1. INTRODUCTION

1.1 Purpose and Project Background

The purpose of this investigation is to provide foundation information and technical documentation for determining the feasibility and preliminary construction cost of relocating the "J"-Levee on the Sacramento River adjacent to Hamilton City, California.

The "J"-Levee was originally constructed around 1904 by the Holly Sugar Company to protect their processing facilities in Hamilton City (DWR, 2000). Subsequent growth and higher intensity land use has made flood control for the surrounding area an important issue. Flood fighting to prevent levee overtopping and foundation piping failures has become common during the high flow events of recent history.

With the emphasis on combining the benefits of flood control and environmental restoration, Ayres Associates was requested to investigate the feasibility of relocating the "J" Levee away from the rivers edge. One of the goals of this investigation was to locate sound geologic control in the foundation where seepage, piping and bank erosion problems would be less problematic. Locating better foundation conditions would lower construction costs and reduce the potential for foundation seepage and piping failures. The hypothetical setback levee alignment is shown in **Figure 1**.

The components of this investigation included 18 foundation borings, bulk soil sampling, laboratory soil testing, slope stability analysis, seepage analysis, conceptual levee design and a preliminary construction cost estimates.

1.2 Authorization and Project Team

This geotechnical investigation was authorized by the Sacramento River Projects Office of The Nature Conservancy (TNC) in Chico, California. The Sacramento office of Ayres Associates performed the foundation investigation and technical analysis with assistance from the Fort Collins, Colorado office for the seepage analysis. Taber Consultants, of West Sacramento, was used for foundation drilling, soil sampling and laboratory testing.

Figure 1.

Location Map

2. REGIONAL GEOLOGY

A regional geology map of the project area is shown in **Figure 2** and a brief description of the mapping units used in this figure is as follows:

- STREAM CHANNEL DEPOSITS – Qsc

Deposits of open, active stream channels without permanent vegetation. These deposits are transported under modern hydrologic conditions, consequently they are light tan and gray, unweathered, and usually in contact with modern surface waters. The depth of these deposits may reach 25 m in the Sacramento River, or be less than a few centimeters in bedrock canyons.

Note: Qhm, Qhms, and Qmb are subsets of Qsc.

Qhm - Historic meander belt

Qhms - Historic meander belt, evidence of scrolling

Qmb - 100 year meander belt

- ALLUVIUM - Qa

Unweathered gravel, sand, and silt deposited by present day stream and river systems. Differentiated from older stream channel deposits by position in modern channels. The deposits form levees along the main course of the Sacramento River.

- MODESTO FORMATION - Qm

Unconsolidated, slightly weathered gravel, sand, silt and clay. It forms alluvial fans along the main channel of the Sacramento River and large levees bordering the Sacramento River from Stony Creek to the Sutter Buttes. Soils from this formation are marked by a noticeable increase in silt content and a distinct red color.

Based on our field observations at exposed Modesto Formation locations along the river, this formation is considered to be more competent as a levee foundation material than the sands and gravels within the young river alluvium and it is also known to be more erosion resistant. This generalized map was used to lay out a hypothetical location for a setback levee within the Modesto Formation and the proposed locations of the foundation soil borings.

Figure 2.

Regional Geology Map

3. FOUNDATION INVESTIGATION

The foundation investigation portion of this project consisted of drilling 18 soil borings, varying from 16.5 feet to 46.5 feet deep. Eight of the borings were located in the existing levee and 10 were located in areas west of the existing levee. The borings were designated SB-1 through SB-18 and the approximate location of each is shown in **Figure 3**. The final location of each soil boring was determined by Ayres Associates at the time of the investigation. The logging of each boring was also performed by Ayres Associates. Standard penetration testing (SPT) was performed at 5-foot intervals to obtain soil samples and measure penetration resistance. The blow counts from the SPT's were recorded and the corresponding "N" values (blow count for 12 inches of penetration) for each test are included in the boring logs in **Appendix 2**. The soil samples from the investigation were packaged for subsequent laboratory testing.

Drilling was performed by Taber Consultants using a CME-45 drill rig during the period of October 23 to 25, 2000. A hollow stem flight auger system was used to advance the soil borings and standard penetration tests were performed using the procedures in ASTM Standard D 1586. Photographs of the drill rig and the sampling procedure through the hollow stem auger are shown in **Figure 4**.

Borings SB-7 through SB-9, SB-12 through SB-14, SB-17 and SB-18 were drilled into the existing levee. The primary purpose of these borings was to determine the soil material types and the suitability as a borrow source for a new levee. The remaining ten borings, SB-1 through SB-6, SB-10, SB-11, SB-15 and SB-16 were taken near the alignment of the hypothetical setback levee, or further west, to locate geologic control. The depth to groundwater was measured in each boring if encountered.

The detailed logs for the soil borings are included in **Appendix 2**.

4. LABORATORY SOIL TESTING

Laboratory testing was performed to verify the field classification of soils and to determine the physical characteristics of selected soil types.

Figure 3

Boring Location Map

Figure 4

Photographs of Geotechnical Drilling

Samples are identified by the boring number, followed by a consecutive number for each sample taken in that boring. The final determination on which samples to test was made by Ayres Associates. Since many samples were of similar types of materials, not all were tested. Taber Consultants performed the laboratory testing of the soil samples. The test results and the individual laboratory data sheets are included in **Appendix 3**.

Table 1 lists the samples tested, depth of sample, the unified soil classification system designation, along with liquid limit, plastic limit and plasticity index, when applicable.

Table 1
Laboratory Soil Test Results

Sample No.	Depth (ft)	U.S.C.S. Classification	Liquid Limit	Plastic Limit	Plasticity Index
SB3-1	1.0-3.0	CL	30	21	9
SB3-2	15.0-16.5	ML	26	22	4
SB3-3	21.0-26.5	SP	N.P.	N.P.	N.P.
SB5-1	20.0-21.5	ML	28	22	6
SB5-4	30.0-31.5	GW	N.P.	N.P.	N.P.
SB5-5	35.5-41.5	GW	N.P.	N.P.	N.P.
SB6-1	1.0-10.0	CL	31	16	15
SB8-1	5.0-6.5	CL	35	22	13
SB10-1	26.0-26.5	ML	25	22	3
SB11-1	35.0-36.5	GW	N.P.	N.P.	N.P.
SB14-1	5.0-6.5	ML	22	N.P.	N.P.
SB15-1	15.0-16.5	CL	32	20	12
SB16-1	20.0-21.5	SP	N.P.	N.P.	N.P.
SB16-2	25.5-26.5	GW	N.P.	N.P.	N.P.
SB17-1	10.0-11.5	CL	32	22	10
SB18-1	10.0-11.5	CL	32	20	12

N.P. Non-Plastic

5. DISCUSSION OF FOUNDATION CONDITIONS

Figures 6 through **9**, located in **Appendix 1**, show the boring logs superimposed on foundation cross sections and profiles. A general discussion of each is as follows:

Figure 6 shows a generalized cross section of the foundation parallel to County Road 23. Soil borings SB–1 through SB-3 were drilled along this cross section within the mapped stream channel deposits formation (Qhm). These borings show a general pattern of 10 to 12 feet of fine-grained overburden, mostly silty clays (CL) and sandy silts (ML), on top of layers of highly permeable sands (SP) and gravels (GP) extending deep into the foundation. These sandy and gravelly materials are highly permeable and very erosive to flow when exposed to the river. This pattern is consistent with stream channel deposits.

Boring SB-4 was drilled in an area mapped as Modesto Formation (Qm). However, from the field investigation and the laboratory testing, the foundation materials at this location were found to have very similar characteristics to SB-1 through SB-3. The distinguishing characteristics of the Modesto Formation (higher content of fine-grained materials and red color) were not present.

Figure 7 is a foundation cross section taken perpendicular to the Sacramento River along soil borings SB–5 through SB-7. The fine grained overburden layer is somewhat thicker in borings SB-6 and SB-7 when compared with the borings in **Figure 6**. The overburden depth is approximately 25 feet in this area, consisting mostly of silty clays (CL), sandy silts (ML) and silty sands (SM). The lower foundation layers consist of highly permeable gravelly sands, (SP) and sandy gravels (GP) similar to the previous cross section. SB-7 was drilled through the existing levee and showed layers of silty and clayey materials consistent with a layered construction pattern within the embankment portion of the boring. Sands and gravels were encountered in the foundation relatively close (approximately 5 feet) to the natural ground surface. SB-5 and SB-6 were drilled in an area mapped as Modesto Formation. Both borings showed similar characteristics with a much thicker layer of fine-grained overburden, however, we cannot say with certainty that this is Modesto Formation. Seepage and foundation conditions are much better at this location than those exhibited in SB-7 which is located in the recent alluvium closer to the river.

Figure 8 shows a profile along the northern portion of the hypothetical setback levee as shown in **Figure 1** using borings SB-9, SB-10, SB-11, SB-15, SB-17 and SB-18. A similar pattern consisting of a fine grained overburden layer, primarily silty clays (CL) and silty sands (SM), covering coarse-grained sands (SP) and gravels (GP and GW) was found. The thickness of the overburden layer increases in this reach of the hypothetical setback levee and is approximately 30 feet thick in the borings SB-10, -11, and –15. Based on the regional geology map, Modesto formation was expected in SB-9, -10, -11, -15 and –16, but once again obvious signs were not observed during the drilling. Based upon a later field review and discussion with Koll Buer, Chief, Geology Section, DWR, Red Bluff, (September 24, 2001) there are physical sign of Modesto formation from the north end of the levee location, south through SB-10. While the boring showed significant amounts of sand and gravel at depth, this is not uncharacteristic of the Modesto. The Modesto can contain layers of cemented sands and gravels, but the drilling and sampling process can disturb the cementation to where it is not recognizable when recovered from the auger or sampler. Boring SB-18 encountered significant fine-grained materials throughout the boring and appears to be a more obvious representation of the fine grained portions of the Modesto formation.

Figure 9 shows a continuation of the profile through the southern portion of the hypothetical setback levee using borings SB-3 and SB-6. These boring have been previously described and in general show the same pattern shown in **Figure 6** and **7**.

6. DISCUSSION OF EXISTING LEVEE AS A BORROW SOURCE

Soil borings SB-7 through SB-9 and SB-12 through SB-14 were used to investigate the existing levee soil materials for their suitability as a borrow source for a new levee. The soil borings and testing showed that the existing levee is composed mainly of silty clays (CL), silts (ML) and some silty sands (SM). The logs show that much of the existing levee contains materials suitable for levee borrow, especially the clays (CL) and some of the higher plasticity, clayey silts (ML). The SM materials may need to be discarded. Some further testing will be required during the design phase to determine the exact amount and borrow locations. At the present, our best estimate is that approximately half of the existing materials will be suitable as borrow for a new levee.

Additional borrow material is available from the G.C.I.D. canal spoil piles located just west of Highway 45. This material has been tested by the G.C.I.D. and is well suited for levee construction. The G.C.I.D. has made a verbal commitment to make this material available for use if any additional borrow materials are needed for levee construction. (G.C.I.D., 2000)

7. PRELIMINARY DESIGN CONCEPT FOR HYPOTHETICAL SETBACK LEVEE

The US Army, Corps of Engineers standards were used as a basis of design for the hypothetical setback levee. Since no published water surface elevations are currently available for the 100-year runoff event at Hamilton City, we estimated that an average of 5 feet of additional height will be necessary to bring the existing levee height up to flood control standards. For estimating purposes, we have assumed that the hypothetical setback levee will have an average height of 15 feet, throughout. **Figure 5** shows this conceptual design configuration. This design was used for our slope stability and seepage analyses as well as for quantities in preparing the construction cost estimate. The preliminary dimensions of the hypothetical setback levee include a top width of 20 feet and side slopes of 2:1 landside, and 3:1 waterside.

8. LEVEE SLOPE STABILITY ANALYSIS

A slope stability analysis was performed for the hypothetical setback levee. The computer program PCSTABL5 (Siegel, 1978) was used to perform the computations. Average strength parameters were estimated using a similar Corps of Engineers' project on the Sacramento River at River Mile 149.0 (Ayres, 2000). Guidance on the required cases for analysis was taken from EM 1110-2-1913 (Corps of Engineers, 1978). For these required cases, the total stress parameters governed and were used for shear strength values in each case.

Figure 5

The cases analyzed and the resulting safety factors are summarized in **Table 2**. The rapid drawdown case includes saturation of the entire foundation and levee up to the design high water surface, with the actual water level in the river at the summer low flow level. The low flow, steady seepage, case includes the river level at the summer low flow and the foundation saturated to that same level. The bankfull flow, steady seepage, case includes the river level at the design high water surface with a saturated foundation and levee. The landside, bankfull, steady seepage, case was performed with the same flow and saturation levels as the bankfull case.

Table 2
Safety Factors for Slope Stability Cases Analyzed for Typical Levee Cross Section

Design Condition	Corps of Engineers Required Safety Factor	Computed Safety Factor
Rapid Drawdown	1.25	1.26
Low Flow Steady Seepage	1.5	1.61
Bankfull Flow Steady Seepage	1.5	1.98
Landside – Bankfull Steady Seepage	1.5	2.87

Slope stability plots for each cross section and the critical failure circle for that site are included in **Appendix 4**. The delineation of each soil layer and the strength parameters are also included in this appendix.

9. LEVEE SEEPAGE AND FLOWNET ANALYSIS

9.1 General

A preliminary seepage and flownet analysis was performed for the hypothetical setback levee. The vertical (exit) seepage gradient at the landward toe of the hypothetical setback levee was determined for the estimated 100-year flood flow in the Sacramento River. The method of analysis, data sources, analysis results, and summary of this investigation are provided in the following sections.

9.2 Method of Analysis

The computer model used for this analysis was the Prickett-Lonnquist Aquifer Simulation Model (PLASM). PLASM is a 2-dimensional, finite difference numerical groundwater model capable of simulating steady state or transient flow in heterogeneous aquifers under water table, leaky, or confined conditions (Prickett and Lonnquist 1971). The model was set up as a vertical cross-sectional representation in order to quantify vertical (exit) seepage gradient in the vicinity of the landward levee toe under estimated 100-year flood event conditions.

Data from field borings were incorporated directly into the model through the construction of a vertical section, which represents average stratigraphic variations in the subsurface deposits. Two generalized foundation configurations were analyzed. The first configuration included a 10-foot thick overburden layer of fine-grained soils covering a highly permeable, sand and gravel foundation. The other configuration included a 30-foot thick overburden layer over the highly permeable sands and gravels. **Figure 10** in **Appendix 5** shows the configuration used for 10 feet of overburden consistent with Run 1 in **Table 4**.

The MODELCAD graphical pre-processor (Geraghty and Miller 1991) was used to assign values of saturated hydraulic conductivity into each finite difference grid cell during the model setup. The vertical grid dimension was set at one-meter increments with a 125-foot total modeled thickness to include the levee and foundation soils. In the horizontal direction, grid cells ranged from 0.5 to 50 meters in width, utilizing smaller cells for finer spatial resolution near the levee for a total width of approximately 1600-feet.

Aquifer hydraulic properties associated with three different soil material types (including the remolded levee material) were entered into grid cells according to the reported depths and thickness from soil borings drilled at the site. The upper foundation soil thickness was modeled at 10 and 30 feet based on the information from the soil borings. The total depth of the sand/gravel layer (from the ground surface) was estimated to be approximately 90 feet based on information in local well logs. Values of hydraulic conductivity used in the model are provided in **Table 3**. The values for the levee soil and upper foundation layers were estimated from a previous Corps of Engineers levee project on the Sacramento River at RM 149.0R (Ayres, 2000). The value for the sand/gravel foundation layer was based on a soil sample gradation from SB-11-1 using the Fair-Hatch formula (Fair and Hatch, 1933).

Boundary conditions on the waterside of the levee consisted of constant head cells located at the land-water interface. Hydraulic head values corresponding to the estimated 100-year flood stage were assigned to the constant head cells. The landside of the levee, constant head boundary cells at the land-air interface were assigned a value equal to the elevation of the land surface. Use of this type of boundary condition is conservative because it assumes that no concurrent flooding occurs outside the levee, and that accumulated seepage flows beneath or through the levee during times of flooding in the river are allowed to drain away freely. In this manner, a total head differential of 7.9 feet is maintained across the levee throughout the course of the groundwater simulation. Simulations were run until the model established steady-state groundwater flow conditions.

Table 3
Hydraulic Properties of Levee and Foundation Soil Types

Soil Type Number	Description	Hydraulic Conductivity (cm/sec)
1	Remolded Levee Soil (95% compaction)	Est. 1.0×10^{-6}
2	Upper Foundation Layer (ML)	Est. 1.0×10^{-6}
3	Sand Layer (SP)	2.5×10^{-1}

9.3 Analysis Results

PLASM modeling determined that the vertical seepage gradient near the landward toe of the setback levee during a 100-year flow event would be greater than the allowable gradient of 0.30 m/m as set forth by the Corps criteria (US Army, 1978), for overburden thickness of 30-feet. Additional models were developed to test the sensitivity of the estimated hydraulic conductivity values and the effectiveness of a slurry wall and a toe drain in reducing the vertical seepage gradient. **Table 4** contains a summary of the PLASM simulation output with a description of the changes made to the base model in the comment column.

Table 4
Summary of Seepage and Flownet Simulations

Run	Model Name	Total Seepage (gpm/mile)	Max. Uplift Gradient (m/m)	Avg. Uplift Gradient (m/m)	Comments
1	JLEVEE	96	0.90	0.89	base model with 10 feet of clay (CL) upper foundation layer
2	JLEVEE30	33	0.33	0.29	base model with 30 feet of clay (CL) upper foundation layer
3	HIGHK30	329	0.40	0.29	30 feet CL; clay conductivity increased to 1.0 x 10^{-5} cm/s
4	LOSAND30	33	0.33	0.29	30 feet CL; sand conductivity decreased to 2.5 x 10^{-2} cm/s
5	LOHIGH30	274	0.38	0.28	30 feet CL conductivity = 1.0 x 1 0^{-5} cm/s sand conductivity = 2.5 x 10^{-2} cm/s
6	SLURRY40	96	0.90	0.89	10 ft CL; slurry wall 40 feet below riverward toe
7	SLURRY50	96	0.90	0.89	10 ft CL; slurry wall 50 feet below riverward toe
8	SLURRYAL	12	0.12	0.11	10 ft CL; slurry wall fully penetrating sand layer
9	TOEDRAIN	186	1.13	0.86	10 ft CL; toe drain placed in clay layer; 92 gpm/mile out toe drain
10	DRAINAL	58,000	0.38	0.21	3 m CL; toe drain hydraulically connected to sand layer; 58,000 gpm/mile out toe drain

A partially penetrating slurry wall or a toe drain was ineffective due to the very large difference between the hydraulic conductivity in the upper foundation layer in relation to the underlying sand layer. This large difference in hydraulic conductivity resulted in most of the head loss occurring in the upper clay soil (i.e. there is very little head loss in the sand layer) during the steady state condition. Only when a slurry wall fully penetrated the sand layer did the vertical seepage gradient fall below the requirement as can be seen from the values in **Table 4**.

However, we need to point out that the vertical seepage gradients derived from PLASM modeling are very conservative because they are based on the assumption that steady state groundwater flow conditions will be reached during peak flood stage in the river. In reality, the response to the additional head induced on the groundwater flow system by the elevated water surface in the river is time-dependent. In addition, the flood stage itself is time-dependent. This time factor for both the flood stage and the groundwater flow system can limit the magnitude of the vertical seepage gradient at the landward toe of the levee. We have also assumed a conservative value for hydraulic conductivity of the foundation and assumed the sand/gravel layers to be uniform while in fact there are many layers with differing values of hydraulic conductivity.

9.4 Discussion of Results

The modeling results show that mitigation measures will most likely be required to stabilize the foundation material near the landward toe of the setback levee due to the elevated vertical (exit) seepage gradients where the overburden layer is less than 30 ft. Also due to the very large difference between the hydraulic conductivity in the upper foundation layer with respect to the underlying sand layer assumed for this preliminary analysis, land side drainage mitigation measures were not effective when steady-state conditions were modeled.

Based on this conservative preliminary analysis, Ayres assumed that a slurry wall would be required when the fine grained overburden layer is less than 30 feet.

10. PRELIMINARY CONSTRUCTION COST ESTIMATES

10.1 Basis of Cost Estimating

A preliminary construction cost estimate has been prepared for the hypothetical setback levee along the alignment shown in **Figure 1** using the configuration shown in **Figure 5**. This new levee configuration is based upon our best estimate of the 100-year water surface plus 5 feet of freeboard. The final height of the levee will need to be set by a detailed hydraulic analysis of the project flood conditions.

Unit prices for the various construction elements were estimated from similar projects along the Sacramento River. A contingency of 25 percent was added to the total cost to account for uncertainties since the quantities are based upon a preliminary design concept.

The construction costs for this levee reflect the most likely construction methods based upon our past experience of similar projects on the Sacramento River. A brief description for major items of work is presented as follows:

a. Clearing and Grubbing. This item includes site preparation and the removal of obstructions above and below the ground surface.

b. Stripping and Excavation. This item includes foundation stripping and excavation to remove unsuitable materials prior to levee fill placement.

c. Levee Fill, On-Site and Off-Site Material. It was assumed that fill material will come from two sources. Some will be trucked from the GCID Canal spoil piles and some from the existing levee. An average unit price has been used for both sources.

d. Slurry Wall. Based upon the seepage analysis, we have determined that a slurry wall will be required for the levee reach downstream of SB-12. The average depth of the slurry wall has been estimated at 70 feet below the level of the existing ground.

e. Aggregate Base Course. This item covers the necessary aggregate road surfacing on the top levee surface.

f. Erosion Control Seeding. This item includes restoration and seeding of all areas disturbed by construction activities.

10.2 Preliminary Construction Cost Estimate Summary

The total construction cost for the hypothetical setback levee is shown in **Table 5**. This cost is based on the alignment shown in **Figure 1** and is approximately 24,000 feet in length. This estimate also includes a levee fill item for raising the existing "J"-Levee in the area upstream of the setback alignment in order to provide the same level of freeboard throughout.

Please note that this cost estimate is for direct construction costs and does not include allowances for right of way, utility relocations, county road or state highway improvements, if necessary.

Table 5
Preliminary Construction Cost Estimate for Hypothetical Setback Levee

Item	Quantity	Unit	Unit Price ($)	Total Cost
Clearing and Grubbing	86.5	Acre	2,500.00	216,250
Stripping and Excavation	210,500	Cy	2.50	526,250
Levee Fill	930,556	Cy	10.00	9,305,560
Slurry Wall	1,065,000	Sf	5.50	5,857,500
Aggregate Base Course	13,471	ton	25.00	336,775
Improvement to u/s levee Levee Fill	72,039	Cy	10.00	720,390
Erosion Control Seeding	78.2	Acre	4,500.00	351,900
Subtotal				**17,314,625**
Contingency (25%)				4,328,656
Total Cost				**21,643,281**

11. INVESTIGATION CONCLUSIONS

Based upon our foundation investigation and subsequent analyses presented herein, we offer the following conclusions.

1. Based on the boring logs and discussions with DWR, there is reasonable certainty that the Modesto Formation was encountered in the foundation investigation at the north end of the hypothetical levee location and southerly to approximately SB-10 near the old Holly Sugar Company refinery.

2. Relatively uniform foundation conditions were encountered along the hypothetical levee alignment (except for the very upstream end, SB-17 and –18). Typically, the foundation consists of fine-grained overburden layers covering thick layers of highly permeable sands and gravels. However, the fine-grained overburden layer became much thinner downstream of SB-12.

3. The hypothetical setback levee location as shown in **Figure 1** is a feasible location, but foundation treatment will most likely be required for seepage and piping control downstream of SB-12.

4. A fully penetrating slurry wall (through all river connected sand and gravel layers) may be the most effective means of controlling foundation seepage and piping.

5. Adequate borrow material is locally available to construct a setback levee. Sources include the existing levee and the G.C.I.D. canal spoil piles.

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Slope Stability Plots

APPENDIX 5

Seepage Analysis

FINAL REPORT

GEOTECHNICAL INVESTIGATION OF THE J LEVEE SACRAMENTO RIVER AT HAMILTON CITY

October 5, 2001

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