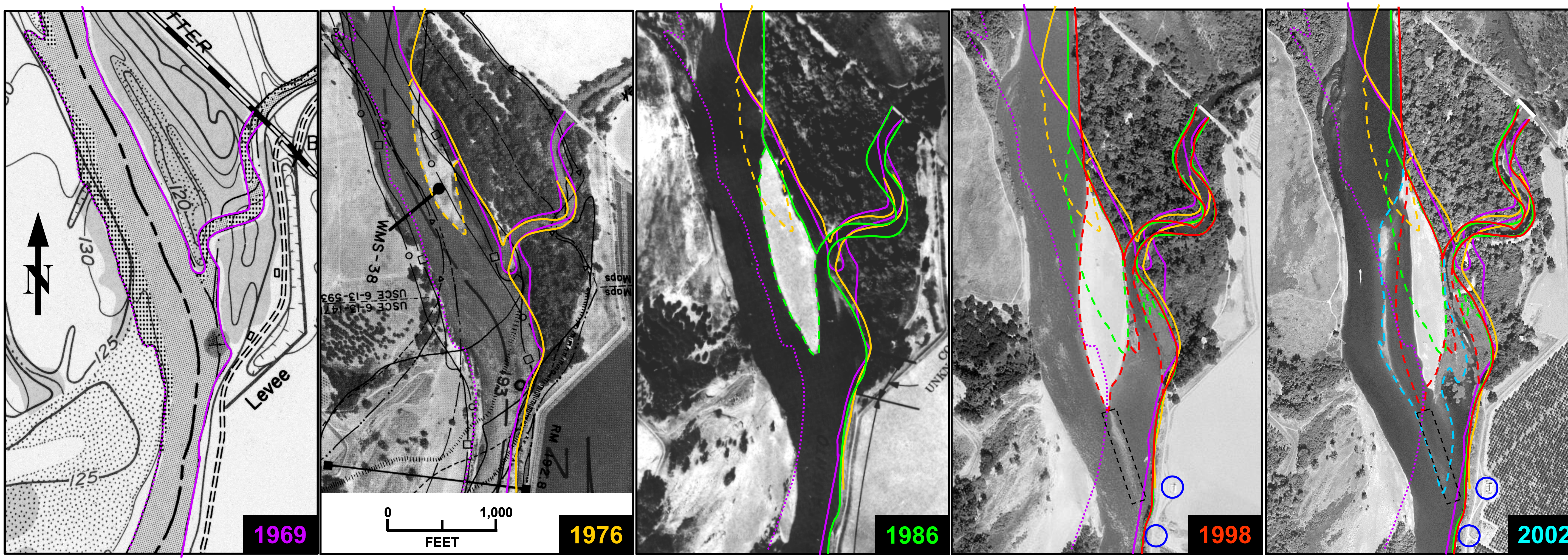

Figure 6. Comparison of bankline positions and gravel bar development at Bidwell River Park from 1969 to 2002.

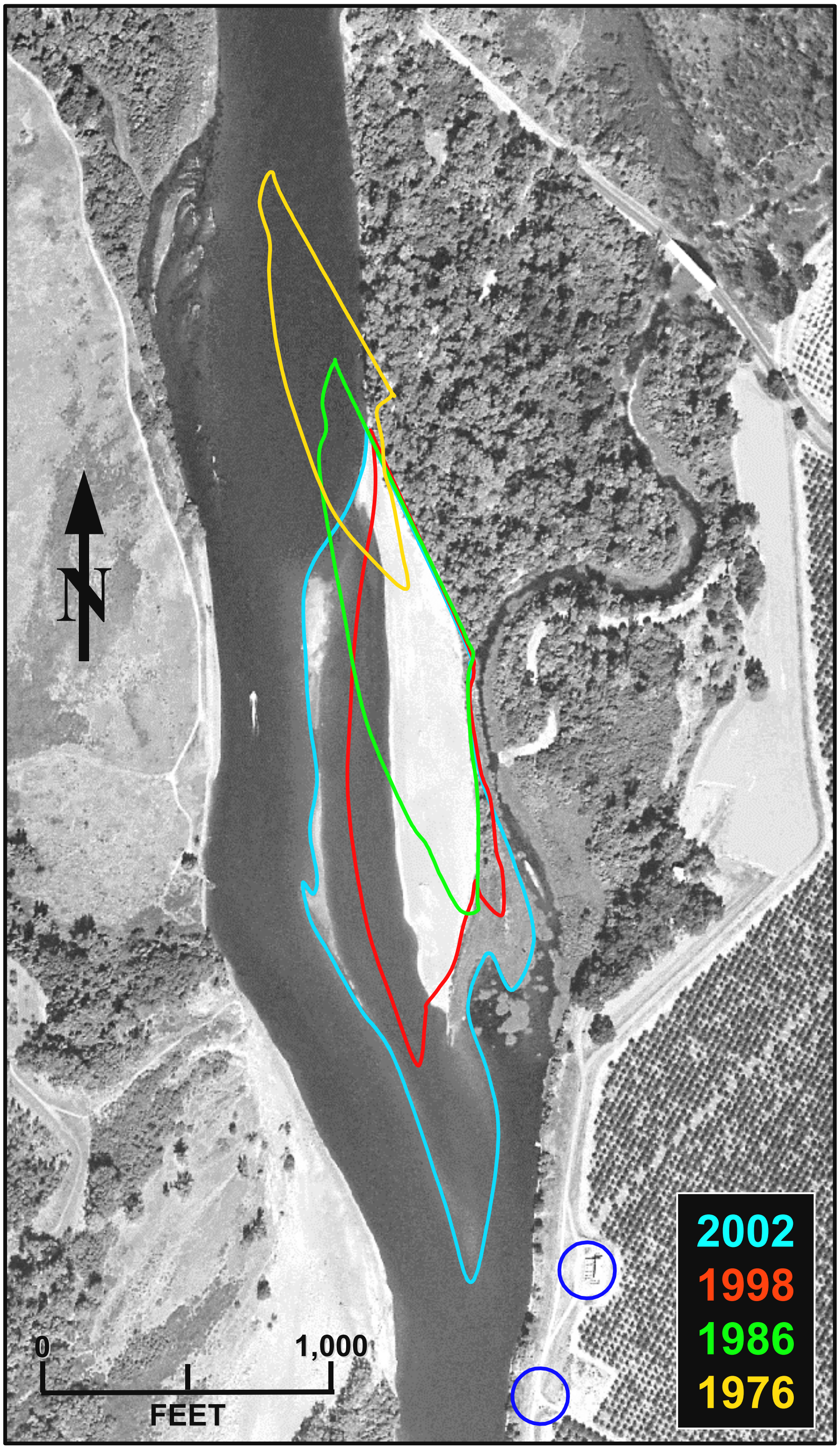

Figure 7. Aerial photo (2002) showing the growth and migration of the gravel bar at Bidwell River Park in relation to the pumping plant and wastewater outfall on the left bank (blue circles).

5. Potential Future Behavior

At the most recent rate (1998-2002), the existing Chico WPCP wastewater outfall will be completely silted in within the next few years. However, complete sedimentation of the channel along the left (east) bank at the wastewater outfall may not occur as long as Big Chico Creek maintains its course along the bankline inboard of the gravel bar. Nonetheless, the continued growth of the Bidwell River Park bend will result in the continued growth and downstream migration of the point bar at the park. As the bend continues to grow, bar sedimentation will likely overwhelm the present location of the confluence of Big Chico Creek and may cause the creek confluence to avulse through the riparian land upstream of the bar or across the bar at a point further upstream from its present location. If the creek confluence shifts upstream from its present position, sedimentation of the outfall site will progress much more rapidly and may aid in the growth and downstream migration of this meander bend.

6. Alternatives to Gravel Bar Growth and Sedimentation

Stillwater Sciences (2001) recommended 5 alternatives: 1) dredging of the bar, 2) cutting a channel through the bar, 3) dredging the bar and armoring the west bank across from the site, 4) excavate/dredge the bar and install spur dikes on the west bank, and 5) redesign or replace the facilities.

6.1. Bar Excavation/Dredging and Right Bank Armoring Alternatives

It is unlikely that the first three alternatives proposed by Stillwater Sciences (2001) will provide a long-term solution to problems at the outfall associated with the gravel bar growth and sedimentation and meander migration. Dredging the bar or a pilot channel through the bar is only a temporary solution because there is sufficient upstream sediment available for transport into the reach such that the dredged area will likely become silted back in during the next major flow event.

Bank protection will also be relatively ineffective. Bank protection in high radius bends, such as this bend, is inadequate because of the relatively flat meander bend geometry and the excessive length of revetment required. In addition, the right (west) bank in the downstream limb is part of a point bar for another meander bend located just downstream at about RM 192.5. Therefore, the design and construction of the revetment would require that it be placed in a relatively straight line along the right bank and would need to be wrapped to the west once it extends down to the point bar of the bend at RM 192.5. Since the revetment would wrap back into the inland portion of the RM 192.5 bend, the existing alignment of the flow would remain relatively unchanged. Therefore, even though the revetment could effectively halt the westward development of the Bidwell River Park bend, the downstream migration of the Bidwell River Park gravel bar would not be impeded.

6.2. Spur Dike and Bar Excavation/Dredging Alternative

Stillwater Sciences (2001) recommended the use of spur dikes placed along the right bank across from the bar and excavation/dredging of the gravel bar. The placement of spur dikes along the right bank was further evaluated in a report submitted by the Ducks Unlimited panel of experts (Harvey et al., 2004).

Spur dikes could be used to deflect flow away from the right (west) bank of the river across from the park and redirect flow toward the gravel bar and the left bank. However, since the dikes would need to be able to direct a significant proportion of the flow away from the right bank, they would need to be of sufficient length to effectively move the thalweg back toward the middle of the river to assist in maintaining or reducing the current size and location of the existing bar, and sufficiently engineered to withstand the impacts of large flows including scour and potential flanking. They should be angled perpendicular to the bank or the general direction of flow or even slightly upstream. The riverward ends should be aligned along a common tangential line that defines the proposed flow path so that a smooth flow transition exists between dikes. The ends should be keyed into the bank and the dikes should slope gently riverward. The volume of riprap in the riverward ends should be sufficient to accommodate scour without reducing the stability of the dike. Design guidelines can be found in Brown (1985), Klingeman et al. (1984), and Lagasse et al. (2003). Because of the size requirements for the dikes, environmental mitigation could also be a significant factor in the decision to install these structures.

One issue of concern is how the dikes will affect the left bank at the park upstream of the bar. It is likely that the erosion of the left bank at and upstream of the park could be accelerated and that the riparian land and forest in that area could be lost over time as a result of erosion associated with the dike field. If this were to occur, there could be potential liability issues regarding the loss of park land and riparian habitat. Thus, the need for bank protection along the left bank across from and just upstream of the dike field.

6.3. Pilot Channel, Bar Relocation, and Outfall Relocation Alternatives

Other alternatives that may prove to be effective in halting or countering the growth of the gravel bar at Bidwell River Park and sedimentation at the outfall diffuser include shifting the gravel bar to the opposite bank, installation of a pilot channel between the river and Big Chico Creek through the riparian land of the park, and moving the outfall structure further downstream.

The relocated gravel bar alternative would require that the gravel bar be excavated from its current location and placed along the opposite bank, effectively extending the head of the point bar of the bend at RM 192.5 further upstream. In addition, the remaining left (east) bank along the river park should be reshaped for a better flow transition through the reach. The right (west) bank should also be riprapped to hold the bank in place and two or three short spur dikes should be placed on the right bank just upstream of the head of the bar to assist in maintaining the flow alignment. This would result in a new bend geometry that has the point bar along the right (west) bank and the outside of the bend and bend apex located at or near the existing outfall. **Figure 8** provides a conceptual representation of this alternative.

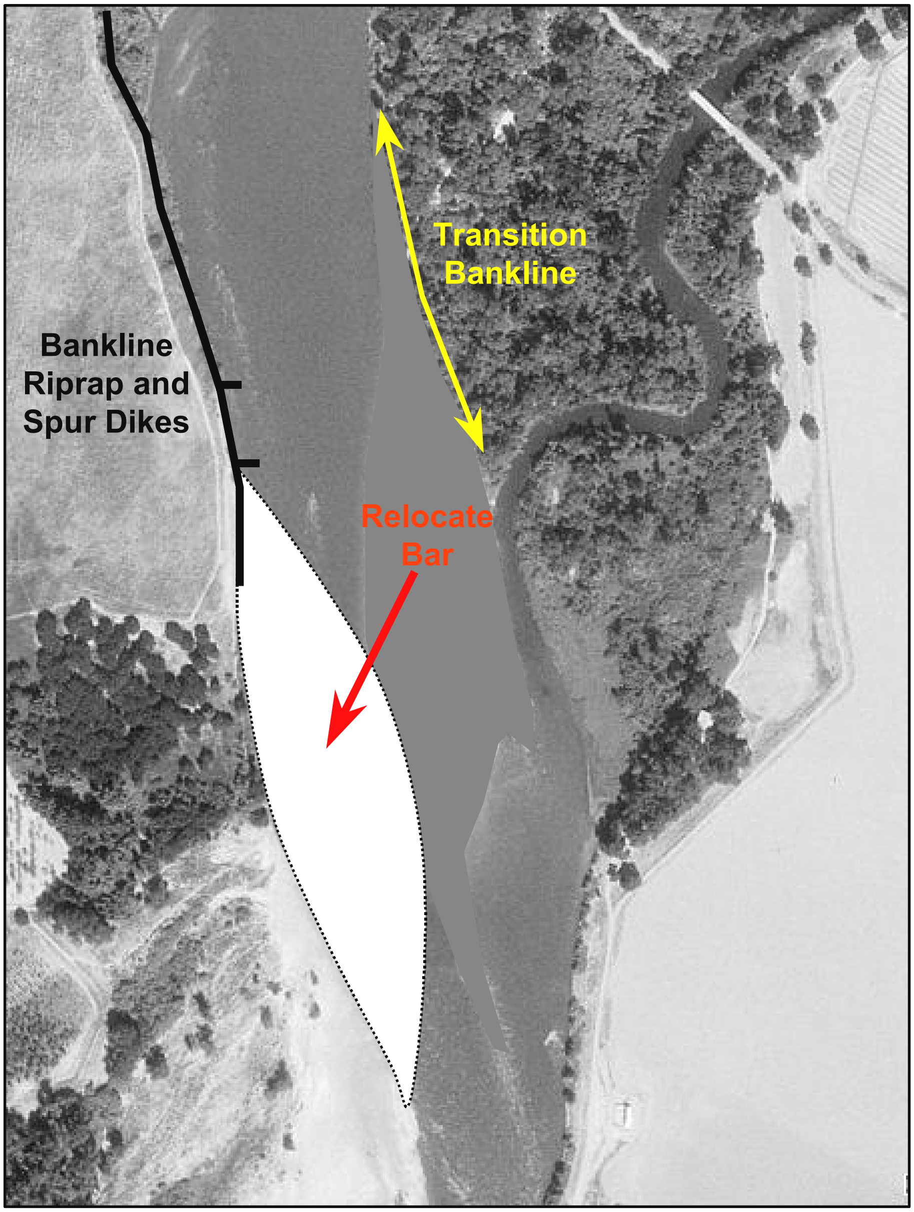

Figure 8. Aerial photo (1998) showing the conceptual view of the alternative requiring the relocation of the Bidwell River Park gravel bar to the opposite side of the river, reshaping of the left bankline upstream of the existing bar location, and the approximate extent of the proposed right bank riprap and spur dikes.

The pilot channel alternative would require that a channel be excavated through the riparian land of the park from the left bank of the river at a point just upstream of the head of the gravel bar and extending inland to intersect Big Chico Creek. The channel should be sufficiently large to convey a significant amount of flow from the river into the creek as well as remain relatively clear of debris and sediment. This should result in a constant flow passing through the mouth of Big Chico Creek and keep sediment from filling in along the left (east) bank of the river at the structures, as long as the confluence of the creek remains along the bankline. **Figure 9** provides a conceptual representation of this alternative.

6.4. Outfall Redesign/Replacement and Relocation Alternatives

The fifth alternative proposed by Stillwater Sciences (2001) requires the redesign or replacement of the wastewater outfall facilities to counter the impacts of the downstream migration of the gravel bar and concomitant sedimentation. This may require that a flexible or movable outfall or an outfall with multiple diffuser locations be installed at an optimal location in the river.

Moving the outfall position downstream can be accomplished two ways: 1) relocating the entire outfall and wastewater line to a new position downstream or 2) constructing an extension from the existing outfall along the bankline in a downstream direction. Relocation of the outfall structure to a new position on the left bank somewhere between 1,200 and 1,500 feet downstream would be an effective alternative. The relocation point is situated on the outer bank of the well developed meander bend at RM 192.5. The bank at this location is composed of erosion resistant material overlain by riprap and is on the opposite side of the river from the bend's point bar. Although the bend will continue to migrate downstream, it is not likely that sedimentation along the left bank at this location will occur for at least 15 to 20 years based on the average downstream migration rate of the bar over the studied 26-year period of record. The alternative location for the wastewater outfall diffuser is shown in **Figure 10**.

Relocation of the outfall could also be conducted without relocating the existing outfall line. This can be accomplished by driving pilings along the toe of the left bank at regularly spaced intervals downstream of the present outfall location, installing an elbow at the bankline, and installing extensions as necessary along the bankline. The use of gradually sloping extensions and movable diffuser provides flexibility to the outfall if the growth and downstream migration of the upstream bar persists and siltation at the current location occurs in the future. **Figure 11** represents a conceptualization of the pipeline extensions and movable diffuser.

Given that the existing diffuser location was about 350 feet from the downstream end of the bar in 2002, the bar would probably reach the current location of the diffuser by or before 2007 (based on migration rate of 78 and 92 ft/yr, respectively). Therefore, the diffuser would probably need to be moved to a location between 450 and 750 feet downstream from its current location by 2007. These locations represent life spans of 5 and 8 years, respectively based on the average migration rate of the bar. Since the costs of moving the diffuser is greater for the 5-year life span versus the 8-year life span, it is recommended that the moveable diffuser be placed 750 feet downstream from its current location and be moved downstream an additional 750 feet downstream if and when it becomes necessary. If the average migration rate is closer to the 78 ft/yr based on the 1976 to 1998 period, then the life span of the moveable diffuser at a point 750 feet downstream from its current position would be longer (about 13 years after 2007).

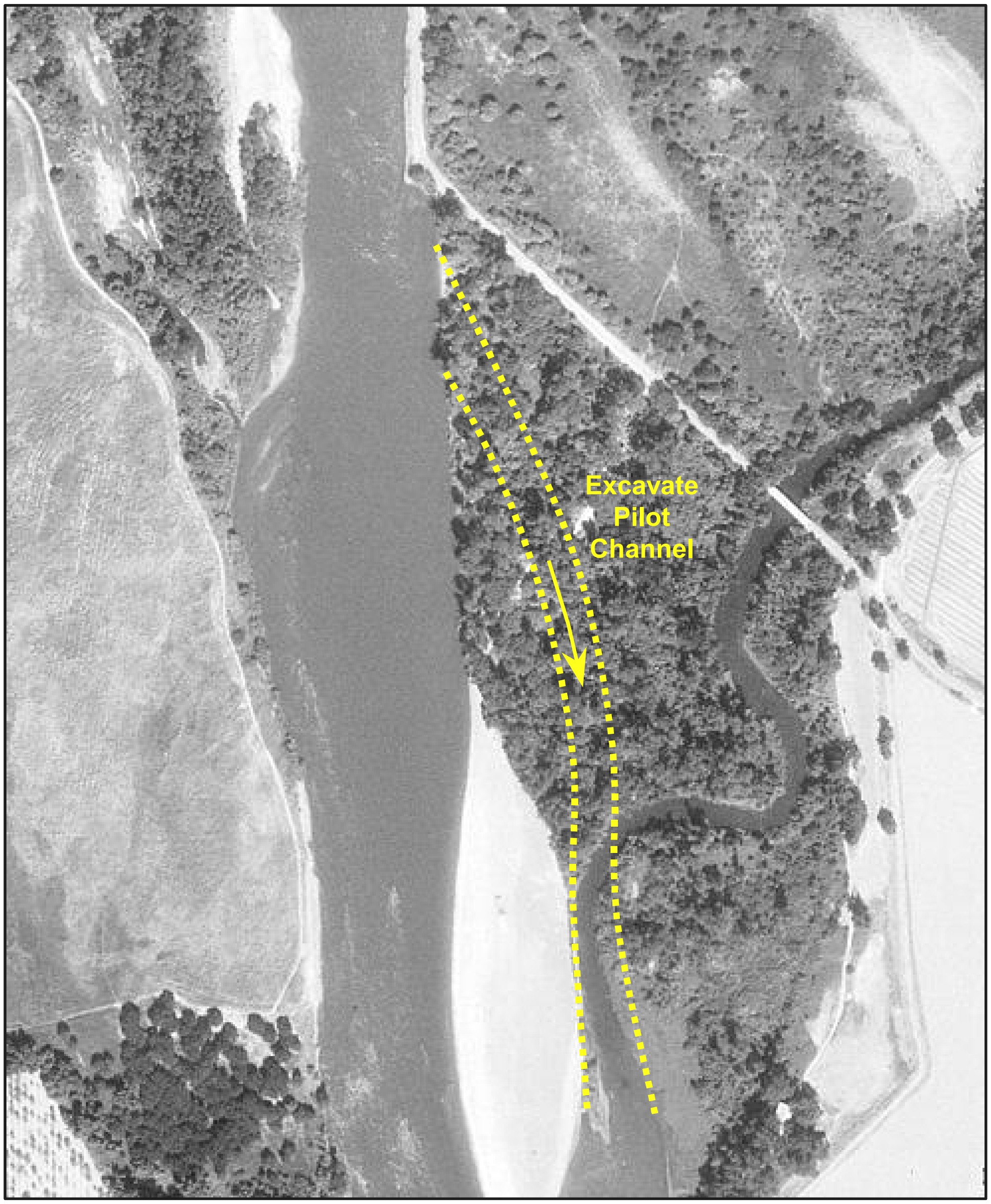

Figure 9. Aerial photo (1998) showing the conceptual view of the pilot channel alternative that will be used to divert flow from the Sacramento River into the confluence of Big Chico Creek through the riparian land of Bidwell River Park.

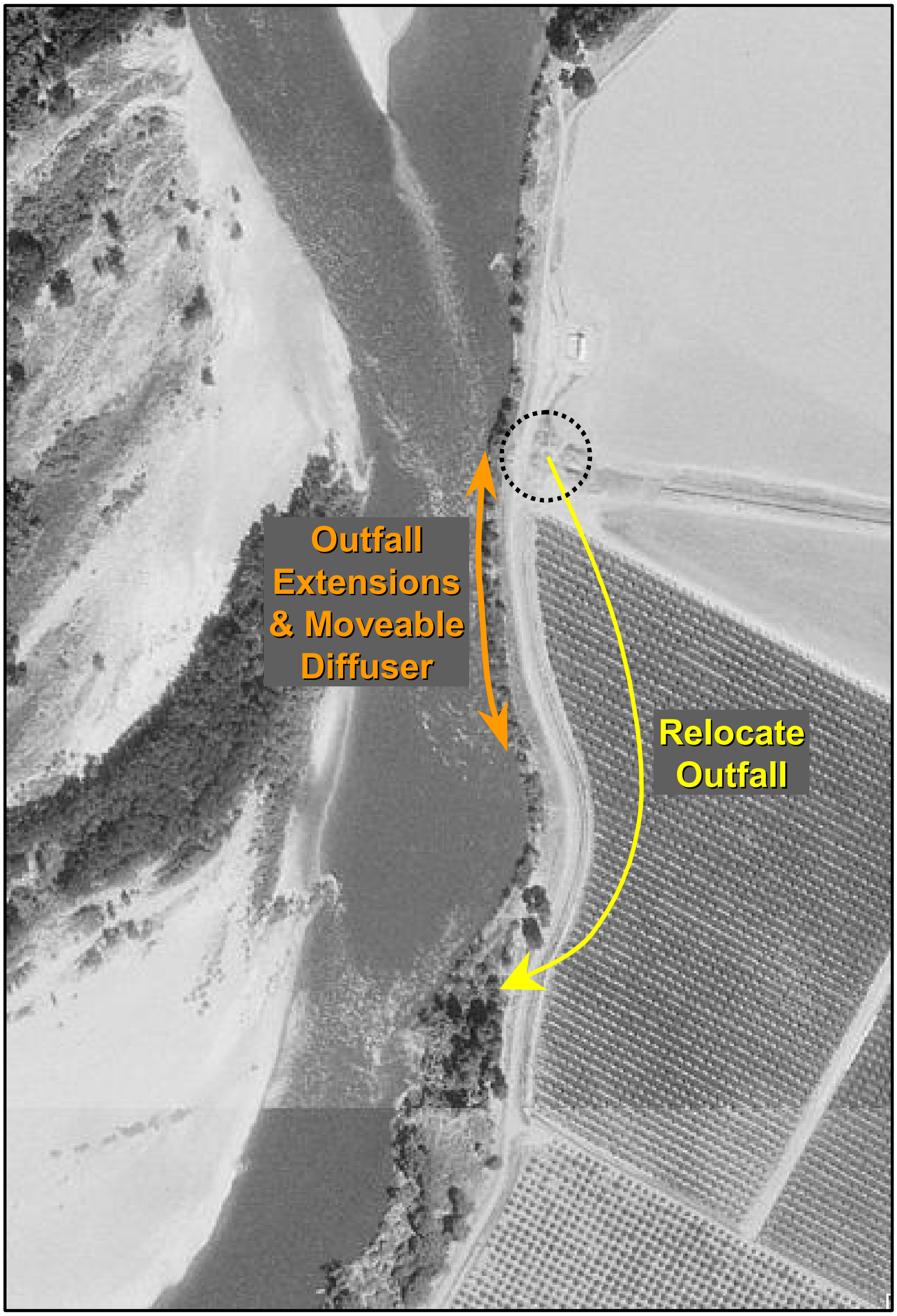

Figure 10. Aerial photo (1998) showing (a) the alternative requiring relocation of the existing wastewater outfall structure to a point on the left bank a minimum of 1,200 feet (or up to 1,500 feet) downstream of the existing site and (b) the alternative requiring the use of pipeline extensions and a moveable diffuser.

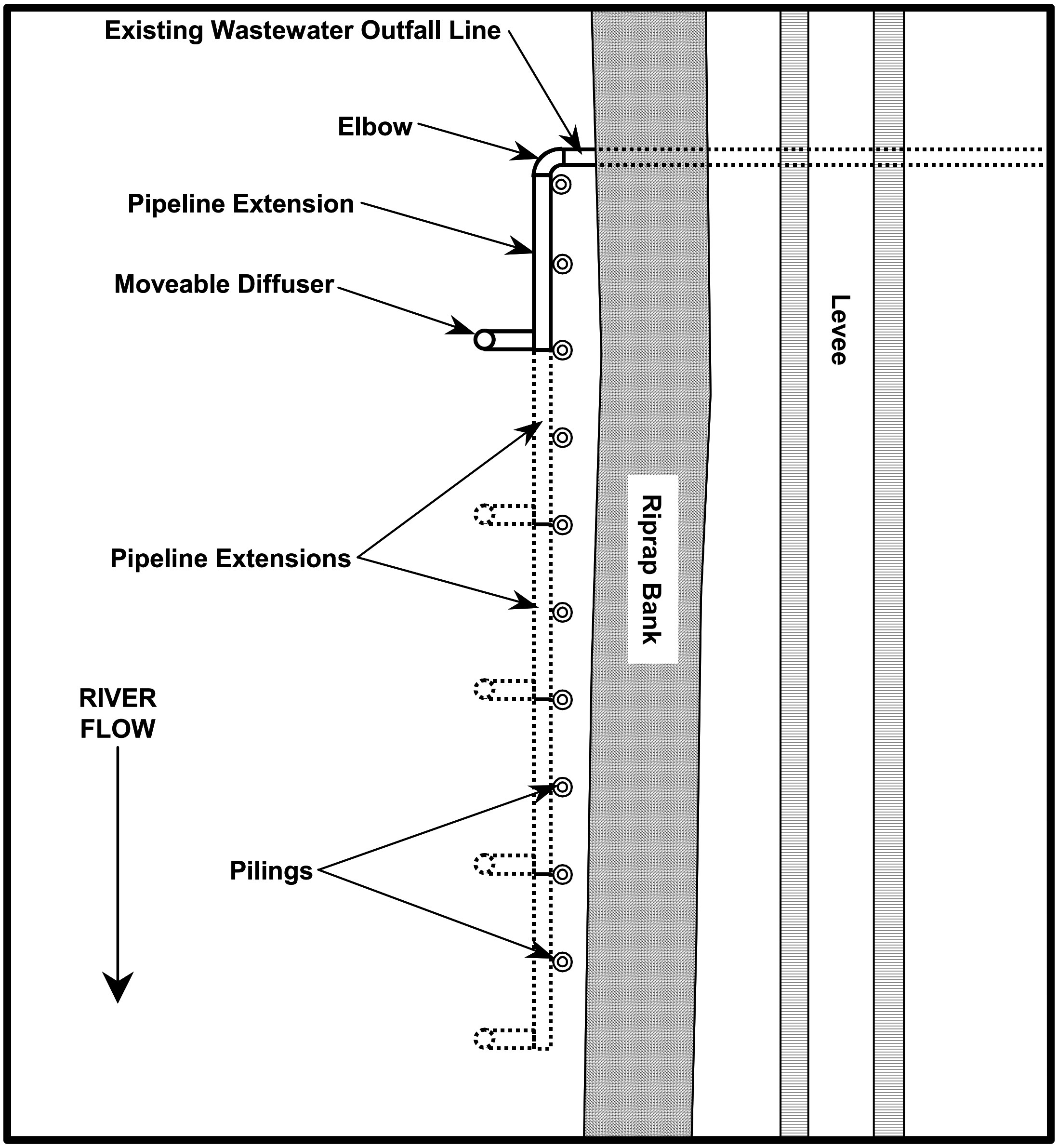

Figure 11. Conceptual plan view showing the alternative requiring the use of pipeline extensions and a moveable diffuser.

It appears, based on design parameters provided by Flow Science (2004), that the diffuser would have to be placed well into the channel and perpendicular to flow for adequate dilution. The designs for the existing diffuser, which are proposed for the moveable diffuser, call for a buried diffuser pipe with risers that extend 3.5 feet above the channel bed. Since the diffuser pipe is a 42-inch (3.5 feet) diameter pipe, it could also be placed on the channel bed as long as the ports do not extend significantly above the pipe. With regard to being a potential navigation hazard, the diffuser pipe, risers, and ports should not project upward into flow such that there is less than 6 feet of water depth above the top of the structure during the mean annual low flow.

Design specifications indicate that the risers only extend about 3.5 to 4 feet above the bed and the average flow depth in the reach where the relocated diffuser will be placed is 15 to 20 feet. Under these conditions, one would not expect debris loading to be a problem, even during periods of extremely low flow when most large debris will be grounded anyway. However, the diffuser at its current location has been subject to debris loading and, therefore, the relocated diffuser could also be subject to debris loading. The time of greatest threat will be during the recession of flood flows when large floating debris will begin grounding itself not just along the banks, but also in the river.

7. Recommendations

It was initially believed that the relocation of the outfall using pipeline extensions and a moveable diffuser was the preferred alternative because of the flexibility provided and the potentially lower cost. It was thought that the moveable diffuser would be much cheaper, but based on the cost estimates provided by Carollo Engineers (2004), it appears that the diffuser, risers, and ports would have the same configuration they have now; that is, they would be placed out into the river and anchored to or buried in the bed of the river perpendicular to flow. It was assumed that the diffuser could be placed along the bankline and attached to the pipeline extensions with a removable coupling. If the present configuration is the one that would be used under the moveable diffuser alternative, then the moveable diffuser alternative is probably not a viable alternative since it would have nearly the same configuration as just relocating the existing diffuser downstream. Preliminary cost estimates prepared by Carollo Engineers (2004) for the various alternatives indicate that the costs associated with this alternative are greater than or comparable to the outfall relocation and spur dike alternatives.

Regardless, the costs for the moveable diffuser are significantly higher than expected leaving two other possible alternatives for further consideration. One is to construct a series of dikes, as recommended to Ducks Unlimited by Harvey et al. (2004), which would be installed along the right bank from RM 193.0 to RM 193.5, and the other alternative is to relocate the diffuser a minimum of 1,200 feet downstream (possibly up to 1,500 feet downstream).

Since the dike field alternative would benefit both the City's effluent outfall and the M&T Chico Ranch/Llano Seco Ranch and Wildlife Refuge pumping facility intake, the potential for cost sharing makes the dike field alternative more attractive for the City of Chico. We would recommend this alternative only if both groups agreed to share the costs and risks. However, the total cost associated with the dike field alternative should be increased to include future maintenance costs. We also think that the cost should include stabilization of the left bank upstream of the Bidwell Park bar to protect the remaining riparian land that exists there.

It should also be noted that any alternative that requires modification of the right bank across from the outfall may be significantly impacted by the current Corps of Engineers efforts to set back the levee in the reach downstream of the Hamilton City Bridge. The Sacramento District

Corps of Engineers should be consulted regarding this issue because overbank flow depths and/or velocities may significantly increase in the area where the dikes are planned and return flood flows could have a major impact on the stability of the proposed dikes.

Given the above limitations and uncertainties associated with the dike field alternative, our recommendation is for the City of Chico to relocate the outfall structure a minimum of 1,200 feet downstream of its current location as described in Section 6.4.

8. References

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