APPENDIX C

Hydraulics and Hydrology

C1 Hydraulic Impact Analysis

SACRAMENTO AREA FLOOD CONTROL AGENCY

NATOMAS LEVEE IMPROVEMENT PROGRAM

SUMMARY REPORT ON HYDRAULIC IMPACT ANALYSES

Prepared for

SAFCA
Sacramento Area Flood Control Agency

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1. OVERVIEW

The Sacramento Area Flood Control Agency (SAFCA) is proposing to raise and strengthen portions of the federal project levee system protecting the Natomas Basin in Sacramento and Sutter Counties in order to provide urban development in the basin with at least a 100-year level of flood protection as quickly as possible, while laying the groundwork for providing at least a 200-year level of flood protection over time. This effort is referred to as the Natomas Levee Improvement Program (or "NLIP"). It is part of a larger program of improvements, including modifications to Folsom Dam that would provide the Sacramento area as a whole with at least a 200-year level of flood protection.

The April 22, 2008 version of this report was originally prepared for and included with the Final Environmental Impact Statement, 408 Permission, and 404 Permit to Sacramento Area Flood Control Agency for the Natomas Levee Improvement Project, Sacramento, California, in November 2008. The report has been revised to include more detail on the modeling of the "With Project" and "Without Project" condition and to include results for the Pleasant Grove Creek Canal (PGCC) and Natomas East Main Drainage Canal (NEMDC) reaches.

Under applicable federal law, no federal project levee or related flood control facility may be altered unless: Congress has authorized the alteration; or, pursuant to 33 U.S.C. 408, the Secretary of the Army acting through the Chief of Engineers of the U.S. Army Corps of Engineers ("USACE") has granted permission for the alteration based on a determination that the proposed work will not be injurious to the public interest and will not otherwise impair the usefulness of the affected facility. Under Title 23 of the California Water Code, such alterations must also be: authorized by the State Legislature; or permitted by the California Central Valley Flood Protection Board ("Board"), formerly the Reclamation Board. In order to coordinate these federal and state decision-making processes, the Board's recent practice has been to issue a letter to the USACE requesting permission for proposed alterations after the Board has made its own determination that the work will not have a detrimental impact on the affected flood control system.

At the heart of both processes is an analysis of the hydraulic effects of the proposed alteration. SAFCA has historically conducted this analysis by evaluating the potential effects of its levee improvement projects on water surface elevations in the stream and river channels in the project area and in the larger watershed within which the project is situated. This approach was used to evaluate the flood related impacts of the NLIP for purposes of meeting the requirements of the California Environmental Quality Act (CEQA). Specifically, SAFCA's engineering consultant, MBK Engineers ("MBK"), has used a UNET hydraulic computer model of the Sacramento River Flood Control Project ("SRFCP"), which was reviewed and approved for use for this project in 2006 by the USACE Sacramento District, to compare existing conditions in the waterways surrounding the Natomas Basin and in the larger SRFCP with and without the NLIP improvements and the other improvements comprising the 200-year flood protection program for the Sacramento area. MBK's initial routings assumed that the levees outside the project area would fail when overtopped. However, in order to test the sensitivity of this assumption, a later set of routings was performed assuming that none of these levees would fail even if overtopped.

The results of the initial routings were presented in the program-level Environmental Impact Report ("EIR") on Local Funding Mechanisms for Comprehensive Flood Control Improvements for the Sacramento Area, which was certified by the SAFCA Board of Directors in February 2007. Using the same methodology, the analysis was performed again and presented in the Draft EIR for the NLIP Landside Improvements Project in September 2007. The 'no levee failure' routings were performed thereafter and presented in the Landside Improvements Final EIR which was certified by the SAFCA Board in November 2007. The modeling showed that the proposed NLIP improvements by themselves would not alter any of the identified water surface elevations in the river channels comprising the SRFCP. Moreover, when the NLIP improvements are analyzed as part of the larger 200-year flood protection program for the Sacramento area, including modifications to Folsom Dam, the result is a lowering of water surface elevations for the 100-year and 200-year floods along the lower Sacramento River for most of the reach adjacent to the Natomas Basin. On this basis, SAFCA has concluded that the NLIP improvements would not cause any significant hydraulic impacts.

This report is a summary of the previous hydraulic impact analyses conducted for the NLIP. The report also presents new information requested by the USACE as part of their National Environmental Policy Act (NEPA) compliance for review of the proposed levee alterations.

2. SRFCP SYSTEM BACKGROUND

The perimeter levee system around the Natomas Basin is part of a larger integrated system of levees, dams, and bypass channels comprising the SRFCP (Figure 1). This system encompasses five historic flood basins in the Sacramento Valley (Colusa, Sutter, Feather, Yolo, and American Flood Basins) and the sub-basins contained therein. Planning, design, and construction of the SRFCP has been ongoing since the early 1900s under the leadership of the USACE and the State of California (State), with local levee and reclamation districts playing the principal role in operating and maintaining the system.

The SRFCP levees were set close to the river channel in order to improve navigation by having the rivers scour hydraulic mining sediments. The design of the system assumed no levee failures, but included five engineered diversions and one natural overflow diversion. The natural diversion is to Butte Basin, which is upstream from the SRFCP levees. This diversion did not include flowage easements because the Butte Basin is a historic flood basin. The five engineered diversions include two additional diversions to Butte Basin (Moulton and Colusa Weirs), one diversion to the Sutter Bypass (Tisdale Weir), and two diversions to the Yolo Bypass (Fremont and Sacramento Weirs). All of the engineered diversions included the acquisition of property rights to support the diversions. The deliberate planning, construction, and maintenance of the diversions ensured that they would function during flood conditions and serve as reliable features of the flood project.

Initially, the river channel and bypass levees in each segment of the system were constructed based on a standard geometry. The levees were designed with a predetermined freeboard allowance tied to specified flows and associated water surface elevations, generally matched to observed conditions during the 1907 and 1909 floods. Over time, the standard levee section was increased because of numerous levee failures. The minimum standard levee changed from a levee with a top width of 10 feet to one with a top width of 20 feet. In addition, the design flows were modified substantially on the Feather and American Rivers. This was the result of floods that occurred after 1909, which demonstrated these rivers could produce substantially greater flows than occurred during the 1907 and 1909 floods. Because numerous levee failures occurred along the Feather River levees between 1920 and 1934, these levees were set back and enlarged to accommodate greater flows. These changes were summarized in memorandums issued by the USACE which define the minimum freeboard requirements for each segment of the SRFCP, collectively referred to as the "USACE 1957 Profile." Over the years, the system capacity of the SRFCP was also greatly expanded by the construction of five major multiple-purpose reservoirs (Shasta, Black Butte, Oroville, New Bullards Bar, and Folsom Reservoirs), containing 2.7 million acre-feet of flood control storage space.

The record floods of 1986 and 1997 triggered additional system modifications. Although these floods were significantly larger than the 1907 and 1909 floods, the availability of reservoir storage largely prevented flows in the system from exceeding the design of the SRFCP. Nevertheless, numerous project levees experienced unexpectedly severe stress and some failed. This experience caused the USACE, the State, and their local partners to perform a series of geotechnical evaluations on the SRFCP levees and to adopt new, more rigorous levee design standards, including updated standards for seepage through and under project levees. To meet these standards, USACE, the State, and local flood control agencies have made substantial investments in addressing identified deficiencies in levees throughout the SRFCP and in improving the level of flood protection provided by the levees, particularly in urban areas. Federal, State and local support for these levee improvements has been secured under several federally authorized projects, including the Sacramento Urban Levee Reconstruction Project, the American River Watershed Investigation, the West Sacramento Levee Improvement Project, the Sutter Basin Project and the Yuba River Basin Project. In the aftermath of the flooding of New Orleans, these authorized projects are being expanded to support an even broader scope of urban levee improvement activity.

The evolution of these urban levee improvements is occurring within a SRFCP management framework that has historically allowed necessary adaptations to the system without undermining its basic operational principles. These principles may be summarized as follows. First, the SRFCP is not intended to provide a uniform level of flood protection (statistical probability of flooding) to the various sub-basins within the protected area. Rather, each sub-basin is protected by levees that are required to at least meet the SRFCP minimum geometrical standards, including freeboard reflecting the water surface profile prescribed for that segment of the system. Second, each sub-basin's flood protection is dependent on the fitness of its own levees and not on the condition (or failure) of any other sub-basin's levees. Accordingly, each sub-basin has the right to keep its levees in the fittest possible condition to ensure that these levees will perform as reliably as possible in a flood. This right ensures the orderly operation and maintenance of the system since even the most modest levee work has the potential to trigger a "transfer of risk" from one sub-basin to another, at least in theory; and there are no data or modeling tools available to quantify such transfers of risk, assess their significance, or determine how they might be mitigated. Third, for this reason, the administration of the SRFCP has historically relied on "change in design water surface elevation" as the guideline for evaluating the effects of any proposed levee work.

The strictest scrutiny is given to levee work involving physical changes in the geometry of the river channel since these changes have the most potential to alter water surface elevations prescribed by the SRFCP design water surface profiles (SRFCP 1957 profiles). This work includes placement of fill or construction of structures in the floodway, construction of new levees, relocation of existing levees, excavation within the floodway, construction of large berms for protecting riverbanks, raising an existing levee (waterside raise), construction of a new bypass, and planting of vegetation within the floodway. Landside levee work of the type proposed as part of the NLIP, such as placing a cutoff wall in a levee, adding a seepage berm to a levee, placing a field of seepage relief wells along a levee, raising a levee (landside raise), widening a levee (increased top width), and relocating a seepage ditch, is also strictly scrutinized; but is not likely to cause impacts.

The standard procedure for this evaluation is to use hydrologic and hydraulic computer modeling tools such as, HEC-1, HEC-2, UNET, HEC-RAS, RMA2, FESWMS, etc. The analysis consists of calibrating the hydraulic model to historic flood events using high-water marks and stream gage data. The calibration activity is normally conducted on a system-wide basis instead of a site-specific basis. However, data available for computer model calibration can be sparse or nonexistent. In addition, assumptions must be made regarding reservoir operations. Because all of the reservoirs that contribute to the operation of the SRFCP (Shasta, Black Butte, Oroville, New Bullards Bar and Folsom) are governed by water control manuals issued by USACE, current reservoir operations are assumed to continue except where it is reasonably foreseeable that the current operation would change. Examples of such changes are at the Folsom Dam and Reservoir: where Congress has directed USACE to formalize the variable space storage operation that has been in effect by agreement between SAFCA and the U.S. Bureau of Reclamation since 1995; and where water control structures are being modified as part of the Folsom Dam Joint Federal Project.

3. APPROACH TO MODELING ANALYSIS

As discussed above, in order to evaluate the hydraulic impacts of the levee alterations proposed as part of the NLIP, MBK used a UNET hydraulic computer model calibrated to historic flood events using high-water marks and stream gage data gathered in connection with the 1997 Flood. Figure 2 displays the geographical extent of the UNET model. Figure 3 provides the UNET model river mile stationing around the Natomas Basin. Results of the model calibration are shown in Figures 4 through 7.

The hydraulic impacts of the levee alterations proposed as part of the NLIP were evaluated based on the potential of the proposed levee alterations to increase one or more of the SRFCP's recognized design water surface elevations: (1) the SRFCP 1957 water surface profiles that serve as the minimum design standard for the SRFCP; (2) the 100-year flood elevations that govern management of SRFCP protected floodplains under the National Flood Insurance Program (33 CFR. 65.10); and (3) the 200-year water surface elevations that are likely to govern implementation of floodplain management standards recently adopted by the State Legislature (Statutes of 2008, Chapter 364 [adding Water Code Section 9602(i)]). In addition, SAFCA has provided information on the project impacts to the 500-year flood elevation. This flood represents an extreme flood event and is the largest flood event for which hydrologic input data has been developed for the hydraulic simulation model.

The modeling runs compare the “Existing”, “Without Project” and “With Project” conditions under each of the above flood scenarios. The Existing Condition analysis provides an evaluation of the levee and reservoir system as it exists in April 2008. The Without Project condition assumes implementation of federally authorized improvements to Folsom Dam and anticipated improvements to the levees protecting existing urban areas outside the Natomas Basin (American River Basin, West Sacramento, Yuba Basin, and Sutter Basin) so as to provide these areas with 200-year flood protection. The With Project condition adds the improvements proposed as part of the NLIP to the Without Project condition. The NLIP improvements consist of levee raises on the Sacramento River, Natomas Cross Canal, PGCC, and NEMDC in the locations shown in Figure 3. The levee raising that is part of the Phase 3 EIS/EIR is highlighted on Figure 3. The magnitude of the levee raise is shown in the levee profile plots provided in Figures 8 through 11. The low spots in the PGCC levee at Howsley Road and Sankey Road (see Figure 10) are not raised and are assumed to retain their existing configurations in the With Project condition. All fill related to the levee raises would occur on the landside of the levees with the exception of an approximately one mile reach of the Natomas Cross Canal where some waterside fill would be required. Figure 12 shows a typical section showing the waterside fill.

In order to compare these conditions, assumptions about the performance of SRFCP levees under flow conditions that exceed the design of the levee system are necessary for the 100-year, 200-year, and 500-year floods. As noted above, the design of the SRFCP was not historically based on assumed levee failures. For floods exceeding the design of the SRFCP, it is improbable to assume that no levees will fail, even in extreme floods that would cause vast lengths of levee overtopping throughout the system. Therefore, these floods have been modeled assuming that failure will occur when the water reaches the top of the levee. However, in order to test the sensitivity of this approach, and in order to model a scenario that resembles the SRFCP's "no basin relies on another basin's failure for protection" tenet, a secondary "no levee failure" scenario has also been modeled. Under this scenario, it is assumed that SRFCP levees that do not currently meet the minimum freeboard requirements of the SRFCP are raised to meet the minimum levee standard and that levees, which are overtopped under any of the targeted flood conditions will not fail. The assumptions supporting these modeling scenarios are summarized in Table 1.

Table 1. Definition of Model Assumptions for Various Conditions			
Condition	**Top of Levee Assumption**	**Levee Failure Assumption**	**Reservoir Ops Assumption**
Existing	Existing top of levee grade April 2008	Levees fail when water reaches the top of the levee	Existing reservoirs and current (2008) operation criteria
Without Project	Same as Existing with the following changes. Federally authorized improvements to Folsom Dam are implemented and urban area levees outside the Natomas Basin are assumed to have levees at 200-year water surface + 3 feet of freeboard. NLIP levees same as Existing Condition.	Levees fail when water reaches the top of levee.	Same as Existing except Folsom Dam will be operated in accordance with the Joint Federal Project currently under construction
With Project	Same as Without Project except NLIP levees raised to design level	Same as Without Project	Same as Without Project
Without Project Sensitivity Analysis	Same as Without Project except that SRFCP levees with top elevations below SRFCP design standard are assumed to be raised to meet this standard	No levee failures	Same as Without Project
With Project Sensitivity Analysis	Same as With Project except that SRFCP levees with top elevations below SRFCP design standard are assumed to be raised to meet this standard	No levee failures	Same as Without Project

As noted above, the Without Project condition assumes that urban areas (outside the Natomas Basin) will be provided with 200-year protection. This is the most likely near term future condition of the levee system based on the information currently available. This condition is reasonable based on California voters November 2006 approval of a bond measure that would provide over $3 billion for urban levee improvements in the Central Valley. Additionally, in September 2007, the State Legislature enacted the Central Valley Flood Protection Act of 2008 (Act), Water Code Section 9600 et seq., which was signed into law by the governor in October 2007. The Act is based on the following findings:

- The Central Valley of California is experiencing unprecedented development, resulting in the conversion of historically agricultural lands and communities to densely populated residential and urban centers.

- The legislature recognizes that by their nature, levees, which are earthen embankments typically founded on fluvial deposits, cannot offer complete protection from flooding, but can decrease its frequency.

- The legislature recognizes that the level of flood protection afforded rural and agricultural lands by the original flood control system would not be adequate to protect those lands if they are developed for urban uses, and that a dichotomous system of flood protection for urban and rural lands has developed through many years of practice.

- The legislature further recognizes that levees built to reclaim and protect agricultural land may be inadequate to protect urban development unless those levees are significantly improved.

- Cities and counties rely upon federal floodplain information when approving developments, but the information available is often out of date and the flood risk may be greater than that indicated using available federal information.

- The legislature recognizes that the current federal flood standard is not sufficient to protect urban and urbanizing areas within flood prone areas throughout the Central Valley.

(Statutes of 2007, Chapter 364, Section 9.)

Based on these findings, the Act embraces a new flood protection standard for urban areas (defined as “developed areas in which there are 10,000 residents or more”) located in levee-protected floodplains in the Central Valley. This new “urban level of flood protection” is defined as “the level of protection that is necessary to withstand flooding that has a 1-in-200 chance of occurring in any given year using criteria consistent with, or developed by, the Department of Water Resources.” (Statutes of 2007, Chapter 364 [adding Water Code Section 9602(i)]).

4. RESULTS OF MODELING ANALYSIS

The flood routings described herein indicate that under the Existing condition, all SRFCP levees would contain the SRFCP 1957 design flood profile. The 100-year flood would overtop some non-urban levees, but this flood would be contained by all urban levees under the Existing condition. The 200-year flood would generate multiple levee overtopping locations in several non-urban areas under both the Existing and Without Project conditions and along the Lower American River under the Existing condition. However, this flood would be effectively contained under both the Existing and Without Project conditions by all existing urban levees outside the American River basin, including the levees around the Natomas Basin. The 500-year flood would cause massive levee overtopping affecting all segments of the system under the Existing and Without Project conditions. Only West Sacramento and the Natomas Basin would avoid overtopping under these conditions with upstream levee failures. Table 2 provides a summary of these conditions.

Table 2. Levee Failure Summary (Number of Levee Failures)

Condition	Design Flood			
	SRFCP (1957)	100-year	200-year	500-year
Existing	0	3	26	62
Without Project	0	3	18	80
With Project	0	3	18	77

Tables 3, 4 and 5 summarize the maximum water surface elevations at several locations in and around the project area for the Existing, Without Project, and With Project conditions for the 100-year, 200-year and 500-year flood events, respectively.

Tables 6, 7 and 8 present the hydraulic impacts of the Project (Without Project to With Project change) from the sensitivity analyses.

Table 3. 100-year Maximum Water Surface Elevation Summary, Levees Fail When Water Reaches Top of Levee

Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)			Change (ft)	
	Existing	Without Project	With Project	Existing to Without Project	Without Project to With Project
Sacramento River					
at Knight's Landing (90.22)	43.77	43.75	43.75	-0.02	0
at Fremont Weir, west end (84.75)	42.46	42.45	42.45	-0.01	0
at Natomas Cross Canal (79.21)	42.52	42.48	42.49	-0.04	+0.01
at I-5 (71.00)	38.10	38.01	38.01	-0.09	0
at Sacramento Bypass (63.82)	33.46	33.09	33.09	-0.37	0
at NEMDC (61.0)	33.96	33.58	33.58	-0.38	0
at I St. (59.695)	33.68	33.31	33.31	-0.37	0
at Freeport Bridge (46.432)	27.31	27.19	27.19	-0.12	0
Natomas Cross Canal					
u/s Hwy 99/70 (4.82)	42.64	42.66	42.67	+0.02	+0.01
Pleasant Grove Creek Canal					
at Sankey Rd. (3.65)	42.64	42.66	42.67	+0.02	+0.01
at Fifield Rd. (1.49)	42.72	42.74	42.75	+0.02	+0.01
at Howsley Rd. (0.40)	42.71	42.73	42.74	+0.02	+0.01
Natomas East Main Drainage Canal					
at Elverta Road (10.35)	30.52	30.52	30.52	0	0
at Elkhorn Blvd. (8.35)	30.30	30.30	30.30	0	0
at Main Ave. (6.09)	38.75	38.21	38.21	-0.54	0
at West El Camino Ave. (2.96)	36.93	36.08	36.08	-0.85	0
Feather River					
at Nicolaus Gage (8.00)	50.82	50.81	50.81	-0.01	0
Yolo Bypass					
at Woodland Gage (51.10)	34.90	34.88	34.88	-0.02	0
American River					
at H St. (6.471)	45.27	42.99	42.99	-2.28	0

Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).

Table 4. 200-year Maximum Water Surface Elevation Summary, Levees Fail When Water Reaches Top of Levee					
Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)			Change (ft)	
	Existing	Without Project	With Project	Existing to Without Project	Without Project to With Project
Sacramento River					
at Knight's Landing (90.22)	43.97	43.97	43.97	0	0
at Fremont Weir, west end (84.75)	43.22	43.23	43.24	+0.01	+0.01
at Natomas Cross Canal (79.21)	43.28	43.28	43.28	0	0
at I-5 (71.00)	39.00	38.47	38.47	-0.53	0
at Sacramento Bypass (63.82)	36.70	34.58	34.58	-2.12	0
at NEMDC (61.0)	37.68	35.13	35.13	-2.55	0
at I St. (59.695)	37.41	34.85	34.85	-2.56	0
at Freeport Bridge (46.432)	30.29	28.31	28.31	-1.98	0
Natomas Cross Canal					
u/s Hwy 99/70 (4.82)	43.32	43.32	43.32	0	0
Pleasant Grove Creek Canal					
at Sankey Rd. (3.65)	43.31	43.32	43.33	+0.01	+0.01
at Fifield Rd. (1.49)	43.38	43.40	43.41	+0.02	+0.01
at Howsley Rd. (0.40)	43.35	43.35	43.36	0	+0.01
Natomas East Main Drainage Canal					
at Elverta Road (10.35)	32.49	32.53	32.57	+0.04	+0.04
at Elkhorn Blvd. (8.35)	31.78	31.84	31.90	+0.06	+0.06
at Main Ave. (6.09)	42.28	40.00	40.00	-2.28	0
at West El Camino Ave. (2.96)	41.31	38.33	38.33	-2.98	0
Feather River					
at Nicolaus Gage (8.00)	52.44	52.44	52.44	0	0
Yolo Bypass					
at Woodland Gage (51.10)	35.76	35.75	35.75	-0.01	0
American River					
at H St. (6.471)	48.79	46.53	46.53	-2.26	0
Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).					

Table 5. 500-year Maximum Water Surface Elevation Summary, Levees Fail When Water Reaches Top of Levee					
Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)			Change (ft)	
	Existing	Without Project	With Project	Existing to Without Project	Without Project to With Project
Sacramento River					
at Knight's Landing (90.22)	43.88	43.92	43.92	+0.04	0
at Fremont Weir, west end (84.75)	43.07	43.13	43.13	+0.06	0
at Natomas Cross Canal (79.21)	43.14	43.14	43.14	0	0
at I-5 (71.00)	39.58	39.40	39.40	-0.18	0
at Sacramento Bypass (63.82)	37.58	37.34	37.34	-0.24	0
at NEMDC (61.0)	38.73	38.50	38.50	-0.23	0
at I St. (59.695)	38.44	38.21	38.21	-0.23	0
at Freeport Bridge (46.432)	30.83	30.68	30.68	-0.15	0
Natomas Cross Canal					
u/s Hwy 99/70 (4.82)	43.53	43.65	43.66	+0.12	+0.01
Pleasant Grove Creek Canal					
at Sankey Rd. (3.65)	44.03	44.08	44.10	+0.05	+0.02
at Fifield Rd. (1.49)	44.05	44.13	44.14	+0.08	+0.01
at Howsley Rd. (0.40)	43.77	43.93	43.94	+0.16	+0.01
Natomas East Main Drainage Canal					
at Elverta Road (10.35)	34.58	34.51	35.33	-0.07	+0.82 [1]
at Elkhorn Blvd. (8.35)	34.06	34.04	34.68	-0.02	+0.64 [1]
at Main Ave. (6.09)	43.32	43.40	43.40	+0.08	0
at West El Camino Ave. (2.96)	42.65	42.57	42.57	-0.08	0
Feather River					
At Nicolaus Gage (8.00)	52.40	52.40	52.40	0	0
Yolo Bypass					
At Woodland Gage (51.10)	35.53	35.81	35.81	+0.28	0
American River					
At H St. (6.471)	48.84	49.94	49.94	+1.10	0

Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).

[1] The computed 500-year "With Project" water surface elevations of 35.33 feet at Elverta Road and 34.68 feet at Elkhorn Blvd. are significantly lower than the SRFCP Design Flood Plane elevations of 39.2 feet at Elverta Road and 39.1 feet Elkhorn Blvd. The with project water surface elevation is also significantly less than the elevation of 39.1 feet that was experienced in the February 1986 flood at both of these locations. The water surface is lower as a result of construction of the Stormwater Pump Station north of Dry Creek. The NEMDC upstream of Elkhorn Blvd. is in Phase 4b and will be evaluated in more detail as part of a future EIS/EIR.

Table 6. 100-year Maximum Water Surface Elevation Summary, No Levee Failures (Sensitivity Analysis)			
Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)		Change (ft.)
	Without Project	With Project	Without Project to With Project
Sacramento River			
at Knight's Landing (90.22)	44.38	44.38	0
at Fremont Weir, west end (84.75)	43.18	43.18	0
at Natomas Cross Canal (79.21)	43.73	43.73	0
at I-5 (71.00)	39.18	39.18	0
at Sacramento Bypass (63.82)	33.73	33.73	0
at NEMDC (61.0)	34.30	34.30	0
at I St. (59.695)	34.02	34.02	0
at Freeport Bridge (46.432)	27.82	27.82	0
Natomas Cross Canal			
u/s Hwy 99/70 (4.82)	43.78	43.78	0
Pleasant Grove Creek Canal			
at Sankey Rd. (3.65)	43.65	43.65	0
at Fifield Rd. (1.49)	43.78	43.78	0
at Howsley Rd. (0.40)	43.79	43.79	0
Natomas East Main Drainage Canal			
at Elverta Road (10.35)	33.48	33.49	+0.01
at Elkhorn Blvd. (8.35)	32.57	32.58	+0.01
at Main Ave. (6.09)	38.13	38.13	0
at West El Camino Ave. (2.96)	35.98	35.98	0
Feather River			
at Nicolaus Gage (8.00)	51.18	51.18	0
Yolo Bypass			
at Woodland Gage (51.10)	35.49	35.49	0
American River			
at H St. (6.471)	43.09	43.09	0
Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).			

Table 7. 200-year Maximum Water Surface Elevation Summary, No Levee Failures (Sensitivity Analysis)			
Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)		Change (ft.)
	Without Project	With Project	Without Project to With Project
Sacramento River			
at Knight's Landing (90.22)	45.67	45.67	0
at Fremont Weir, west end (84.75)	44.75	44.76	+0.01
at Natomas Cross Canal (79.21)	45.18	45.20	+0.02
at I-5 (71.00)	40.52	40.52	0
at Sacramento Bypass (63.82)	35.76	35.76	0
at NEMDC (61.0)	36.34	36.35	+0.01
at I St. (59.695)	36.06	36.06	0
at Freeport Bridge (46.432)	29.68	29.69	+0.01
Natomas Cross Canal			
u/s Hwy 99/70 (4.82)	45.20	45.22	+0.02
Pleasant Grove Creek Canal			
at Sankey Rd. (3.65)	44.94	44.95	+0.01
at Fifield Rd. (1.49)	45.18	45.19	+0.01
at Howsley Rd. (0.40)	45.20	45.22	+0.02
Natomas East Main Drainage Canal			
at Elverta Road (10.35)	37.38	37.77	+0.39
at Elkhorn Blvd. (8.35)	37.17	37.58	+0.41
at Main Ave. (6.09)	38.87	38.87	0
at West El Camino Ave. (2.96)	38.13	38.13	0
Feather River			
at Nicolaus Gage (8.00)	53.47	53.48	+0.01
Yolo Bypass			
at Woodland Gage (51.10)	36.84	36.85	+0.01
American River			
at H St. (6.471)	46.68	46.68	0
Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).			

Table 8. 500-year Maximum Water Surface Elevation Summary, No Levee Failures (Sensitivity Analysis)			
Location (Comp Study River Mile)	Maximum Water Surface Elevation (ft NAVD88)		Change (ft.)
	Without Project	With Project	Without Project to With Project
Sacramento River			
at Knight's Landing (90.22)	46.55	46.59	+0.04
at Fremont Weir, west end (84.75)	46.07	46.13	+0.06
at Natomas Cross Canal (79.21)	45.96	46.13	+0.17
at I-5 (71.00)	42.04	42.13	+0.09
at Sacramento Bypass (63.82)	40.25	40.28	+0.03
at NEMDC (61.0)	40.25	40.28	+0.03
at I St. (59.695)	39.95	39.97	+0.02
at Freeport Bridge (46.432)	32.56	32.58	+0.02
Natomas Cross Canal			
u/s Hwy 99/70 (4.82)	45.73	45.99	+0.26
Pleasant Grove Creek Canal			
at Sankey Rd. (3.65)	45.53	45.70	+0.17
at Fifield Rd. (1.49)	45.78	45.99	+0.21
at Howsley Rd. (0.40)	45.76	46.01	+0.25
Natomas East Main Drainage Canal			
at Elverta Road (10.35)	42.64	44.00	+1.36
at Ellkhorn Blvd. (8.35)	42.63	43.99	+1.36
at Main Ave. (6.09)	46.04	46.05	+0.01
at West El Camino Ave. (2.96)	44.99	45.00	+0.01
Feather River			
at Nicolaus Gage (8.00)	55.73	55.75	+0.02
Yolo Bypass			
at Woodland Gage (51.10)	38.24	38.29	+0.05
American River			
at H St. (6.471)	51.44	51.45	+0.01
Note: Water surface elevations originally calculated in NGVD29 vertical datum. Converted to NAVD88 by adding 2.28 ft. (0 NGVD29 = 2.28 NAVD88).			

Computed water surface elevation profiles for each of the key flow conditions in the project area (Sacramento River channel downstream of the Fremont Weir) are shown in Figures 13 through 28. Figures 13 through 16 show the relationship between the 1957 design and the height of the levees for the Sacramento River, Natomas Cross Canal, PGCC and NEMDC, respectively. Figure 13 also shows the locations in which the non-urban Sacramento River west levee would be raised to meet the minimum freeboard requirements of the SRFCP 1957 design standard under the sensitivity analysis. Figures 17 through 20 show the profile of the current 100-year flood. Figures 21 through 24 show the profile of the 200-year design condition (no levee failure) flood. Figures 21 through 24 also show the likely 200-year water surface profile assuming upstream levee failures in non-urban areas. Figure 21 shows that the current height of the Sacramento River east levee along the Natomas Basin is essentially at the same elevation as the 200-year (no levee failure) design water surface profile and considerably higher than the likely water surface profile assuming upstream levee failures. It also shows the extent to which the Sacramento River west levee across from Natomas would be overtopped in a 200-year flood. Figures 25 through 28 show the profiles for the 500-year flood with upstream levee failures. The 500-year (with levee failures) water surface elevation in the Sacramento River channel is lower throughout the most critical portion of this reach than the 200-year (no levee failure) design water surface elevation. As reflected in Figures 25 through 28, under the likely assumption that upstream levees will fail when water reaches the top of the levee, the water surface elevations around Natomas would be dramatically lower than the 200-year (no levee failure) profile that was used for design of NLIP. This 200-year levee design condition thus represents a worst-case scenario for the Sacramento River and the Natomas Cross Canal, and underscores the high degree of protection against Natomas Basin levee overtopping that would be provided by the design of the NLIP improvements.

Under the sensitivity analysis of the 500-year (no levee failure) flood, the maximum water surface elevation change on the Sacramento River between the Without Project and With Project conditions, as shown in Table 8, is 0.17 feet. The maximum water surface change in the NCC is 0.26. However, even these relatively minor impacts are considered extremely implausible, given that over 80 miles of upstream and adjacent levees could be overtopped (see Table 9) by this flood without any levee failures occurring.

Table 9. Extent of Levee Overtopping, 500-year Flood Event, No Failures (all values approximate)

River	Leveed Length (miles)	Left Bank		Right Bank	
		Length of Overtopped Levee (miles)	Max. Depth of Overtopping (ft.)	Length of Overtopped Levee (miles)	Max. Depth of Overtopping (ft.)
American River	13	7	4	12	3
Feather River	50	14	3	13	3
Natomas Cross Canal	5	4	1	3.5	2.5
Sacramento Bypass	1.7	0.5	0.5	0.2	0.5
Sacramento R. upstream of Natomas Cross Canal	90	13	4	7	3
Sacramento R. Adjacent to Natomas	18	8	1	6	3
Sacramento R. downstream of American R.	60	2	2	2	2
Sutter Bypass	30	4	4	7	4
Tisdale Bypass	4	0.5	0.5	0.5	1
Wadsworth Canal	4	4	1	4	2
Yolo Bypass	37	5	2.5	2	2

5. SUPPORT OF IMPACT ANALYSIS METHODOLOGY

California Legislature

Consistent with its approval of a new more rigorous standard for urban flood protection, the State Legislature also approved “the project features necessary to provide a 200-year level of flood protection along the American and Sacramento Rivers and within the Natomas Basin as described in the final engineer’s report dated April 19, 2007, adopted by the Sacramento Area Flood Control Agency.” (Statutes of 2007, Chapter 641 [amending Water Code Section 12670.14(b)]). Moreover, in connection with this approval, the legislature adopted the following findings and declarations (Statutes of 2007, Chapter 641, Section 1[k]):

> *As evidenced by the environmental impact reports certified in connection with these projects, including the hydrology and hydraulics impact analysis set forth in the environmental impact report prepared by the Sacramento Area Flood Control Agency with regard to local funding mechanisms for comprehensive flood control improvements for the Sacramento area dated February 2007, the increase in flood protection associated with improving the American and Sacramento River levees and modifying Folsom Dam will be accomplished without altering or otherwise impairing the design flows and water surface elevations prescribed as part of the Sacramento River Flood Control Project. Accordingly, these improvements will not result in significant adverse hydraulic impacts to the lands protected by the Sacramento River Flood Control Project. Thus, it is not necessary or appropriate to require these projects to include hydraulic mitigation.*
>
> *The projects authorized in Section 12670.14 of the Water Code will increase the ability of the existing flood control system in the lower Sacramento Valley to protect heavily urbanized areas within the City of Sacramento and the Counties of Sacramento and Sutter against very rare floods without altering the design flows and water surface elevations prescribed as part of the Sacramento River Flood Control Project or impairing the capacity of other segments of the Sacramento River Flood Control Project to contain these design flows and to maintain water surface elevations. Accordingly, the projects authorized in that section will not result in significant adverse hydraulic impacts to the lands protected by the Sacramento River Flood Control Project and neither the Reclamation Board nor any other state agency shall require the authorized projects to include hydraulic mitigation for these protected lands.*

Although these findings are not legally binding, they indicate the legislature’s concurrence with SAFCA’s approach to analyzing hydraulic impacts. Congressional authorization for raising and strengthening a twelve-mile reach of the Sacramento River east levee in the 1996 Water Resources Development Act (“WRDA”), and for raising and strengthening all five-plus miles of the NCC south levee in the 1999 WRDA without in either case requiring hydraulic mitigation, offers additional indirect legislative support for SAFCA’s approach.

USACE HQ

USACE has been using a risk-based analysis for economic evaluation for some time and has been moving to a risk-based analysis for system performance, largely for certification of levees for FEMA. However, in his memo dated *August 2, 2007, Subject: Section 408 Approval of a Flood Control Project Alteration - Sacramento River Flood Control Project, Feather and Yuba Rivers, California* (copy enclosed), Deputy Director of Civil Works Steven L. Stockton indicated that the discussion of flood protection in terms such as 100-year or 200-year level of protection is acceptable to comply with NEPA and other environmental statues. However, a risk-based analysis as required by ER 1105-2-100 and ER 1105-2-101 will be needed to determine the terms of any eventual Section 104 reimbursement.

6. NLIP COORDINATION WITH REGIONAL IMPROVEMENTS

SAFCA's approach to providing an urban standard of flood protection to the Natomas Basin is being replicated in the other urbanizing sub-basins in the lower Sacramento Valley (West Sacramento, Marysville extending south to Reclamation District 784, and Yuba City). However, these improvements are intended to complement rather than substitute for pursuing improvements on a regional scale that would improve the flow of water through the Yolo and Sacramento Bypass systems and lower water surface elevations throughout the lower Sacramento Valley. In 2002 through 2003, SAFCA made substantial investments in hydraulic studies and analyses of the improvements that would be required to move more flood water into and through the Yolo Bypass during large flood events in the Sacramento-Feather River watershed to reduce flows and water surface elevations in the Sacramento River channel downstream of the Fremont weir. The Lower Sacramento River Regional Project Initial Report (SAFCA 2003) indicated that this could be accomplished by widening the Fremont weir, setting back the levees on the east side of the Yolo Bypass, discharging flood flows into the Sacramento Deep Water Ship Channel, and eliminating low, restricted elevation levees at the lower end of the Yolo Bypass. However, these improvements would be extremely costly and time consuming to implement; they would occur entirely outside SAFCA's jurisdiction, and would require extraordinary cooperation among affected federal, state, and local interests; and they would not resolve the seepage problems affecting the Sacramento River east levee and the Natomas Cross Canal south levee adjacent to the Natomas Basin. For these reasons, SAFCA concluded that this alternative would not achieve the objectives of the NLIP; and therefore, it was not carried forward for further analysis.

On a long-term basis; however, regionally oriented improvements to the Yolo and Sacramento Bypass systems may help to address potential changes in hydrology due to climate change and may reduce the risk of uncontrolled flooding on a system-wide basis. Although this flooding is most likely to occur in lightly populated agricultural areas, reducing its frequency by increasing the conveyance capacity of the SRFCP would avoid the cost of repairing and reconstructing damaged levees and other public infrastructure and would increase public support for the "dichotomous system of flood protection for urban and rural lands" that exists in the Sacramento Valley. Early implementation of the NLIP, as well as early implementation of proposed improvements to SRFCP levees protecting other urban areas, would not preclude any of the alternatives contemplated for the update of the Central Valley Flood Protection Plan.

7. CONCLUSION

Raising and strengthening portions the federal project levee system protecting the Natomas Basin in Sacramento and Sutter Counties as proposed by SAFCA would not result in any significant, adverse hydraulic impacts to other sub-basins protected as part of the SRFCP. Furthermore, these improvements would be consistent with the principles that have guided the management of the SRFCP over the past century and with the policies adopted by the State Legislature calling for an immediate and comprehensive effort to increase the level of flood protection provided to Sacramento and the other urban areas within the SRFCP. The NLIP improvements would also be consistent with the direction given by Congress when it approved raising and strengthening 12 miles of the Sacramento River east levee (WRDA 1996) and 5.3 miles of the Natomas Cross Canal south levee (WRDA 1999).

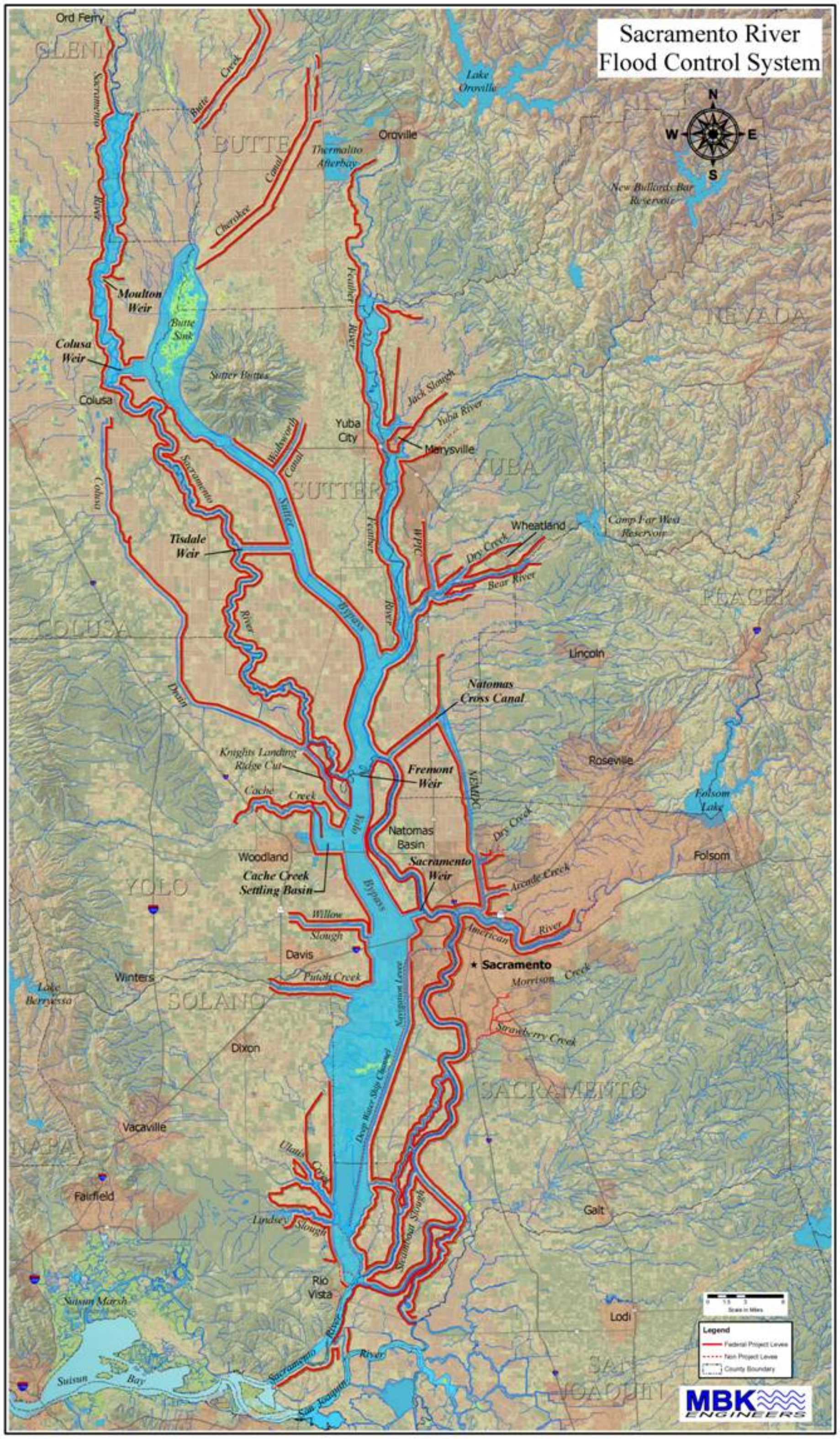

Figure 1. Sacramento River Flood Control System Map

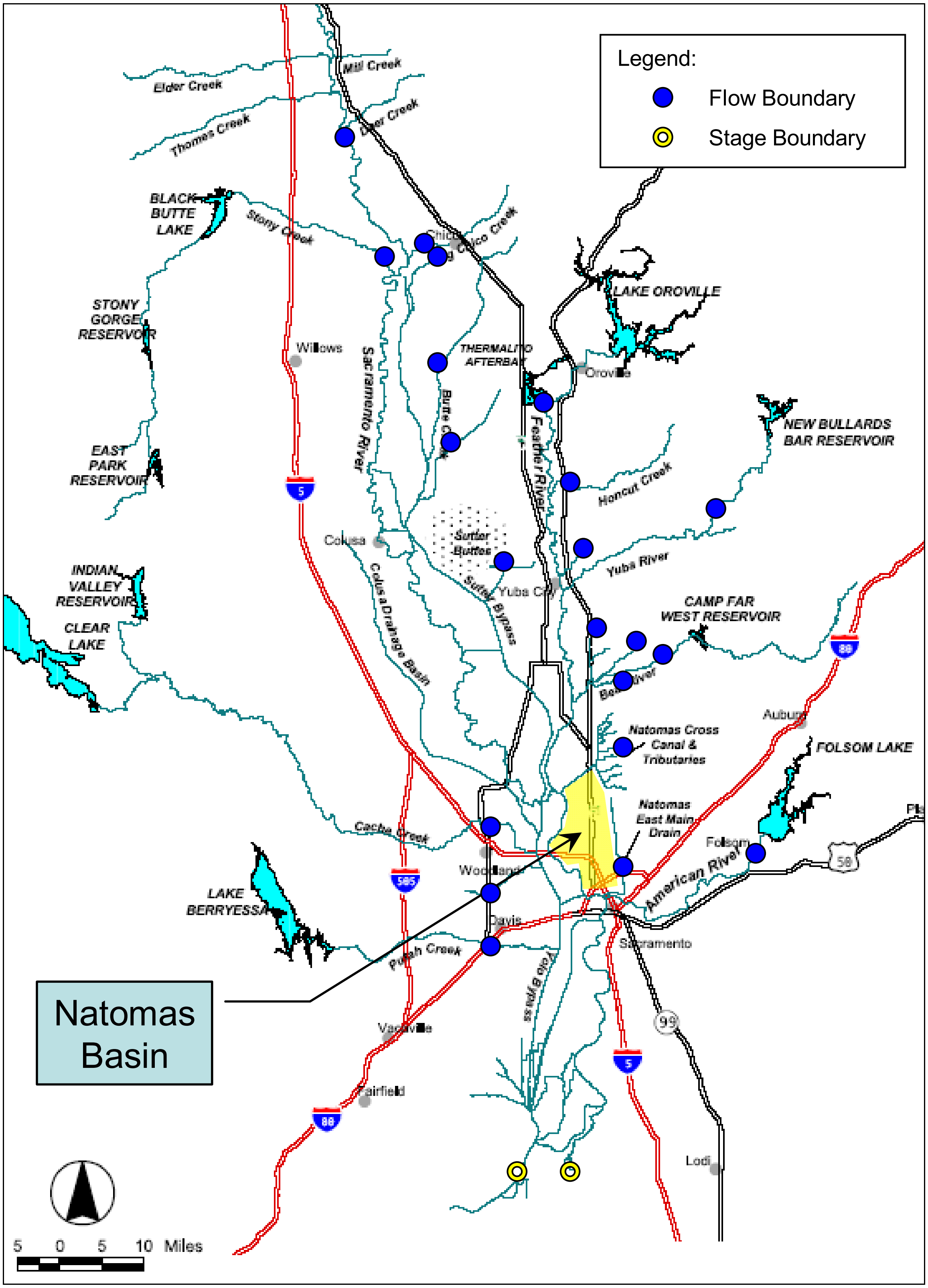

Figure 2. Sacramento River UNET Model Extents

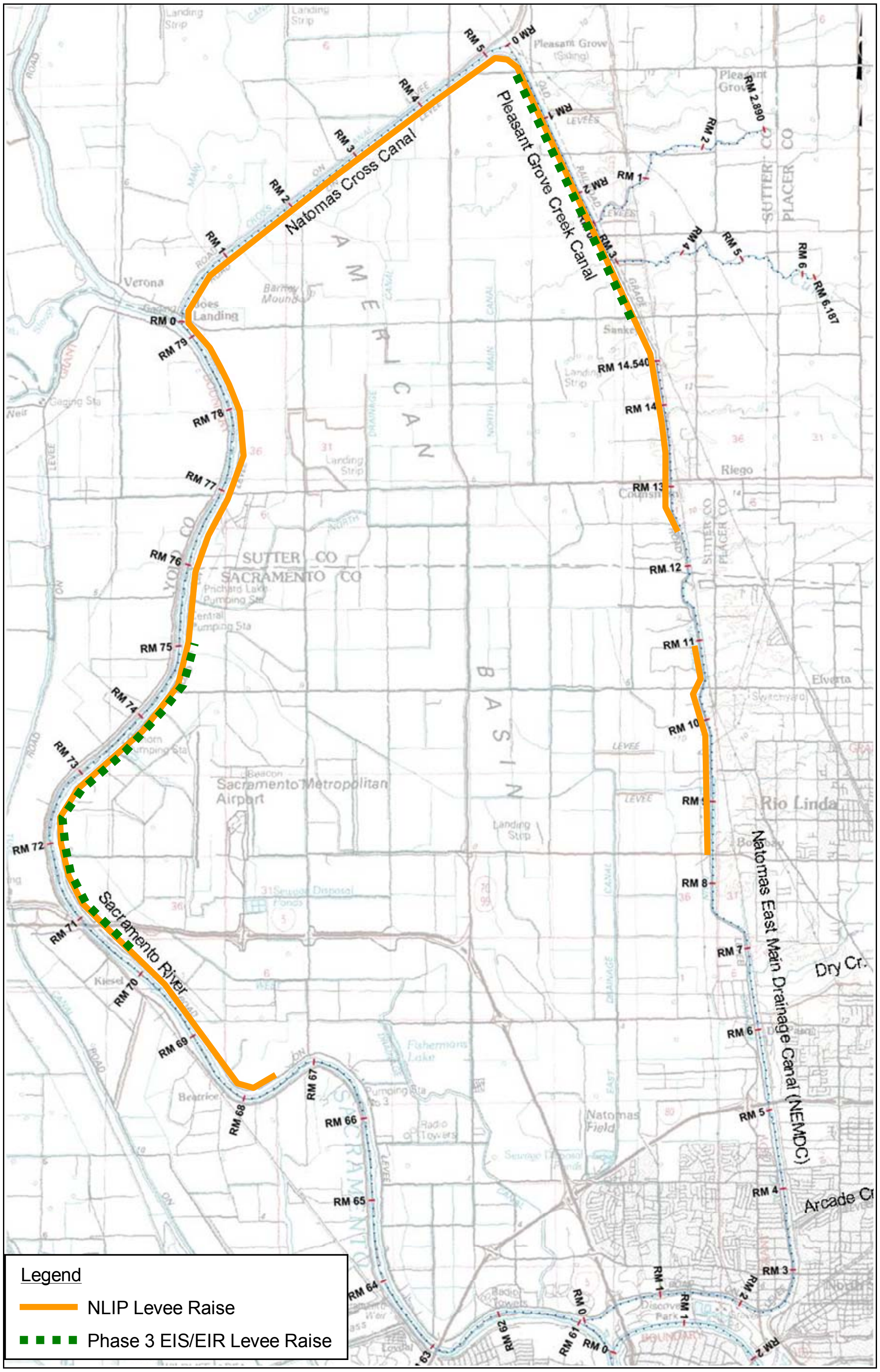

Figure 3. Natomas Levee Improvement Program Study Area

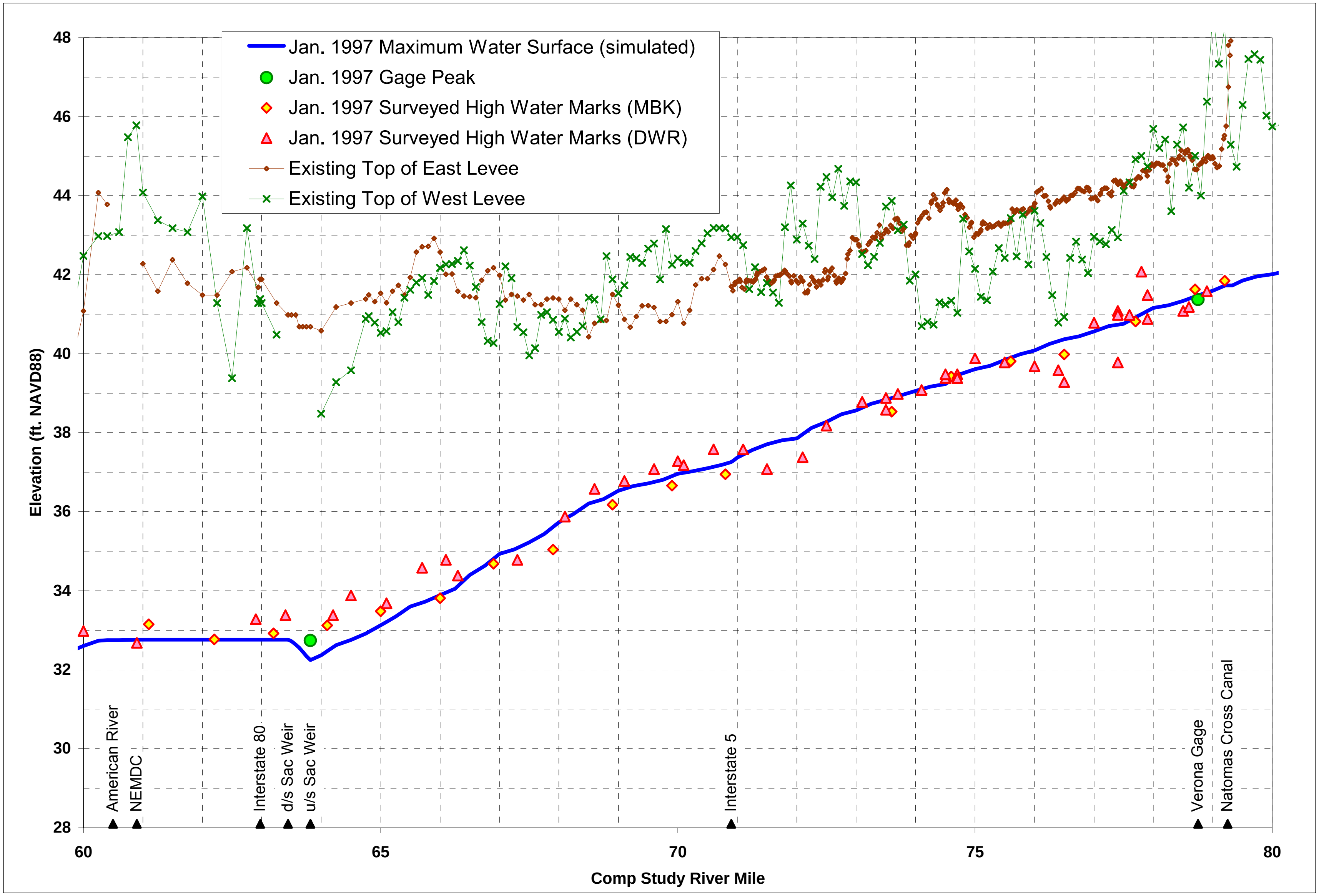

Figure 4. Model Calibration – Sacramento River Profile

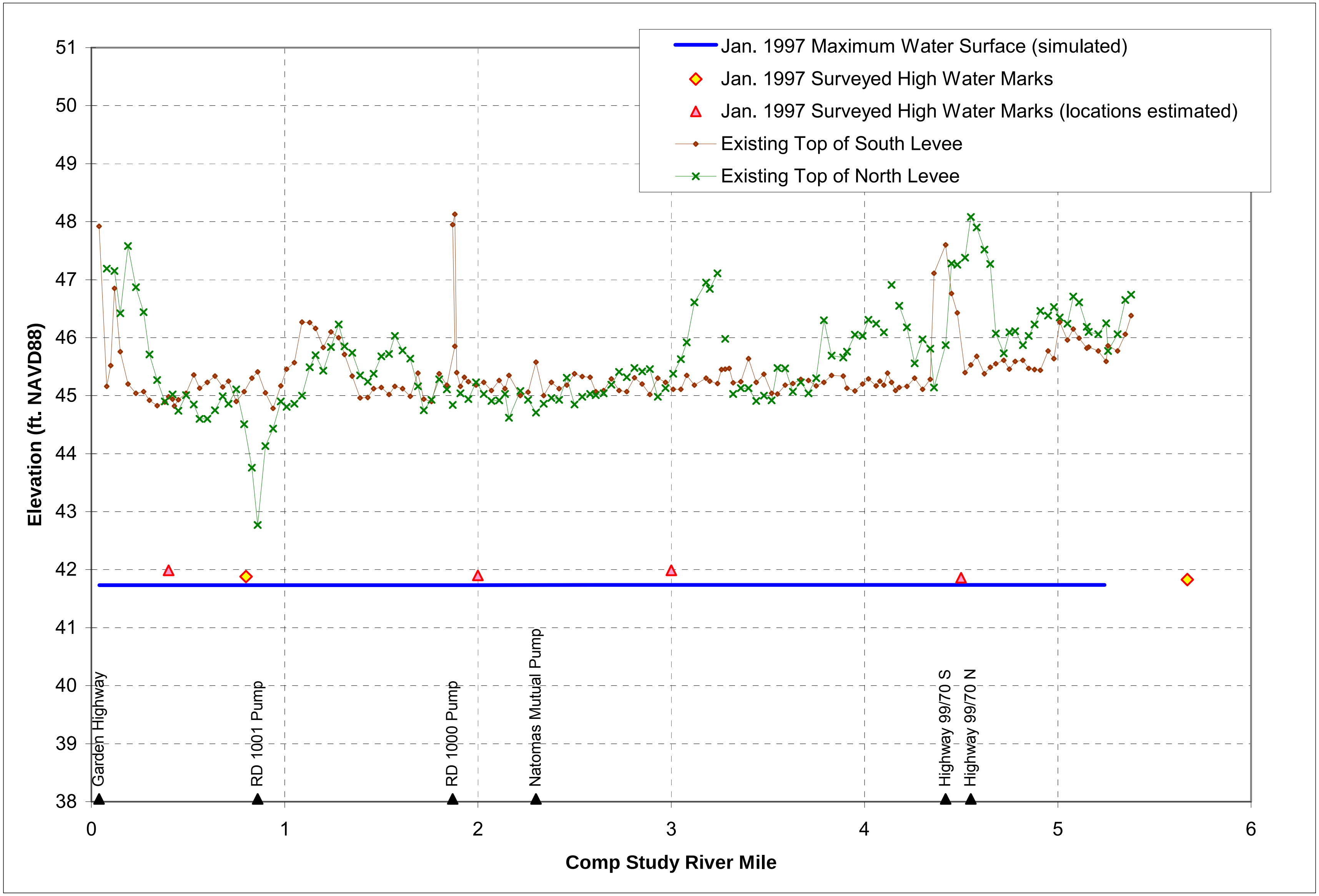

Figure 5. Model Calibration – Natomas Cross Canal Profile

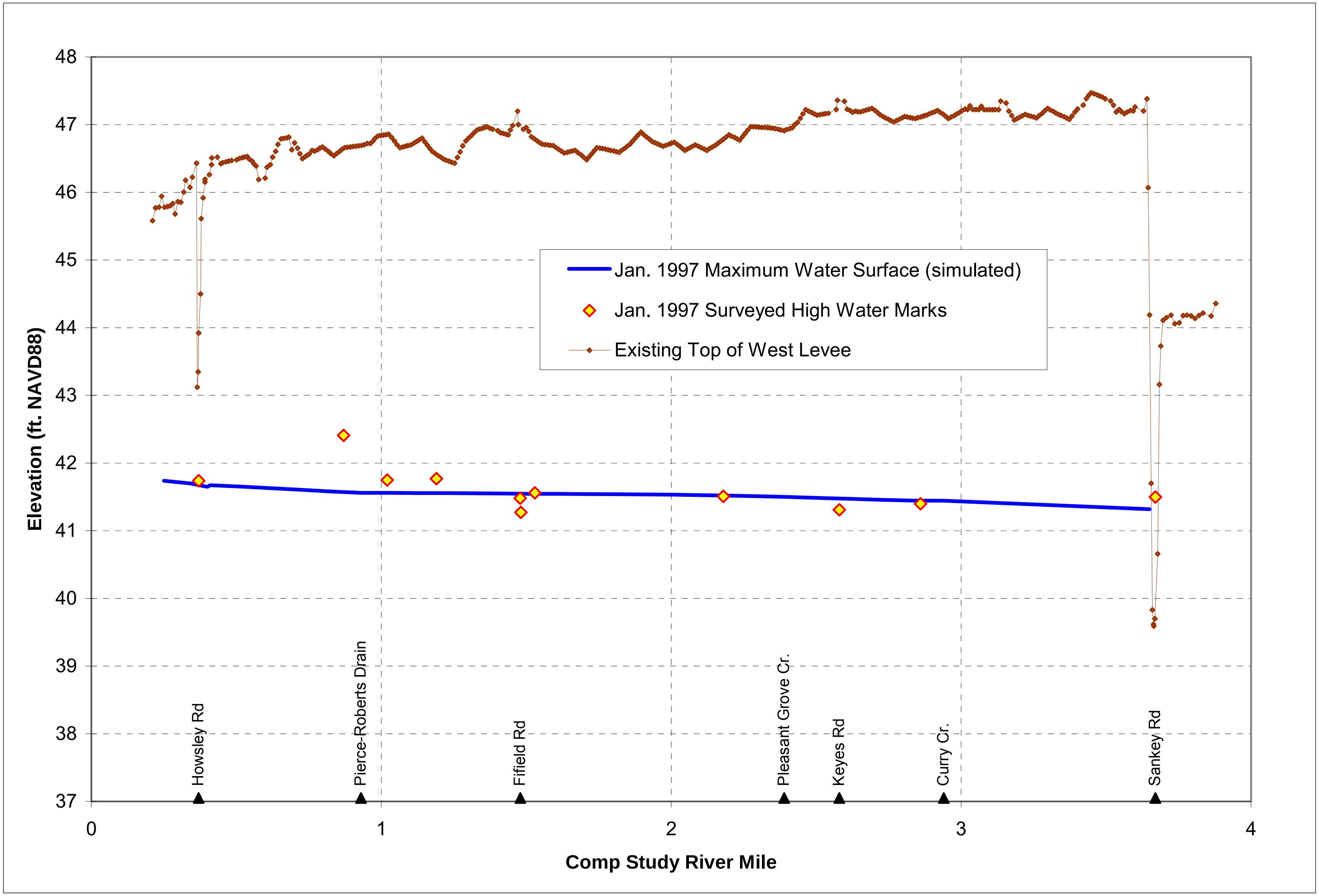

Figure 6. Model Calibration – Pleasant Grove Creek Canal Profile

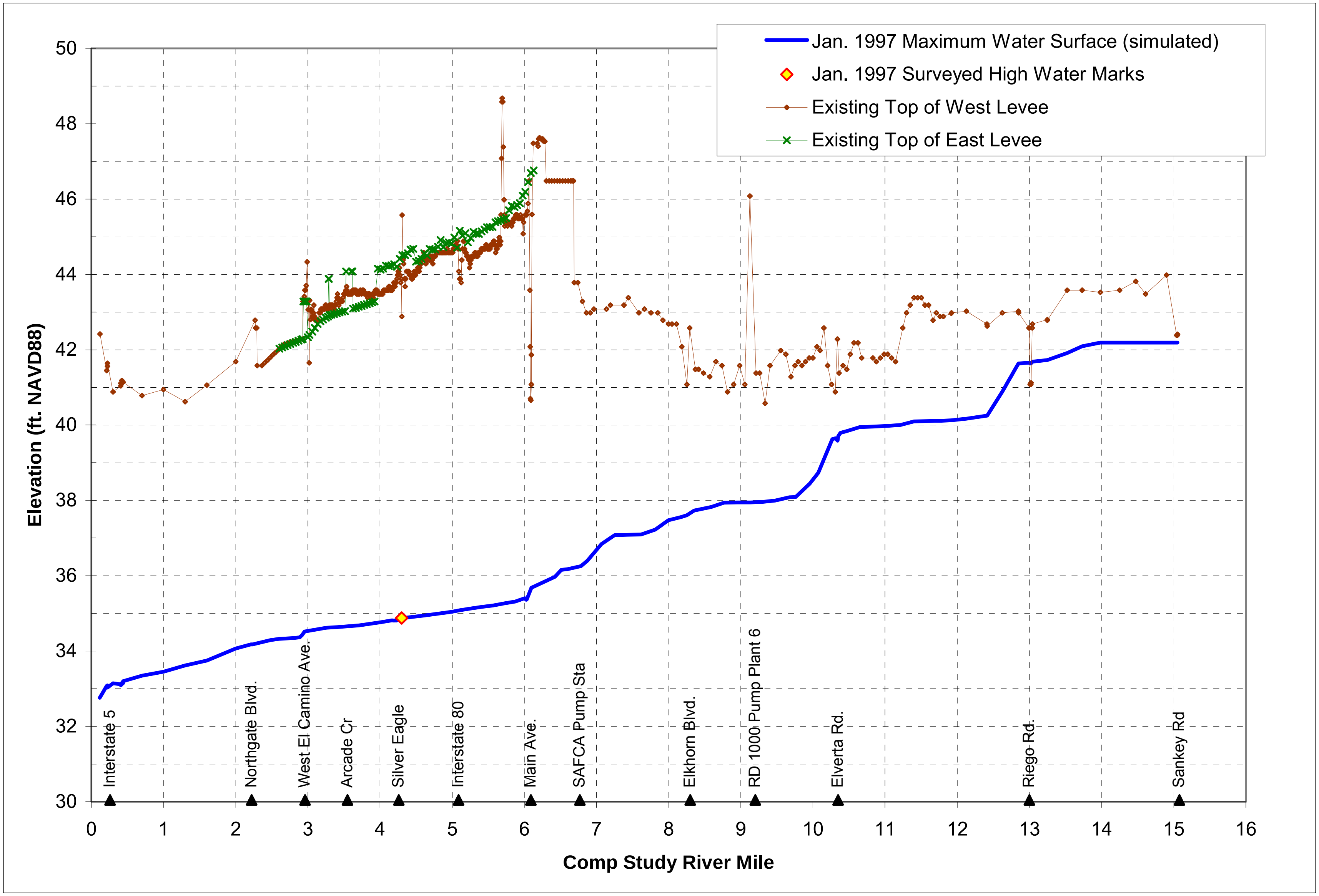

Figure 7. Model Calibration – NEMDC Profile

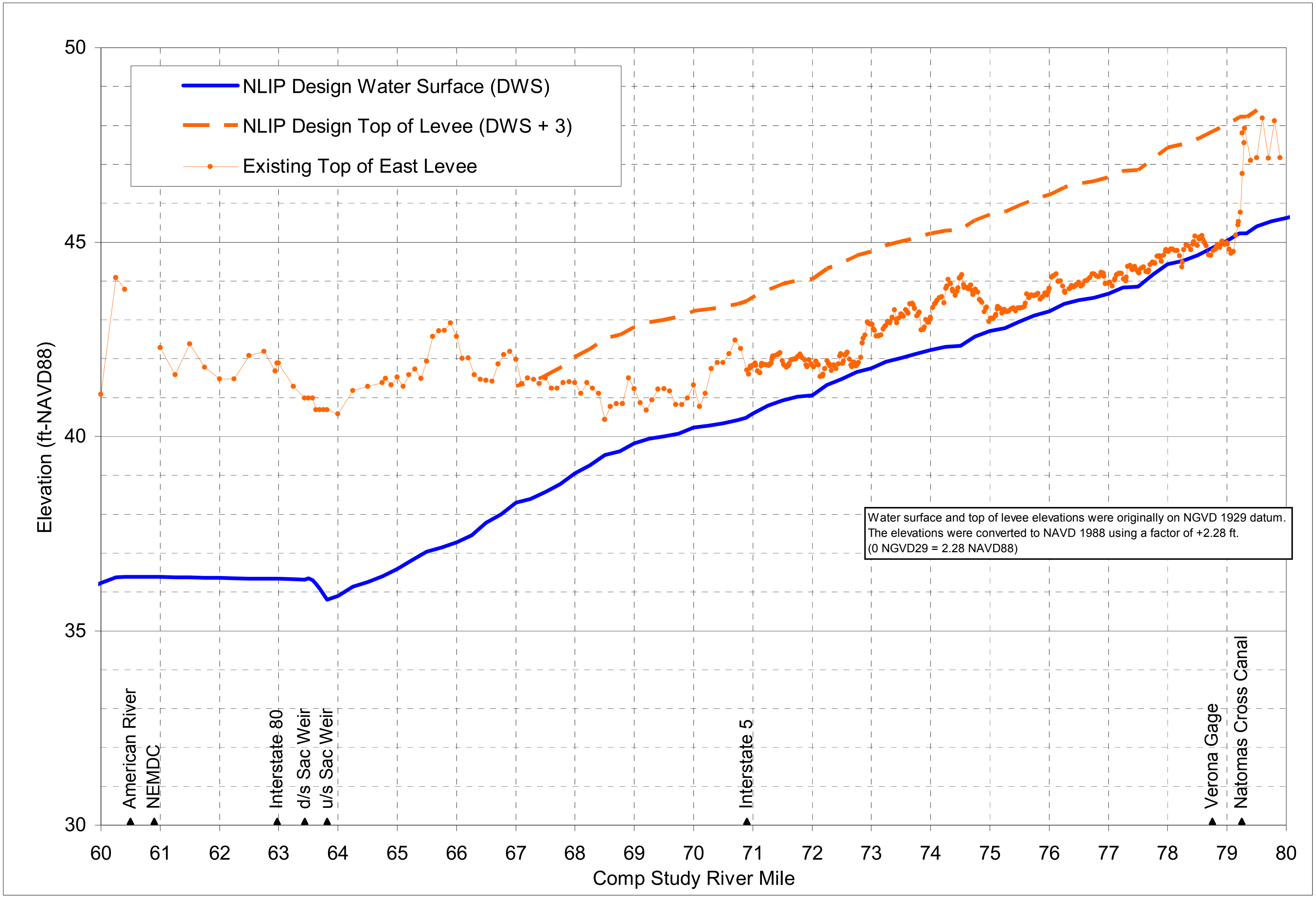

Figure 8. NLIP Design Top of Levee Profile – Sacramento River

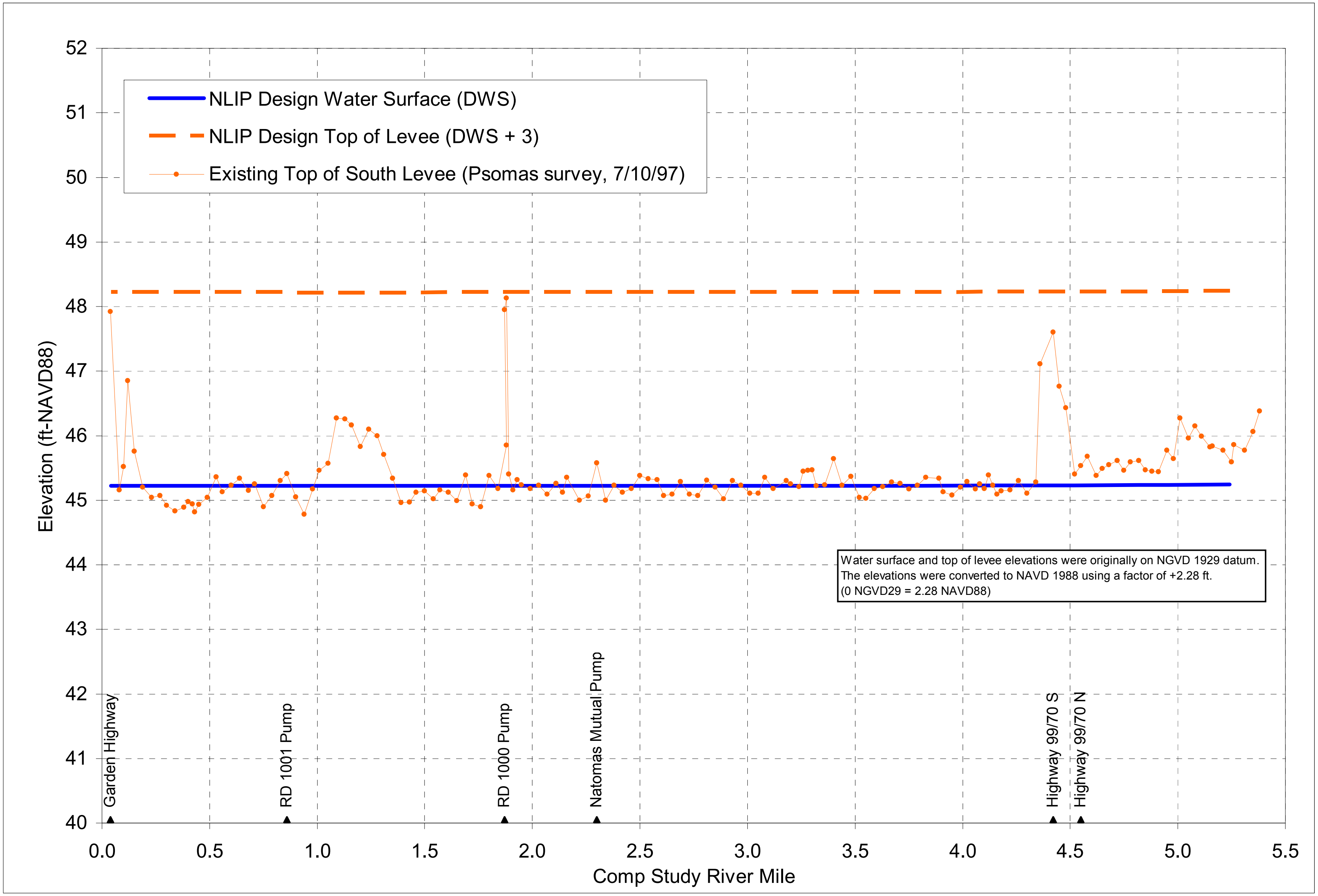

Figure 9. NLIP Design Top of Levee Profile – Natomas Cross Canal

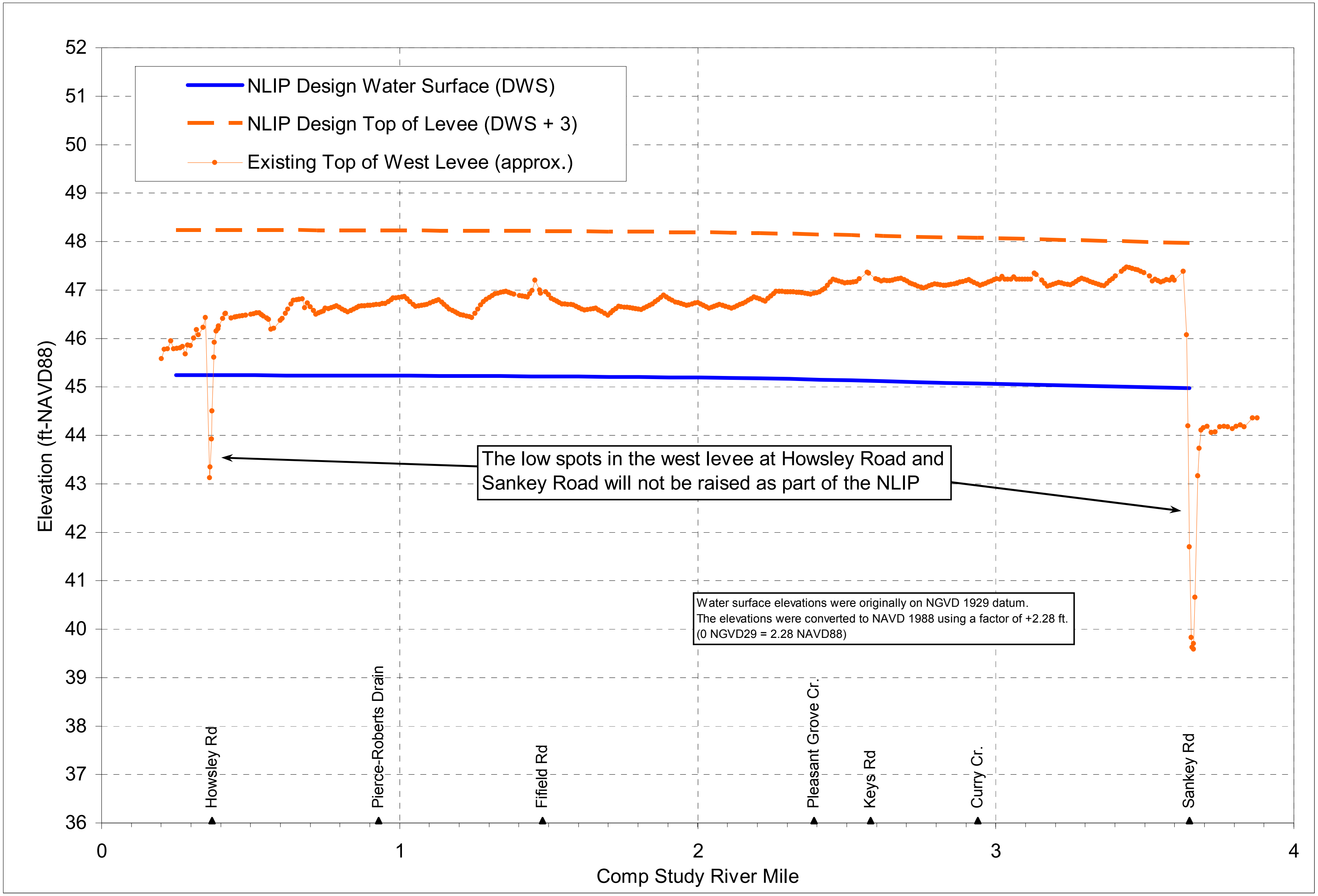

Figure 10. NLIP Design Top of Levee Profile – Pleasant Grove Creek Canal

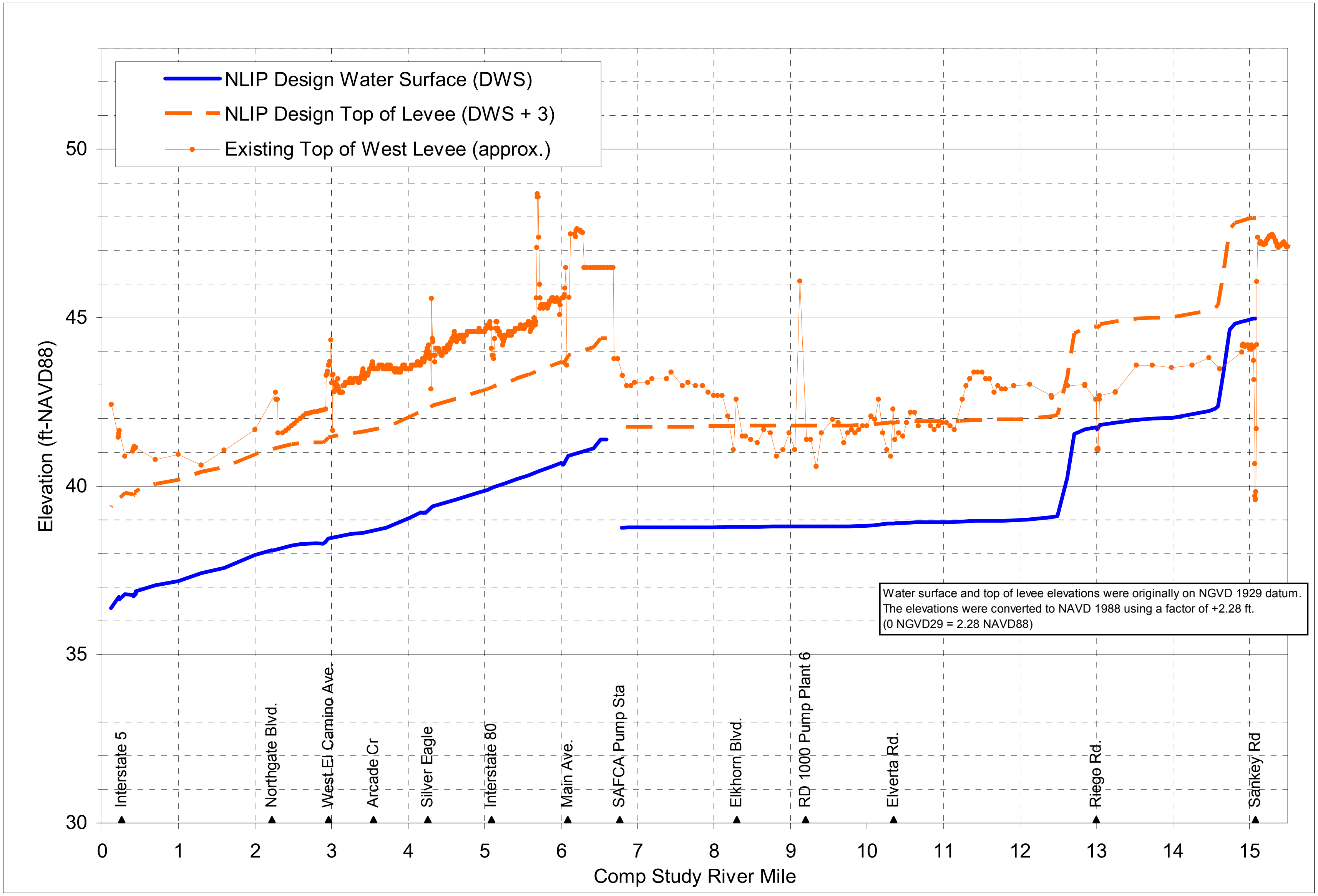

Figure 11. NLIP Design Top of Levee Profile – NEMDC

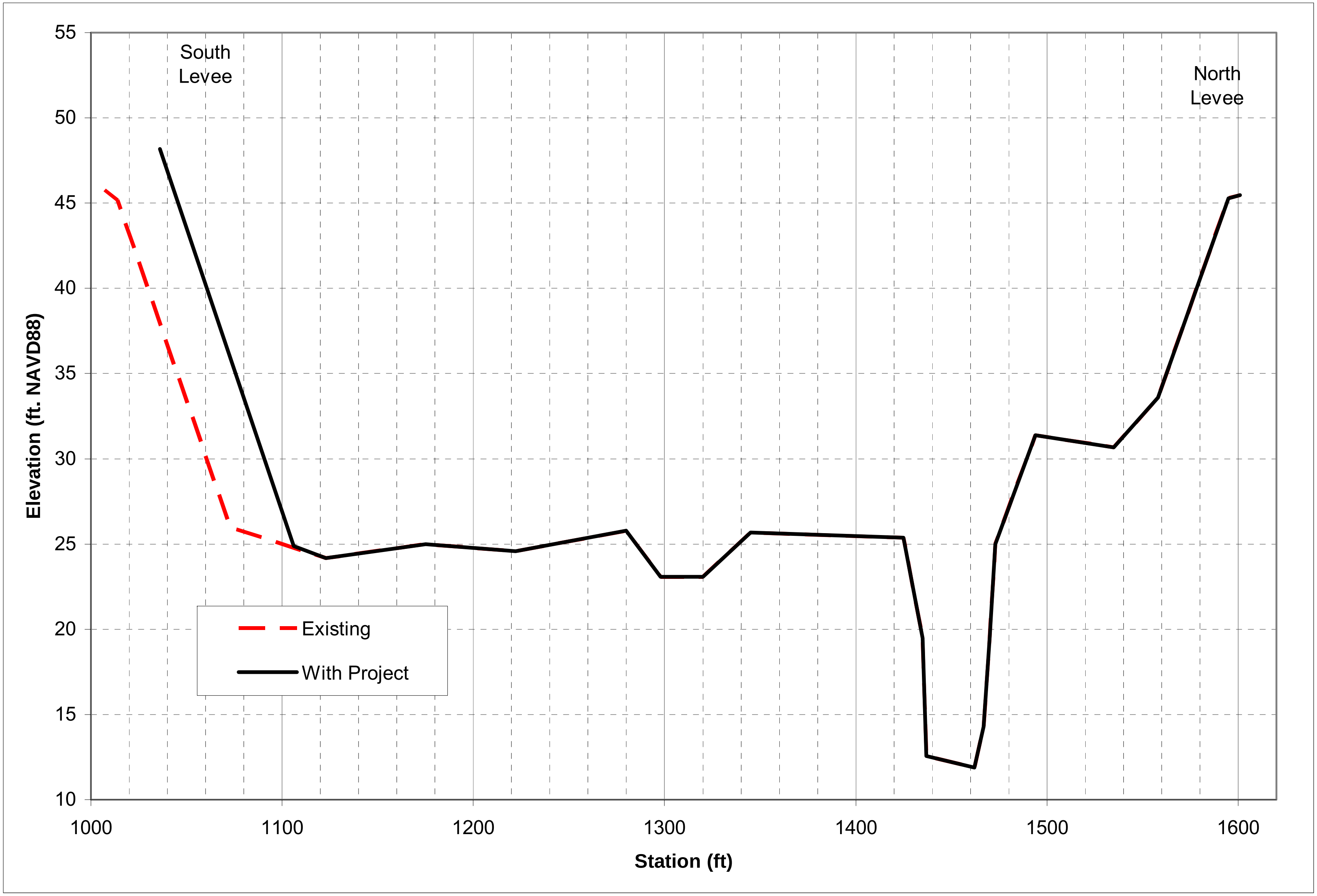

Figure 12. Typical Natomas Cross Canal Section with Waterside Fill

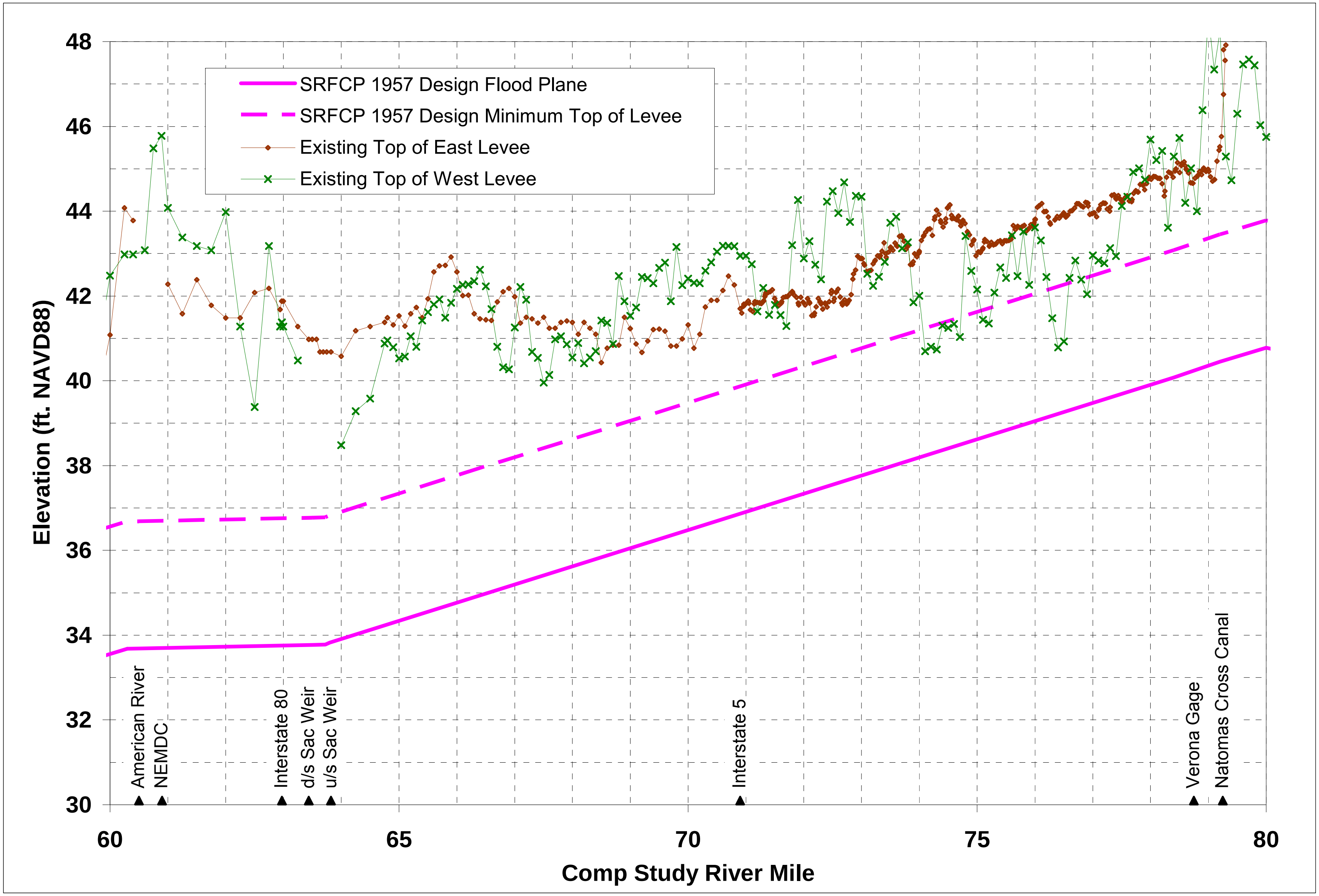

Figure 13. SRFCP 1957 Design Profile, Sacramento River Natomas Reach

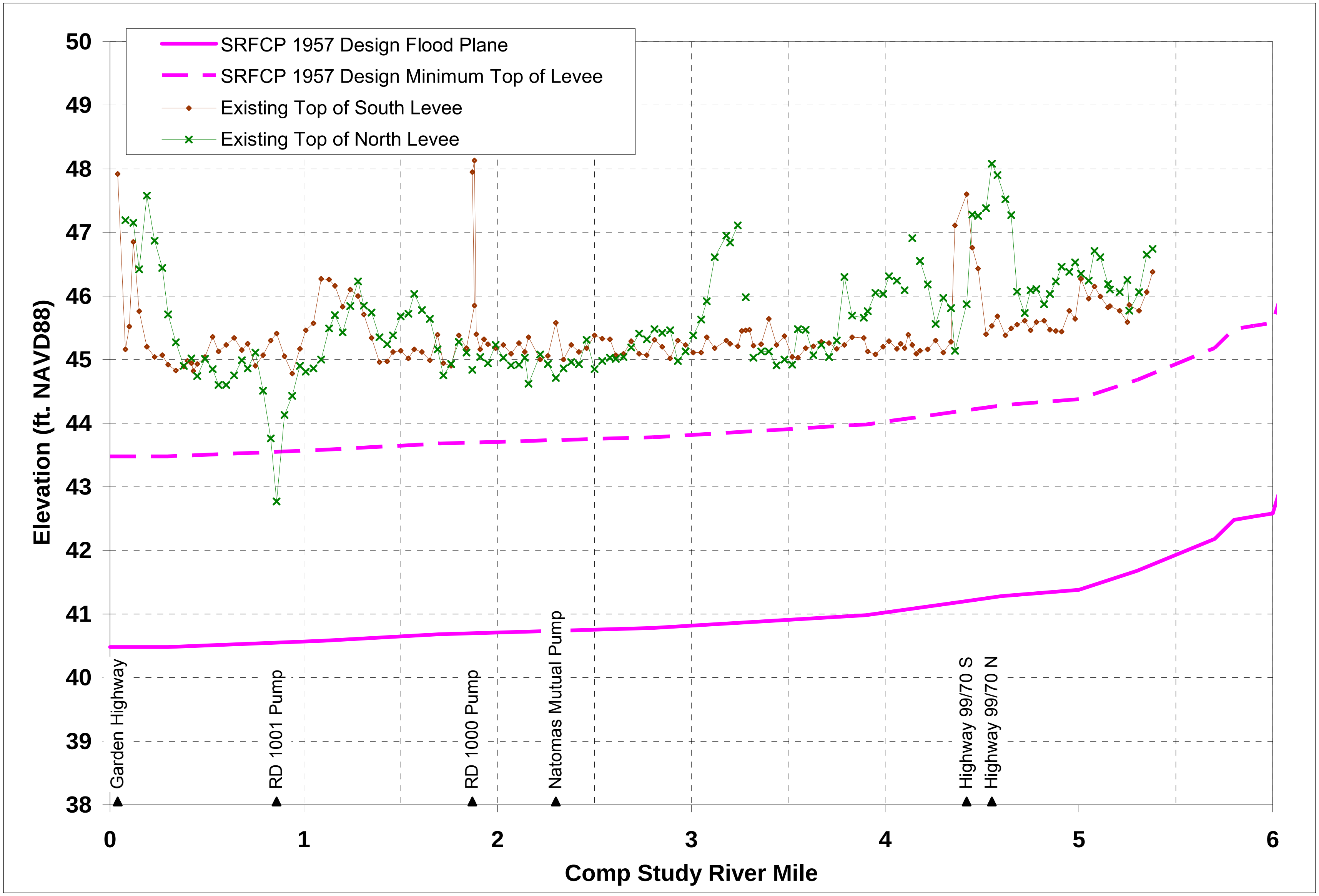

Figure 14. SRFCP 1957 Design Profile, Natomas Cross Canal

MBK ENGINEERS

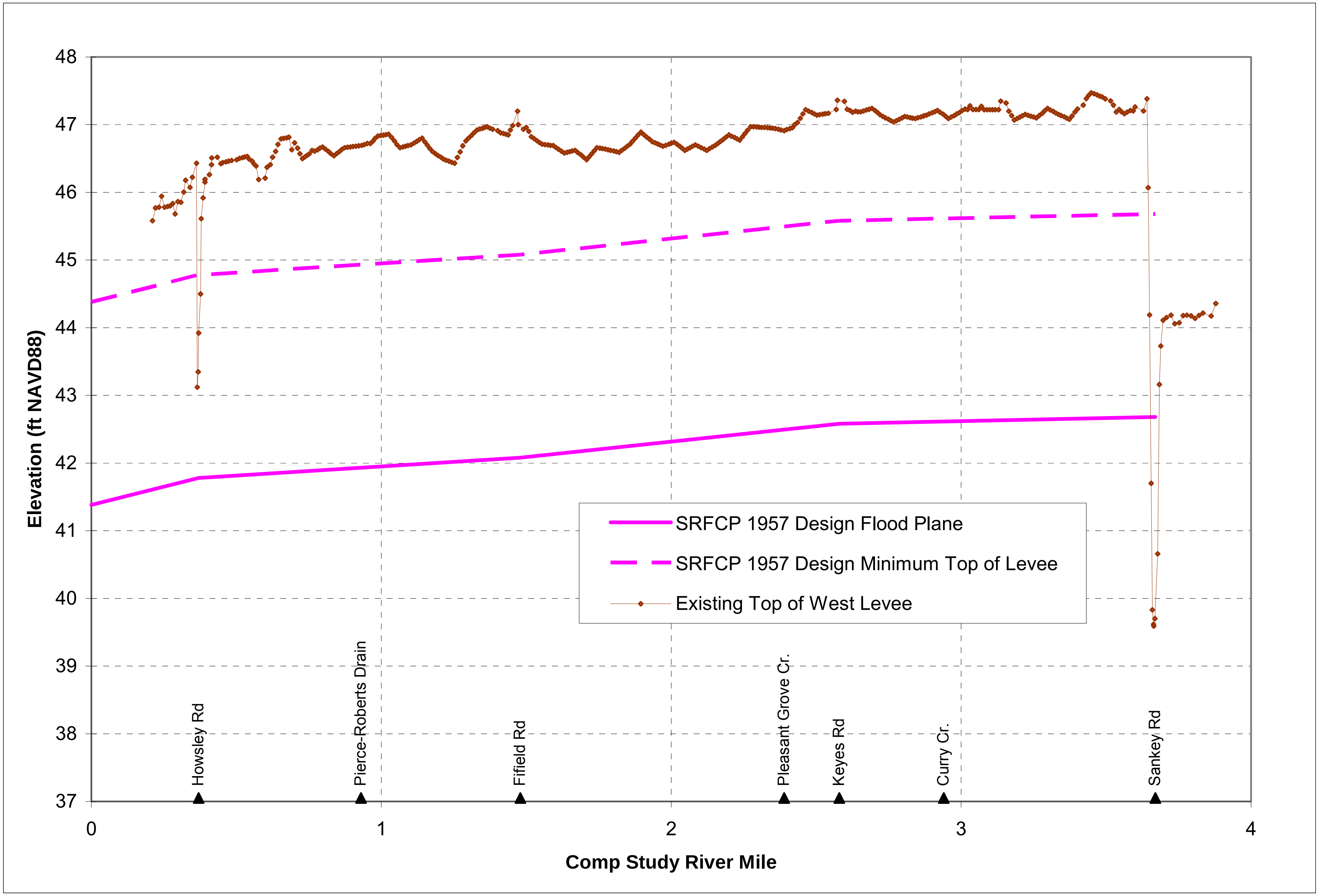

Figure 15. SRFCP 1957 Design Profile, Pleasant Grove Creek Canal

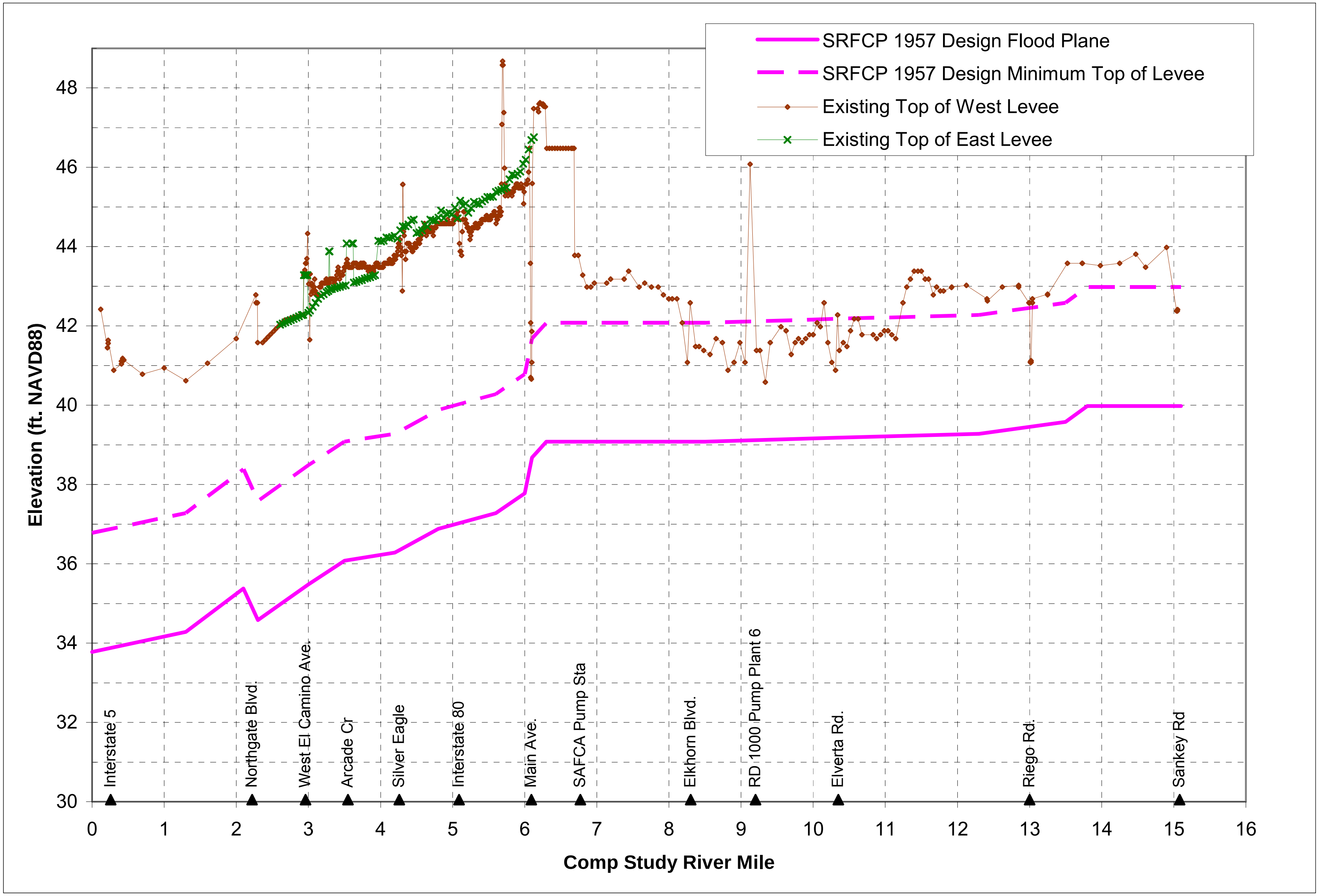

Figure 16. SRFCP 1957 Design Profile, NEMDC

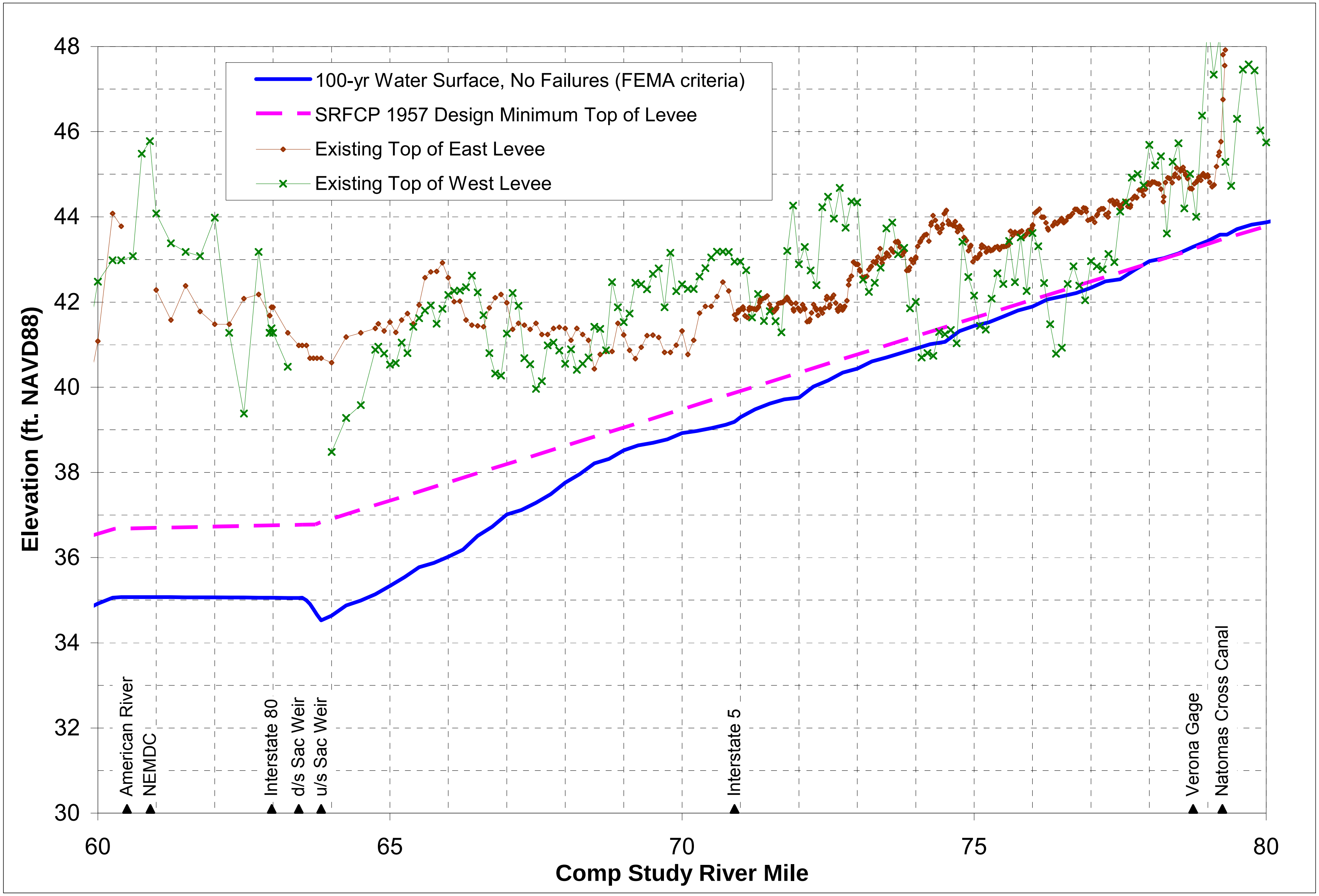

Figure 17. 100-year Water Surface Profile – Sacramento River Natomas Reach

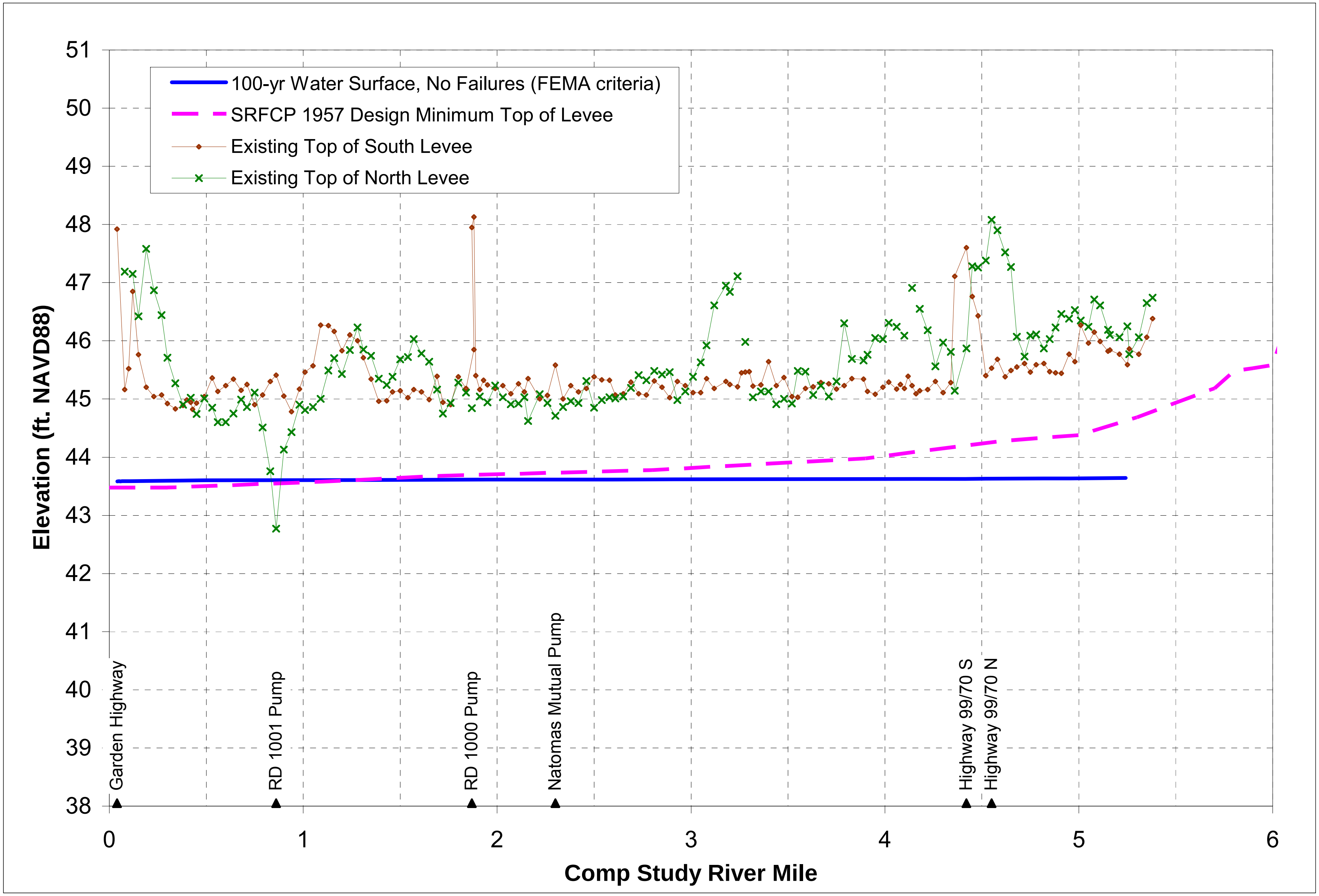

Figure 18. 100-year Water Surface Profile – Natomas Cross Canal

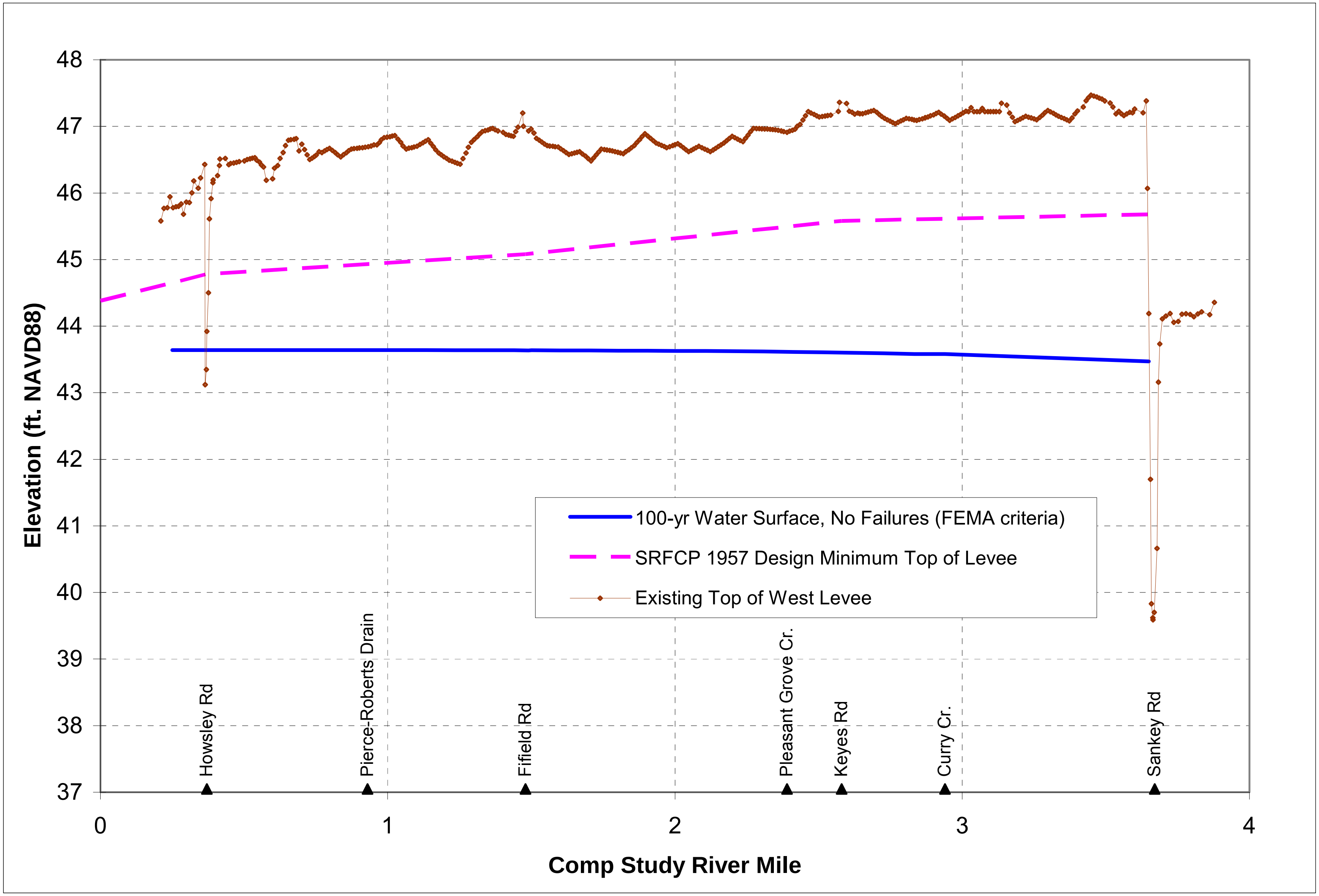

Figure 19. 100-year Water Surface Profile – Pleasant Grove Creek Canal

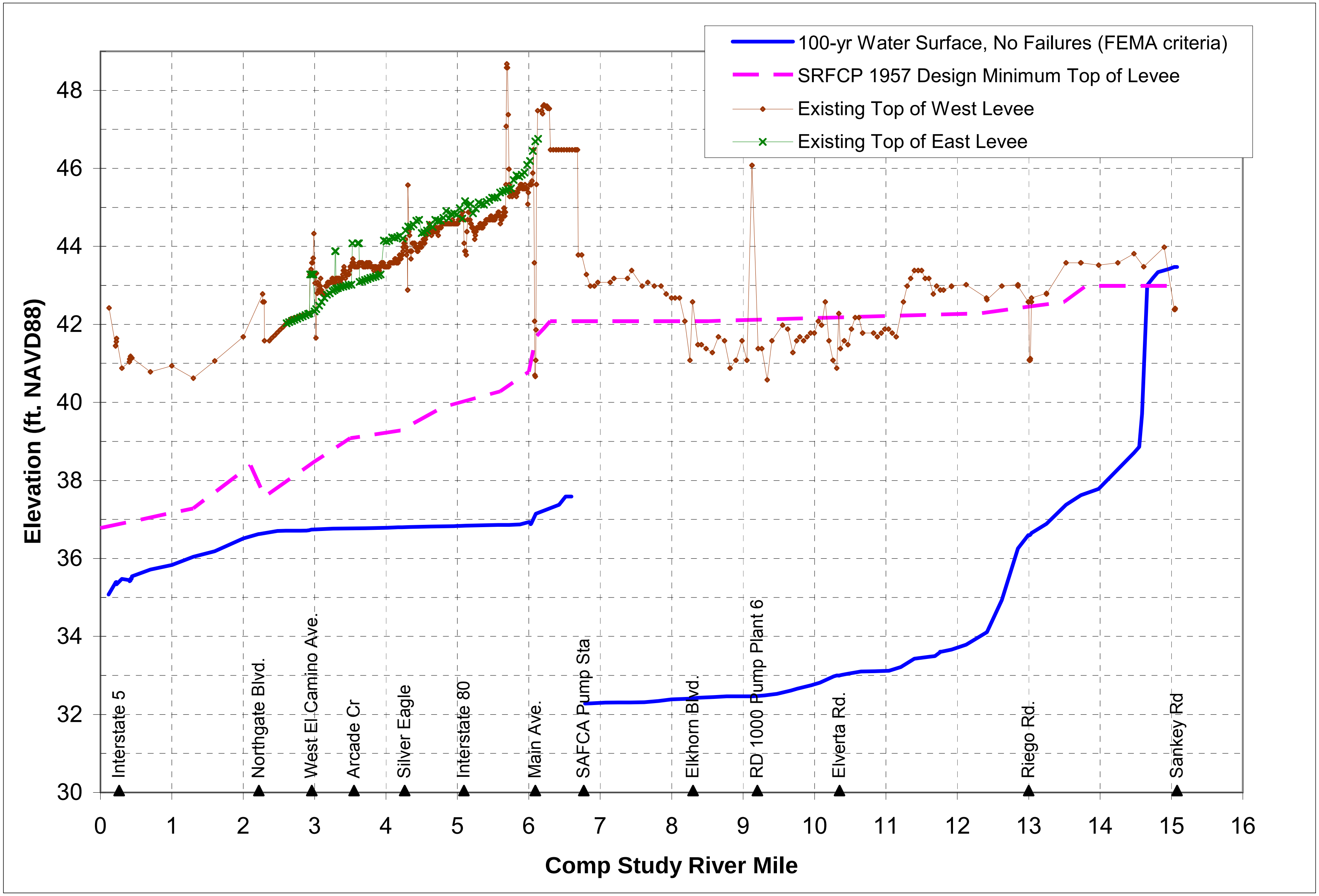

Figure 20. 100-year Water Surface Profile – NEMDC

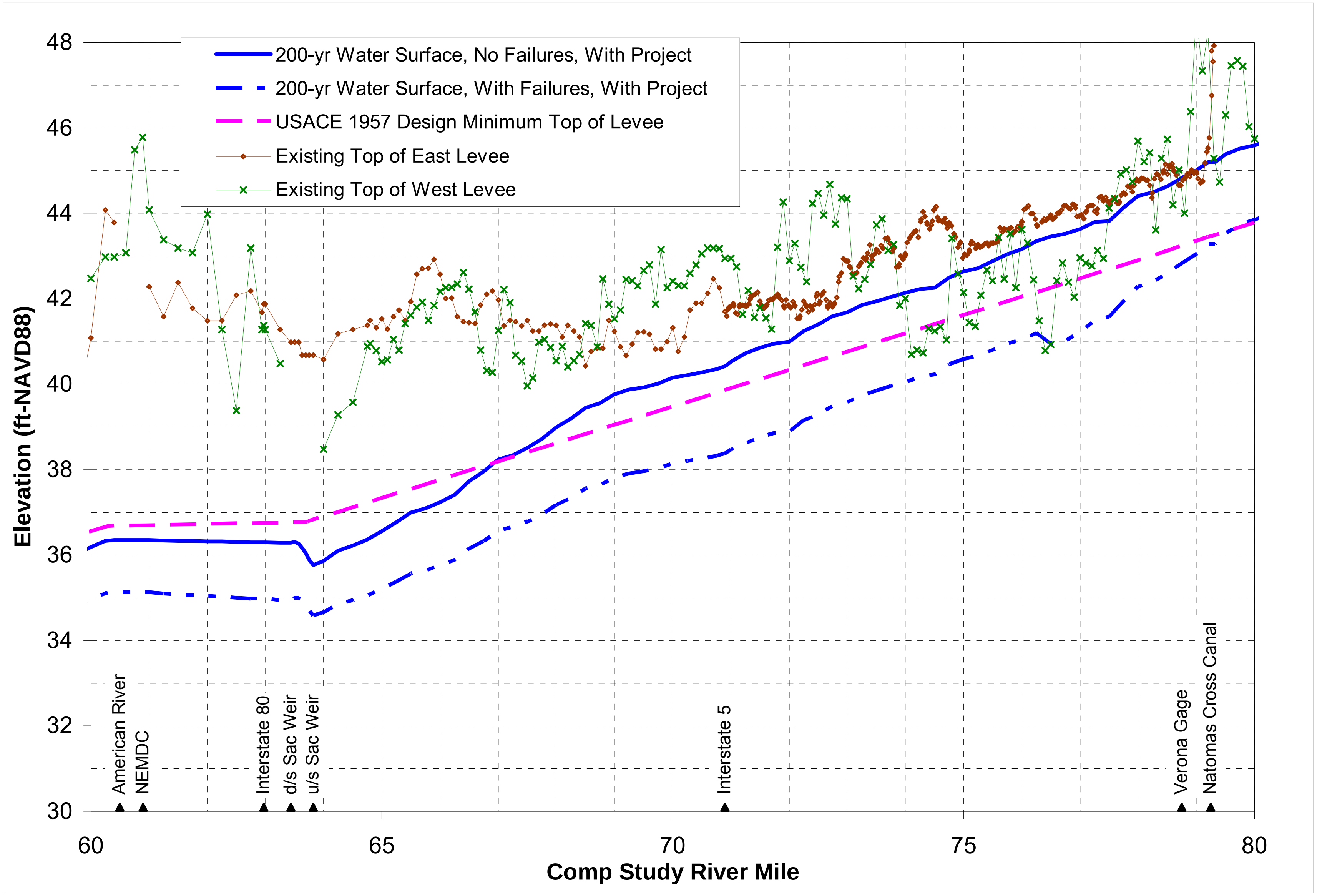

Figure 21. 200-year Water Surface Profile – Sacramento River Natomas Reach

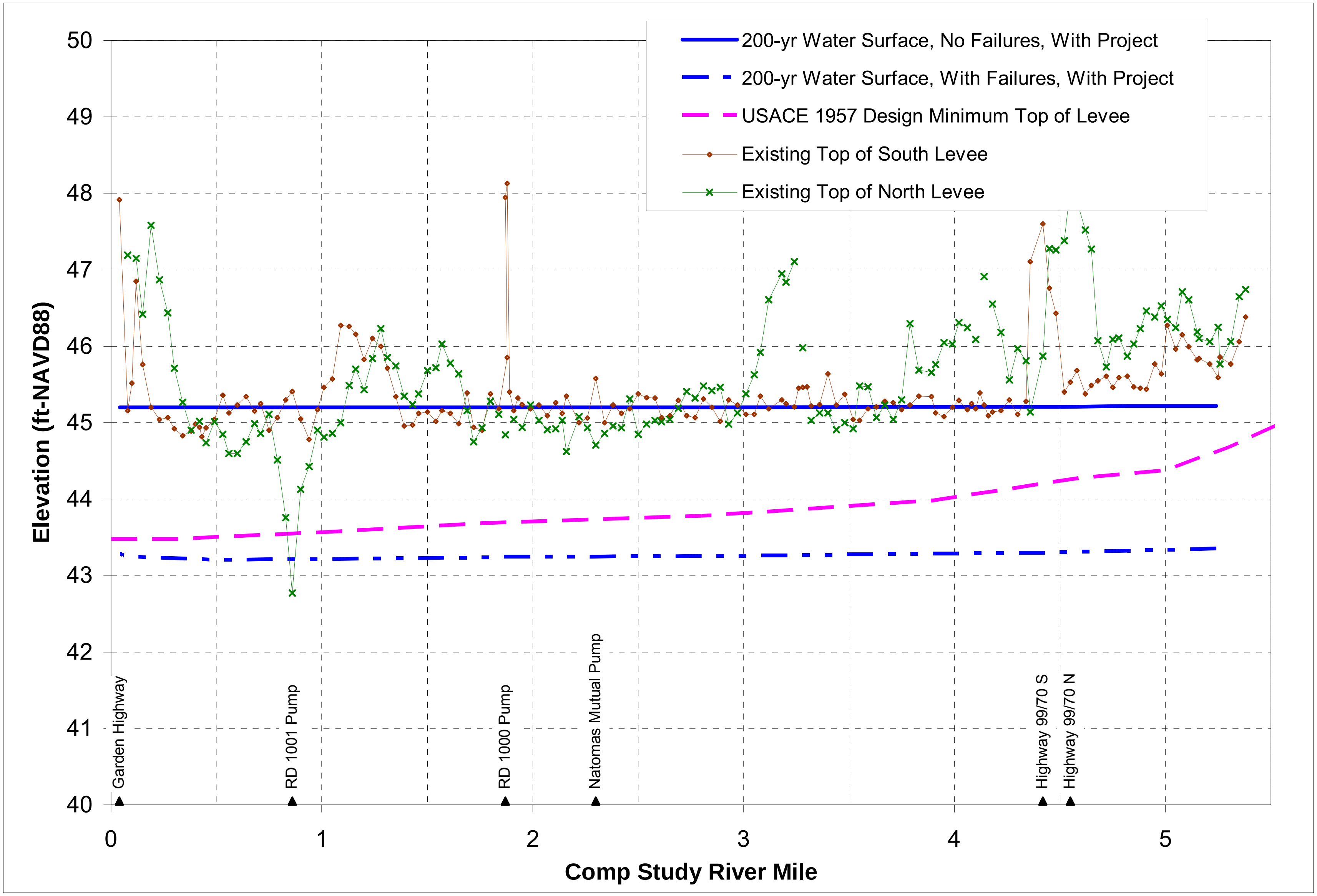

Figure 22. 200-year Water Surface Profile – Natomas Cross Canal

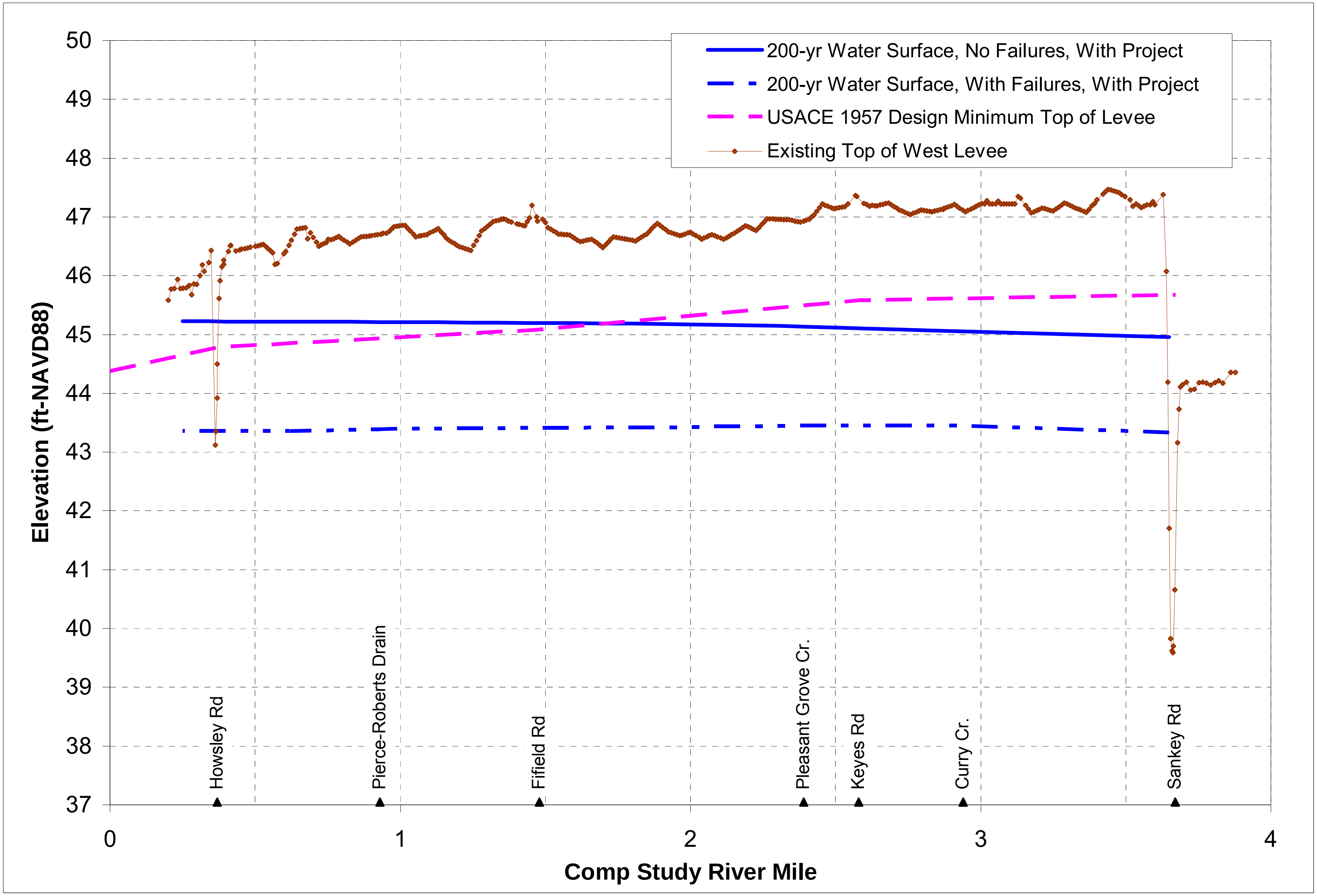

Figure 23. 200-year Water Surface Profile – Pleasant Grove Creek Canal

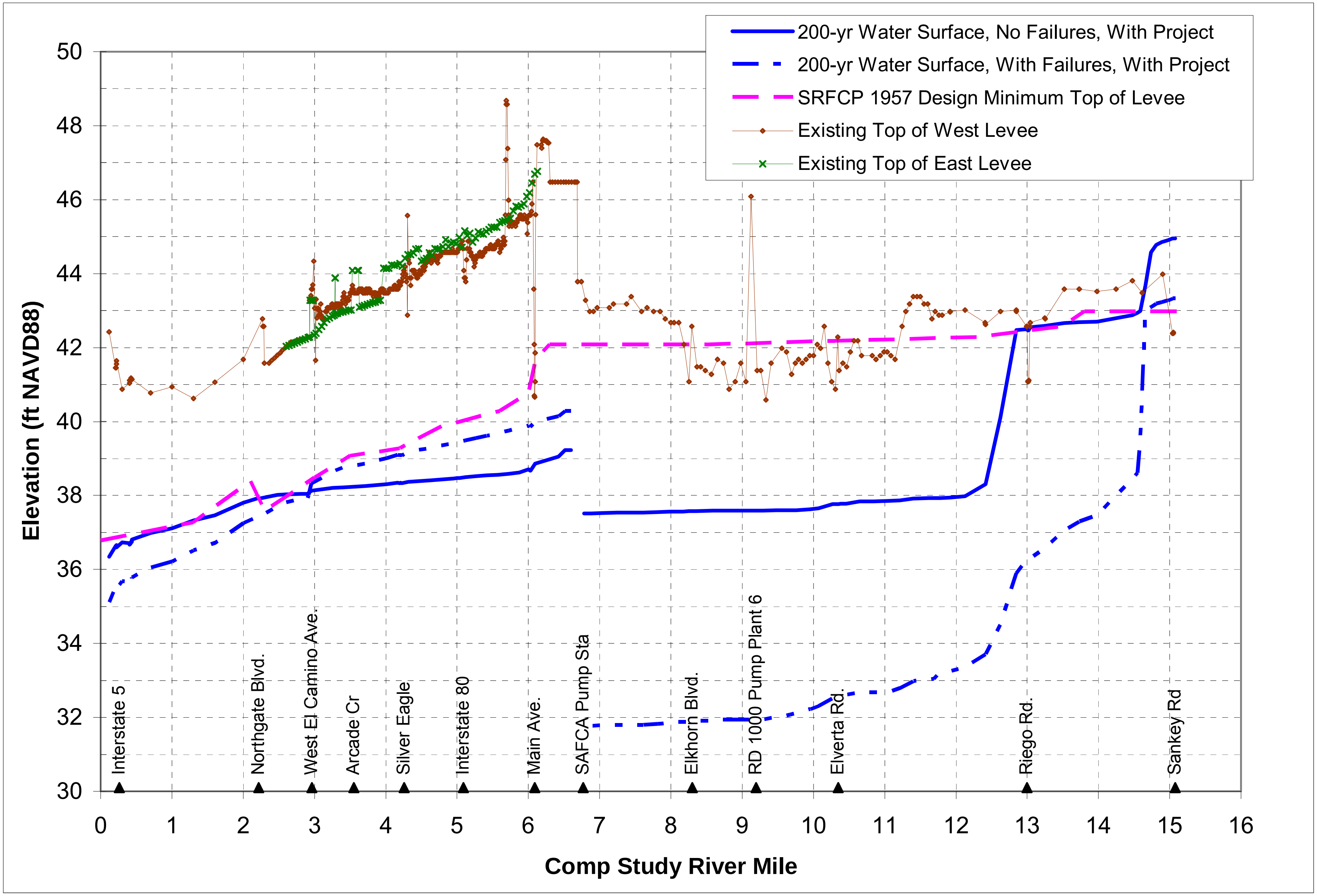

Figure 24. 200-year Water Surface Profile – NEMDC

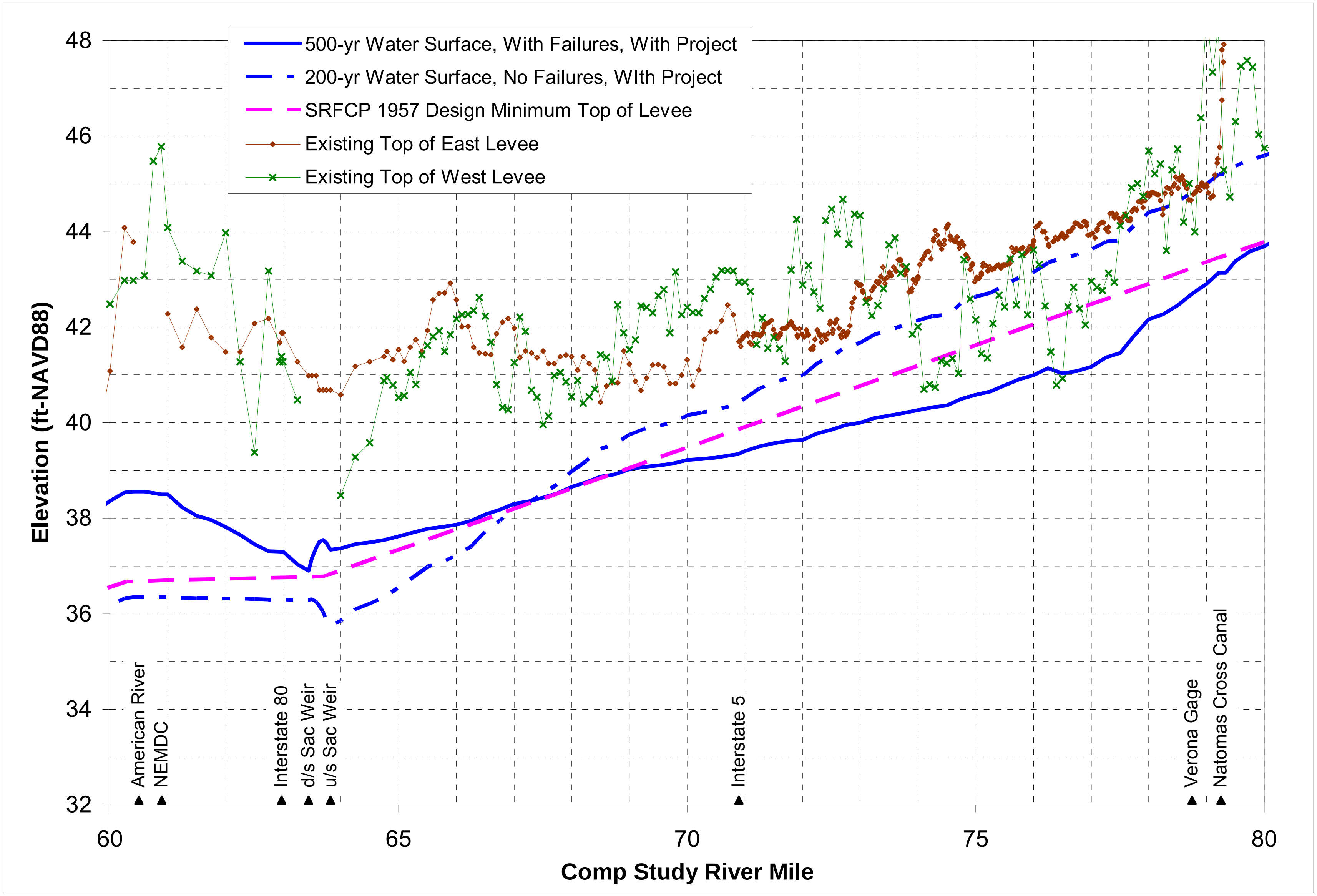

Figure 25. 500-year Water Surface Profile – Sacramento River Natomas Reach

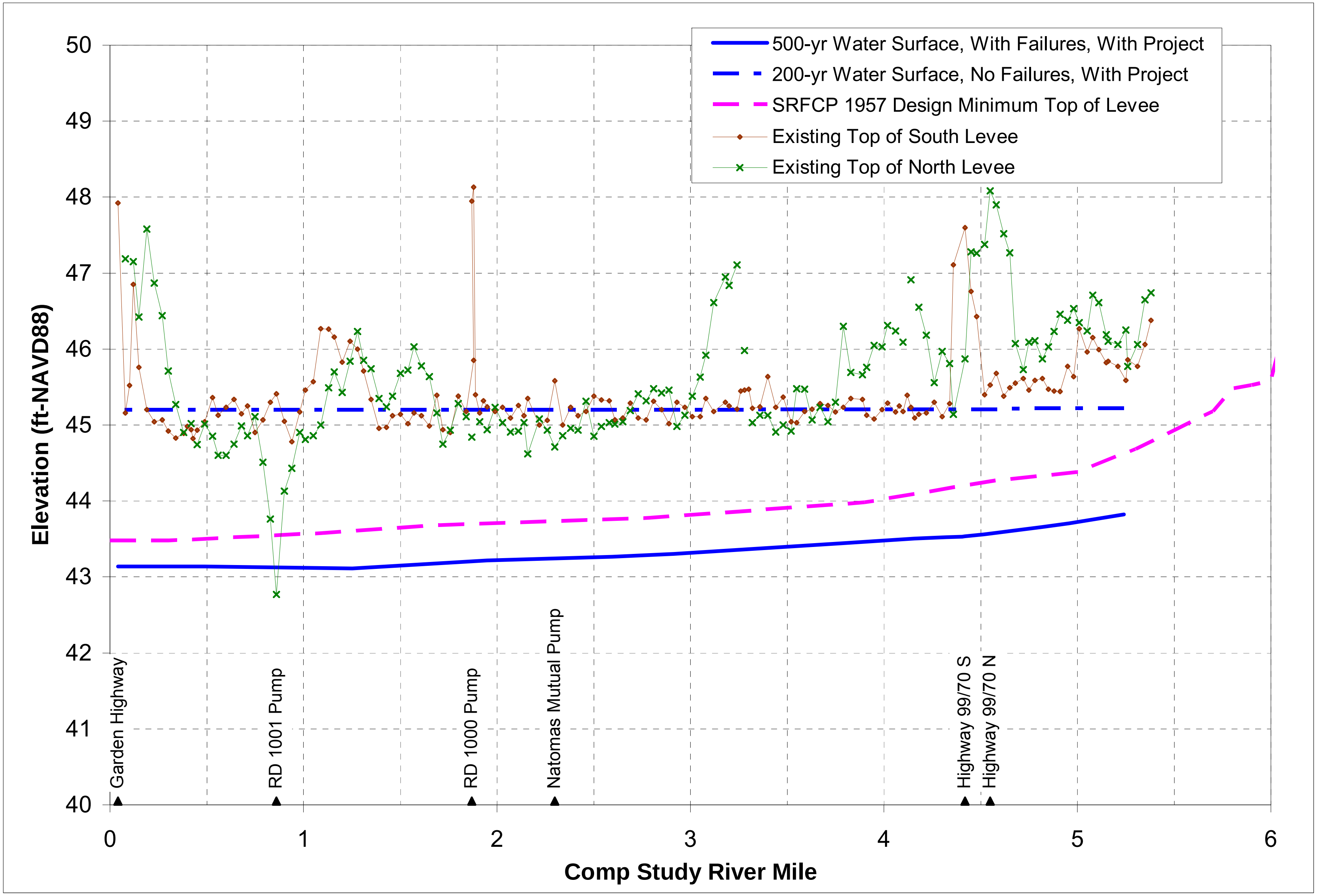

Figure 26. 500-year Water Surface Profile – Natomas Cross Canal

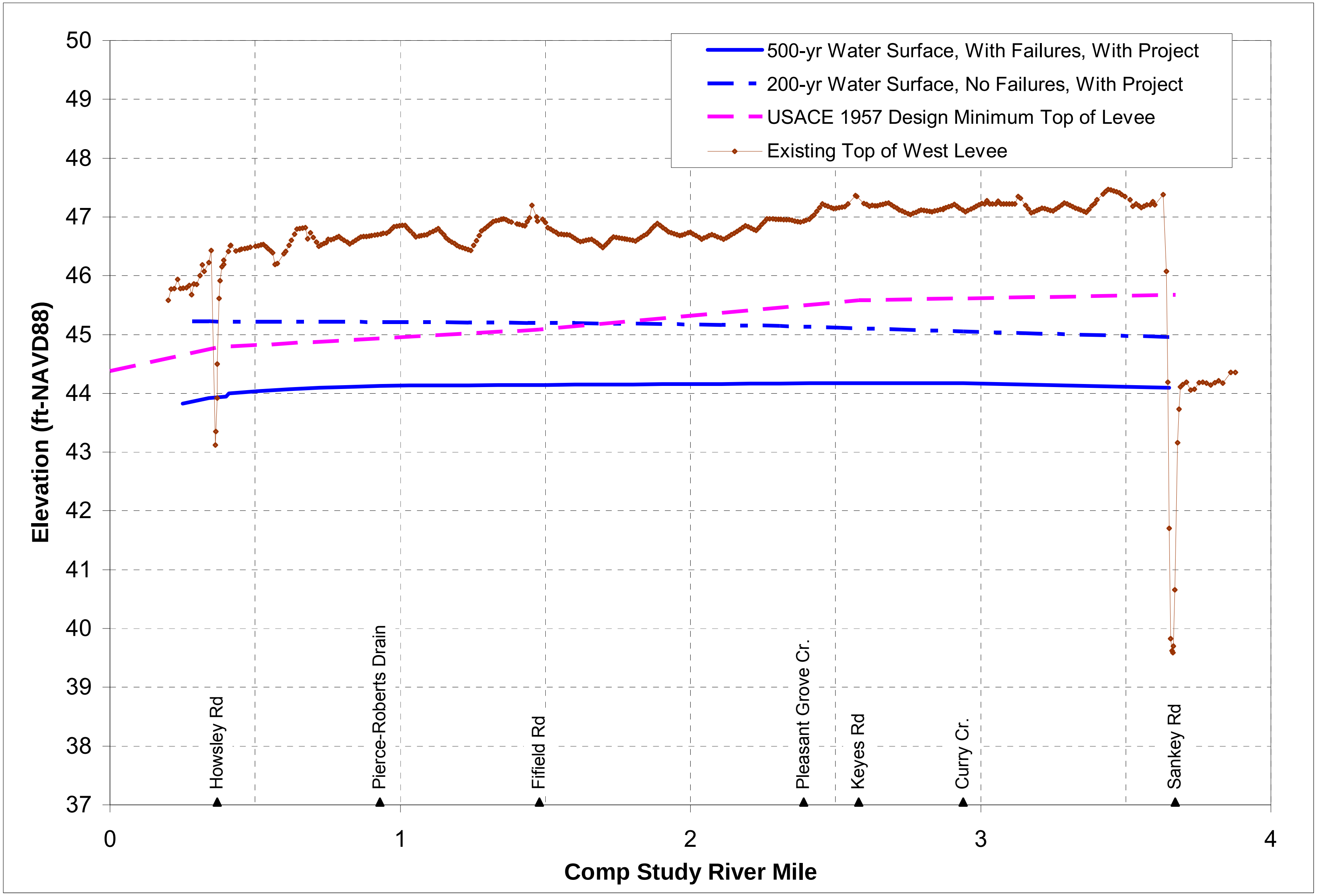

Figure 27. 500-year Water Surface Profile – Pleasant Grove Creek Canal

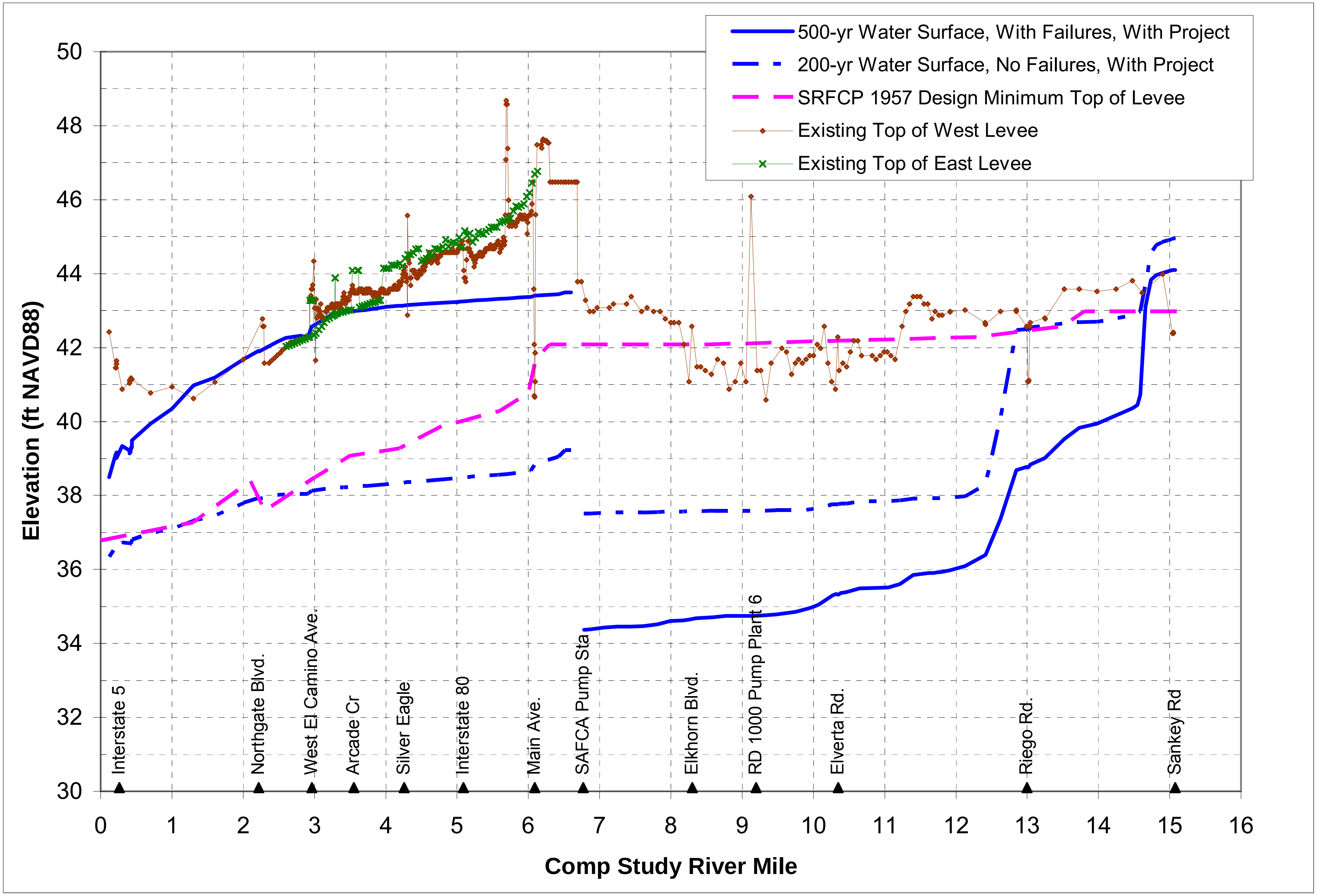

Figure 28. 500-year Water Surface Profile – NEMDC

C2 Groundwater Impact Analysis

Evaluation of Potential Groundwater Impacts Due to Proposed Construction for Natomas Levee Improvement Program

prepared for:

Sacramento Area Flood Control Agency
(SAFCA)

prepared by:

Luhdorff & Scalmanini,
Consulting Engineers

May 4, 2009

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Acronyms and Abbreviations

AFB	Air Force Base
af	acre-feet
af/ac/yr	acre-feet per acre per year
af/ft^2	acre-feet per square foot
afy	acre-feet per year
CVIGSM	Central Valley Integrated Groundwater and Surface Water Model
DWR	California Department of Water Resources
EIR	Environmental Impact Report
EIS	Environmental Impact Statement
ET	evapotranspiration
FAA	Federal Aviation Agency
ft	feet
ft/day	feet per day
ft/ft	feet per foot
GGS	giant garter snake
GPS	Global Positioning System
HEC	Hydrologic Engineering Center
HDR	HDR Engineering, Inc.
IGSM	Integrated Groundwater and Surface Water Model
lf	linear feet
LSCE	Luhdorff & Scalmanini, Consulting Engineers
M&H	Mead & Hunt
M&I	municipal and industrial
MBK	MBK Engineers
msl	mean sea level (based on NAVD88)
MW	Montgomery Watson
MWH	Montgomery Watson Harza
NARIGSM	North American River Integrated Groundwater and Surface Water Model
NAVD	North American Vertical Datum
NBC	Natomas Basin Conservancy
NBHCP	Natomas Basin Habitat Conservation Plan
NCC	Natomas Cross Canal
NCMWC	Natomas Central Mutual Water Company
NEMDC	Natomas East Main Drainage Canal
NGVD	National Geodetic Vertical Datum
NLIP	Natomas Levee Improvement Project
pers. comm.	personal communication
PGCC	Pleasant Grove Creek Canal
RD 1000	Reclamation District No. 1000
SACIGSM	Sacramento County Integrated Groundwater and Surface Water Model
SAFCA	Sacramento Area Flood Control Agency

Acronyms and Abbreviations (continued)

SCS	Soil Conservation Service
SIA	Sacramento International Airport
URS	URS Corporation
USACE	U.S. Army Corp of Engineers
VVA	Valley View Acres
WRIME	Water Resources & Information Management Engineering

1.0 Introduction

The Sacramento Area Flood Control Agency (SAFCA) requested that Luhdorff and Scalmanini, Consulting Engineers (LSCE) conduct an investigation of the potential groundwater impacts of levee improvements proposed by SAFCA along portions of the levees surrounding the Natomas Basin. These include the Sacramento River East Levee, the Natomas Cross Canal (NCC) South Levee, the Pleasant Grove Creek Canal (PGCC) West Levee, the Natomas East Main Drainage Canal (NEMDC) and Steelhead Creek West Levee, and the American River North Levee. Most of the proposed levee improvements will have no effect on groundwater, but there are potential effects due to land use changes, slurry cutoff walls, new or relocated canals, and borrow site excavation. LSCE (2008a) prepared a preliminary evaluation on the effects of proposed Sacramento River East Levee slurry cutoff walls in a previous report entitled *Evaluation of Potential Groundwater Impacts Due to Proposed Sacramento River East Levee Improvements with Emphasis on Reaches 2 and 3*. The information in this report updates and supercedes the contents of the previous report.

This report includes detailed water budgets prepared for the Natomas Basin to evaluate the groundwater impacts of all proposed SAFCA construction activities. The water budgets are partially based on the results of two existing numerical groundwater flow models that together simulate the North and South American Subbasins (including the Natomas Basin) in Sutter, Placer, and Sacramento Counties. Water Resources and Information Management Engineering, Inc. (WRIME) updated these models in 2007-2008 to better reflect existing and predicted future land and water use in the Natomas Basin. Some of the groundwater budget results summarized below are based on the 2030 simulations, which are summarized in LSCE (2008b). A groundwater budget for proposed SAFCA construction activities was calculated separately and was used to evaluate the cumulative impacts of these activities on existing and future groundwater conditions in the Natomas Basin and the North American Subbasin.

1.1 Report Revisions

This is a revised version of the report submitted to SAFCA on November 14, 2008. Revisions to this and other reports prepared for the Natomas Levee Improvement Project (NLIP) Phase 3 Project Environmental Impact Report (EIR)/Environmental Impact Statement (EIS) were necessary due to a requirement by the U.S. Army Corps of Engineers (USACE) that all elevations be converted from the NGVD 1929 vertical datum to the NAVD 1988 vertical datum. Revisions based on the datum change were made to one table and 13 figures in the report.

Other changes to the report were made to reflect updated plans for slurry cutoff walls surrounding the Natomas Basin. As of April 2009, planned mitigation for levee seepage calls for additional cutoff walls along a number of reaches the Sacramento River East Levee, the PGCC West Levee, the NEMDC West Levee, and the American River North Levee. However, many of these planned cutoff walls are shallower than those previously proposed.

Changes to the analysis of potential slurry cutoff wall impacts were also necessitated by recent revisions to a groundwater flow model prepared by Kleinfelder, Inc. (Kleinfelder) to estimate seepage beneath the Sacramento River East Levee with and without slurry cutoff walls. That analysis was originally summarized in a report entitled *Evaluation of Cutoff Walls Impact on Groundwater Recharge, Sacramento River East Levee, Natomas Levee Improvement Project, Sacramento and Sutter Counties, California*. (Kleinfelder, December 19, 2007). The revised report is dated April 21, 2009. The analysis of the potential groundwater impacts of slurry cutoff walls in this report is partially based on results of the 2009 Kleinfelder model.

1.2 Project Description

The analysis of groundwater impacts in this report relies on project descriptions for proposed SAFCA construction activities obtained from a variety of sources. These include the Draft and Final EIR for the NLIP prepared by EDAW (2007a and 2007b) and the Draft EIS prepared by USACE (2008). Design and engineering work for most of these projects is still in progress, so assumptions were made about the most likely configuration of each project. In cases where even preliminary project descriptions were not available, a conservative option was selected for analysis. Assumptions about many of these projects were provided primarily via personal communications (pers. comm.) with David Rader of EDAW and Marieke Armstrong of Mead & Hunt (M&H). Other information was provided by Wood Rodgers and the engineering team at Kleinfelder.

1.2.1 Levee Improvements

Groundwater impacts from proposed levee improvements are primarily limited to the potential effects of land use changes and slurry cutoff walls. Slurry cutoff walls and seepage berms are proposed mitigation measures to reduce problems of excess seepage beneath the levees, but no direct groundwater impacts are expected from seepage berms because they would be above the water table. The slurry cutoff walls are intended to reduce seepage beneath the levees, and impacts resulting from this reduction are addressed in this report. The location of the five levees discussed below are shown in **Figure 1-1**. A total of about 29 miles of slurry cutoff walls is currently proposed.

Sacramento River East Levee – Levee improvements will require land use changes, including removal of 20 acres of rice, 175 acres of field crops, and five acres of orchard. Slurry cutoff walls are proposed for 12 reaches (total of 10.1 miles) of the 18.1 mile length of the East Levee. These cutoff walls will range in depth from about 14 to 115 feet, with an average depth of about 65 feet.

Natomas Cross Canal South Levee – Proposed land use changes along the NCC South Levee will require removal of about five acres of rice fields. Slurry cutoff walls are being constructed for the entire length (about 5.4 miles) of the NCC. These cutoff walls are projected to be about 70 feet deep. Approximately 5,400 lineal feet (lf) of cutoff wall was installed in 2007, and another 3,600 lf was planned to be installed in 2008.

Pleasant Grove Creek Canal West Levee – The PGCC West Levee is about 3.3 miles long, and slurry cutoff walls ranging in depth from 20 to 50 feet are currently proposed for about

14,000 lf of the levee. Proposed land use changes along the PGCC West Levee would require removal of about 50 acres of rice fields.

Natomas East Main Drainage Canal West Levee – The NEMDC and Steelhead Creek West Levee is about 13.3 miles long. Improvements to the NEMDC West Levee are in the early planning stages, but slurry cutoff walls are being considered for about 8.7 miles of the levee. The estimated depths of these cutoff walls are range from 30 to 45 feet for the North NEMDC and 30 to 53 feet for the South NEMDC. Land use changes due to NEMDC levee improvements have not been evaluated, but irrigated agriculture is limited to the northern portion of the levee and effects are expected to be minimal.

American River North Levee – The American River North Levee is about 2.2 miles long in the Natomas Basin. Plans for improvements to this levee are in the very early planning stages, but slurry cutoff walls are under consideration for the entire length of the levee. Proposed cutoff walls would have an estimated depths of approximately 35 feet for Reaches 1 and 2 and 80 feet for Reaches 3 and 4. There is no irrigated agriculture in this area to be affected by levee improvements.

1.2.2 Canal Improvements

SAFCA is planning to construct one new canal in the Natomas Basin and relocate or improve three existing canals. This construction will necessitate land use changes, including the loss of irrigated agricultural land. Although seepage from existing canals has not been quantified, it is considered to be a significant contributor to groundwater recharge in the Natomas Basin. The new and relocated canals will be unlined and will result in an overall increase in the rate of canal seepage. The proposed locations of new and existing canals discussed below are shown on **Figure 1-1**.

Giant Garter Snake/Drainage Canal – SAFCA plans to construct a new Giant Garter Snake (GGS) and Drainage Canal east and roughly parallel to the Sacramento River East Levee. The GGS/Drainage Canal will be about 4.4 miles long and 50 feet wide at the waterline, and will be unlined. A total of 45 acres of the land where the GGS/Drainage Canal will be constructed is currently planted to field crops.

West Drainage Canal – The GGS/Drainage Canal begins at the terminus of the West Drainage Canal. A number of improvements to the West Drainage Canal are planned, including rerouting of about 4,700 lf of the existing canal. The overall length of the canal will increase from about 3.6 to 3.9 miles, and the average width at the waterline will increase from 30 to 72 feet.

Elkhorn Canal – The Elkhorn Canal, which is located east of the Sacramento River East Levee and northwest of the Sacramento International Airport (SIA), is about 3.8 miles long and 16 feet wide. SAFCA plans to relocate this canal to make room for levee improvements. The relocated canal will be about 4.2 miles long and 32 feet wide. Approximately one mile of the existing Elkhorn Canal is lined with concrete, and about 6,000 lf of the relocated canal is proposed to be lined. In addition, two sections of the relocated canal (total of about 3,950 lf), primarily through the Teal Bend Golf Course, would be piped.

Riverside Canal – This canal, which is located east of the Sacramento River East Levee in the southwestern corner of the Natomas Basin is about 3.7 miles long and seven feet wide. SAFCA plans to relocate the Riverside Canal to accommodate levee construction, and the new canal would be about 3.9 miles long and ten feet wide.

1.2.3 Borrow Sites

SAFCA will require several borrow sites in the Natomas Basin to obtain sufficient soil for the proposed levee and canal improvements. The locations of these borrow sites are shown on **Figure 1-1**.

Airport North Bufferlands – The Airport North Bufferlands borrow site consists of 737 acres owned by the SIA and located north of the airport. Approximately 630 acres of this site that had previously been planted to rice have recently been removed from rice cultivation or other land uses that would attract water fowl at the request of the Federal Aviation Agency (FAA) and is currently fallow. SAFCA plans to remove about four to six feet of borrow material and restore the site to non-irrigated grassland.

Brookfield Property – The Brookfield property consists of 353 acres at the northern tip of the Natomas Basin. Approximately 325 acres of this property is currently planted to rice, and SAFCA plans to restore it to rice cultivation after removing the borrow material. The current crop mix is about 50% regular rice and 50% wild rice (Jack DeWit, pers. comm., July 8, 2008). Up to six feet of soil will be excavated, including one foot of topsoil that will be stockpiled and replaced after borrow operations are complete. The property is currently irrigated with groundwater, but SAFCA plans to provide the infrastructure so that most of the property can be irrigated with surface water after removal of borrow material. Engineering work is still in progress, but SAFCA estimates that about 80 percent of the property would be irrigated with surface water in the future after reclamation is complete.

Fisherman's Lake – The Fisherman's Lake borrow site is located at the northern end of the existing Fisherman's Lake in the southwestern portion of the Natomas Basin. Engineering work has not been completed for this site, but SAFCA estimates that about 100 acres of land currently planted to rice would be used for borrow material and would be restored to managed marsh.

1.3 Potential Impacts

The purpose of this report is to evaluate the potential groundwater impacts of SAFCA's proposed construction activities. These potential impacts can be grouped into three general categories:

1) Changes in groundwater recharge. These will occur due to land use changes and canal improvements. Specifically, the conversion of land from irrigated to non-irrigated land uses will reduce groundwater recharge, and canal construction and widening will increase groundwater recharge.
2) Changes in groundwater flow. Groundwater flow beneath the levees surrounding the Natomas Basin will be reduced due to the proposed slurry cutoff walls. Reductions in groundwater flow will generally be in the form of:
    a) Reduced groundwater recharge from the Sacramento and American Rivers;
    b) Reduced subsurface inflow from the north beneath the NCC; or

c) Reduced subsurface outflow to the east beneath the PGCC and NEMDC.

3) Changes in groundwater pumping.

Other potential groundwater impacts include:

- Groundwater quality degradation in the Natomas Basin due to reduced inflow of good quality recharge from the River and reduced groundwater outflow; and
- Impacts to the yield of wells located along levees where the cutoff walls would be constructed.

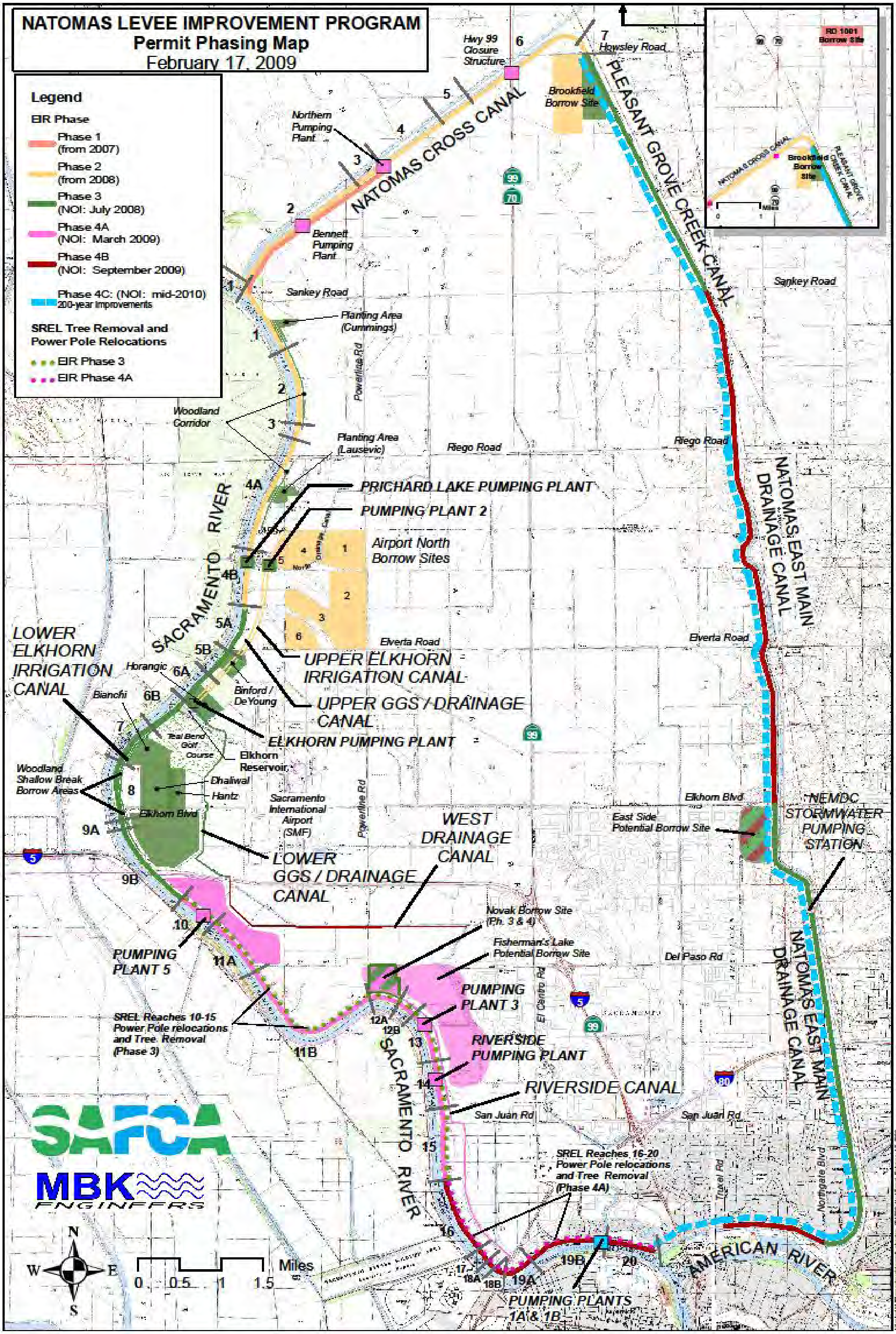

Figure 1-1
Proposed SAFCA Construction Locations for Natomas Levee Improvement Program

2.0 Hydrogeologic Conditions

2.1 Land Use and Water Supply

The Natomas Basin was used as the primary study area for the water budgets discussed below. As shown on **Figure 1-1**, the Natomas Basin is located on the east side of the Sacramento River, between the rural community of Pleasant Grove and the City of Sacramento, in Sutter and Sacramento counties. It consists of about 54,400 acres of agricultural and urban land surrounded by the Sacramento River on the west, the NCC on the north, the PGCC and the NEMDC on the east, and the American River on the south. Except for the SIA and the Teal Bend Golf Course, urban development in the area is primarily limited to the southeast corner of the Natomas Basin at present. This is expected to change in the future as several large developments are in the planning stages.

The Natomas Basin is surrounded by 42 miles of levees, which are maintained by Reclamation District No. 1000 (RD 1000). RD 1000 also operates and maintains a large drainage system within its boundaries to recirculate or dispose of agricultural and urban runoff. This system includes seven large pumping plants and 180 miles of canals and ditches.

Land use in the Natomas Basin is primarily agricultural, with rice being the primary crop. Approximately 28,700 acres were irrigated in 2004, and rice accounted for about 79 percent of the total. Other crops include alfalfa, clover, and oat hay; tomatoes and sugar beets; and crops such as wheat and safflower that are rotated with rice and tomatoes. Most of the agricultural land is irrigated by surface water diverted from the Sacramento River by Natomas Central Mutual Water Company (NCMWC). Much of the information provided below is based on the NCMWC Draft Groundwater Management Plan (2002) and the Integrated Water Resources Management Plan (American States Water Company, et al., 2006).

NCMWC operates three primary river diversions on the Sacramento River. Water is also diverted at two locations from the NCC. Water diverted from the NCC flows from north to south, while water diverted from the River flows generally from west to east, then south. NCMWC's surface water diversions average about 100,000 acre-feet per year (afy). This includes an estimated 10,000 afy diverted during the fall and winter to reflood fields for rice straw decomposition.

NCMWC completed the installation of a tailwater recirculation system in 1986 so that drainage water can be reused during the irrigation season to improve Sacramento River water quality, reduce river diversions, and increase overall efficiency. The recirculation system recaptures tailwater for re-use either directly to fields or back into the main irrigation canals. In recent years, NCMWC has relied heavily on recycled tailwater to supplement its Sacramento River entitlement. Tailwater is recycled partly because it cannot be discharged back to the Sacramento River due to water quality regulations. During a normal irrigation season, all agricultural drainage water is recirculated during the rice growing season, which typically ends in August.

The NCMWC Draft Groundwater Management Plan contains an estimate of 30,000 afy of recycled tailwater (NCMWC, 2002).

Approximately 3,300 acres of agricultural land are irrigated primarily with groundwater. This includes the entire northeastern portion of the Natomas Basin, which is not served by the existing NCMWC surface water distribution systems. The total groundwater pumpage in the Natomas Basin was estimated to be about 24,500 af in 2004 (LSCE, 2008b). Most of this was agricultural pumpage and included about 18,500 af in Sutter County and 6,000 af in Sacramento County.

The Natomas Basin Conservancy (NBC) currently owns over 4,000 acres of land in the Natomas Basin. The NBC began land acquisitions after completion of the Natomas Basin Habitat Conservation Plan (NBHCP) by the U.S. Fish and Wildlife Service and the California Department of Fish and Game in 1997. The NBHCP specified that lands be acquired for habitat conservation as mitigation for the effects of urban development in the Natomas Basin on endangered species and other wildlife. Under the terms of the NBHCP, NBC will ultimately acquire about 8,750 acres of land to mitigate the loss of approximately 17,500 acres slated for development. Most of the NBC mitigation lands have historically been planted to rice, and NBC plans to keep 50 percent of the lands in rice production and convert 25 percent to managed marsh and another 25 percent to upland habitat. As of 2004, approximately 475 acres had been converted to managed marsh.

Irrigated acreage within the Natomas Basin has decreased in recent years as more land has been converted to urban uses. Land use estimates indicate that the acreage irrigated with surface water decreased by about 4.7 percent per year between 1996 and 2006 (American States Water Company, et al., 2006). NCMWC land use data indicate that the amount of irrigated shareholder lands decreased by about 5.2 percent per year between 2004 and 2007.

2.2 Groundwater Basin and Subbasin Description

The Natomas Basin does not represent a groundwater basin or subbasin as defined by the California Department of Water Resources (DWR). It is located within the North American Subbasin, which is part of the Sacramento Valley Groundwater Basin. The North American Subbasin is located along the eastern edge of the Sacramento River Valley and encompasses about 351,000 acres in Sutter, Placer, and Sacramento counties. The North American Subbasin is bounded by the Bear River on the north, the Feather and Sacramento Rivers on the west, the American River on the south, and the approximate edge of the alluvial aquifer in the Sierra Nevada foothills on the east. The North American Subbasin and adjacent groundwater subbasins are shown on **Figure 2-1**.

2.3 Geology of the Natomas Basin

Prior to development, groundwater in the northern portion of the North American Subbasin flowed to the west and southwest from the Sierra Nevada toward the Feather and Sacramento Rivers. Most wells in the subbasin pump groundwater from either the volcanic Mehrten Formation or the overlying alluvial deposits, which have a westerly dip toward the axis of the valley. The following summary of geologic conditions in the Natomas Basin is based primarily on the *Feasibility Report, American Basin Conjunctive Use Project* (DWR, 1997). This summary focuses on the shallow aquifers that could potentially be impacted by the proposed slurry cutoff walls.

The thickness of the fresh water-bearing deposits in the Natomas Basin increases from about 1,100 feet in the northeast to over 2,000 feet in the southwest. These deposits can be divided into upper and lower aquifer systems. The division between the two aquifer systems is inexact due to data limitations and the difficulty in accurately determining formation contacts. DWR (1997) indicates that the upper aquifer system consists of saturated Laguna Formation and younger sediments that collectively extend to a depth of 200 to 300 feet. For purposes of this study, the upper zone is defined as the upper 300 feet of the aquifer system, and the lower zone is assumed to extend from a depth of 300 feet to the base of fresh water.

The upper aquifer system in the Natomas Basin generally appears to be unconfined or semi-confined due to the presence of clay and silt confining layers within and underlying the upper zone. Sands and gravels in the upper zone are generally thin and laterally discontinuous, and there are thick sequences of fine-grained strata between the more permeable aquifer materials.

The youngest geologic units in the Natomas Basin are flood basin deposits and alluvium. Laterally extensive exposures generally occur along the western margin, adjacent to and within the active channels of the Sacramento River. The flood basin deposits are predominantly fine-grained sediments that have accumulated in flood basins along the major rivers of the Sacramento Valley. The flood basin deposits consist primarily of silt and clay, which yield little water to wells. The flood basin deposits also contain local lenses of sand and gravel deposited by the migrating ancestral river channels. These lenses have high permeabilities and can yield large quantities of groundwater to wells. The thickness of the flood basin deposits in the subbasin ranges up to 100 feet (Olmstead and Davis, 1961).

The alluvium consists primarily of sand, gravel, and silt, with minor amounts of clay, deposited in Recent geologic time (last 10,000 years) by the Sacramento River. Although the alluvium is highly permeable, it is too thin to represent a significant groundwater source. Most high-yield wells completed in the recent alluvium also draw groundwater from underlying formations.

Underlying the alluvium, the Riverbank and Modesto formations of Pleistocene age consist of a heterogeneous mixture of silt, sand, gravel, and clay. The units exhibit large variability in grain size over short distances, both laterally and vertically. The maximum combined thickness of the two units is 50 to 75 feet in the subbasin. On average, these units have moderate permeability but contain some coarser zones with high permeability (Olmstead and Davis, 1961).

The Laguna Formation of Pliocene age and the Turlock Lake Formation of early Pleistocene-age underlie the Riverbank and Modesto formations. Both formations consist primarily of a heterogeneous mixture of interbedded silt, clay, and sand. They contain a few gravel lenses, which are poorly sorted and have relatively low permeability. In general, these two formations are more fine-grained than overlying units, although it is difficult to determine subsurface contacts from drillers' logs. Wells completed in clean Laguna Formation sands and gravels can produce significant quantities of groundwater. The combined thickness of the two units in the subbasin is probably less than 200 feet.

The lower aquifer system consists of non-marine, Mehrten Formation deposits and includes a smaller percentage of coarse-grained sediments. However, individual coarse-grained zones in the lower aquifer are typically thicker than in the upper aquifer. In some areas, the lower aquifer is further divided into two distinct units. The upper unit is comprised of gray to black andesitic sand and associated lenses of stream gravel containing andesitic cobbles and boulders interbedded with thicker blue or brown clay. The lower unit has been described as a dense, hard, gray tuff breccia. It is composed of angular pieces and blocks of andesite in a cemented matrix of andesite, devitrified lapilli, and ash derived from volcanic eruptions in the Sierra Nevada. Based on information from DWR monitoring wells, the Mehrten Formation is at least 900 feet thick near the Sacramento Airport, and the typical lower unit gray tuff does not occur at that location. The lower zone exhibits more confinement than the upper zone but is still considered to be semi-confined. There is a delayed response to imposed stresses in the upper aquifer, indicating hydraulic interconnection between these water-bearing strata.

2.4 Aquifer Hydraulic Conductivity

The ability of an aquifer to transmit water is measured by its hydraulic conductivity (which is closely related to permeability) and saturated thickness; the product of these two parameters is commonly known as aquifer transmissivity. The hydraulic conductivity of alluvial aquifer materials varies over many orders of magnitude, with fine-grained materials (clay and silt) at the bottom of the range and coarse-grained materials (sand and gravel) at the top. Most groundwater flow occurs through sand units, which are much more common in the subsurface than gravels. The hydraulic conductivity of sands is highly variable, depending on grain size, sorting, and cementation.

Long-term, constant-rate pumping tests are the preferred method for estimating hydraulic conductivity and other aquifer properties. Other field methods include short-term pumping tests and slug tests. If borehole logs are available, equations that estimate hydraulic conductivity based on grain-size distribution can be used in the absence of test data. The most common of these is the Kozeny-Carman equation (Kozeny, 1927 and Carman, 1937 and 1956) which has been used by Kleinfelder and URS Corporation (URS) to estimate the hydraulic conductivity of geologic materials beneath the east levee.

As further discussed below, the hydraulic conductivity of sand units underlying the levees is a primary input and the source of greatest uncertainty for models used to estimate seepage beneath the levees. A summary of hydraulic conductivity estimates for the Natomas Basin is provided in **Table 2-1**. The estimates vary by more than an order of magnitude, from 14 to 488 feet per day (ft/day), with a mean of 116 ft/day and a median of 51 ft/day. Values at the low end of the range were estimated by Kleinfelder using the Kozeny-Carman equation, and the highest value was estimated from a short-term pumping test. LSCE estimated a hydraulic conductivity of 36 ft/day based on an aquifer test conducted in the Paulson well in southern Sutter County (LSCE, 2008b).

Groundwater flow models that encompass the North American Subbasin also have relatively high hydraulic conductivities in the Natomas Basin. Hydraulic conductivity estimates used in numerical groundwater flow models are typically adjusted during the calibration process. A groundwater flow model of the Sacramento Valley developed by DWR (1978) used hydraulic conductivity estimates of 51 to 139 ft/day for the upper layer of the model in the Natomas Basin. The groundwater models discussed in Chapter 4 have hydraulic conductivities in the upper layer ranging from 33 to 118 ft/day in the Natomas Basin.

Table 2-1
Hydraulic Conductivity Estimates in Natomas Basin

Estimated By	Location	Hydraulic Conductivity (ft/day)	Material Type	Source
Kleinfelder (2007)[1]	-	14	Sand with 3-7% silt	Kozeny-Carman equation
	-	28	Sand with 0-2% silt	Kozeny-Carman equation
URS (2007)[2]	STA 217+00	56	Sand to silty-sand	Kozeny-Carman equation
		283	Gravel	Kozeny-Carman equation
LSCE	Bianchi Wells 1 and 2	33-49	Sand to silty-sand	Estimated from specific capacity
	Lennar Westlake Well 1	488	Fine to coarse sand with gravel	2-hour pump test (11/21/00) in well perforated 112-132 ft.
	Lennar Paulson Well	36	Sand to silty-sand	36-hour pump test (7/3/07) in well perforated 185-397 ft.
DWR (1978)[3]	Node 37 (Sutter County)	51	Mixed	Sacramento Valley groundwater flow model
	Node 43 (Sacramento County)	139	Mixed	Sacramento Valley groundwater flow model
WRIME	Sutter County portion of Natomas Basin	86-118	Mixed	Layer 1 of North American River IGSM model
	Sacramento County portion of Natomas Basin	33-53	Mixed	Layer 1 of Sacramento County IGSM model
	Average	**116**		
	Median	**51**		

1. Kleinfelder, Inc. 2007. Basis of Design Report, Sacramento River East Levee Reaches 1 Through 4B (Draft)
2. URS Corporation, 2007. Preliminary Geotechnical Reevaluation Report, Sacramento River East Levee (Draft)
3. DWR. 1978. Evaluation of Groundwater Resources: Sacramento Valley

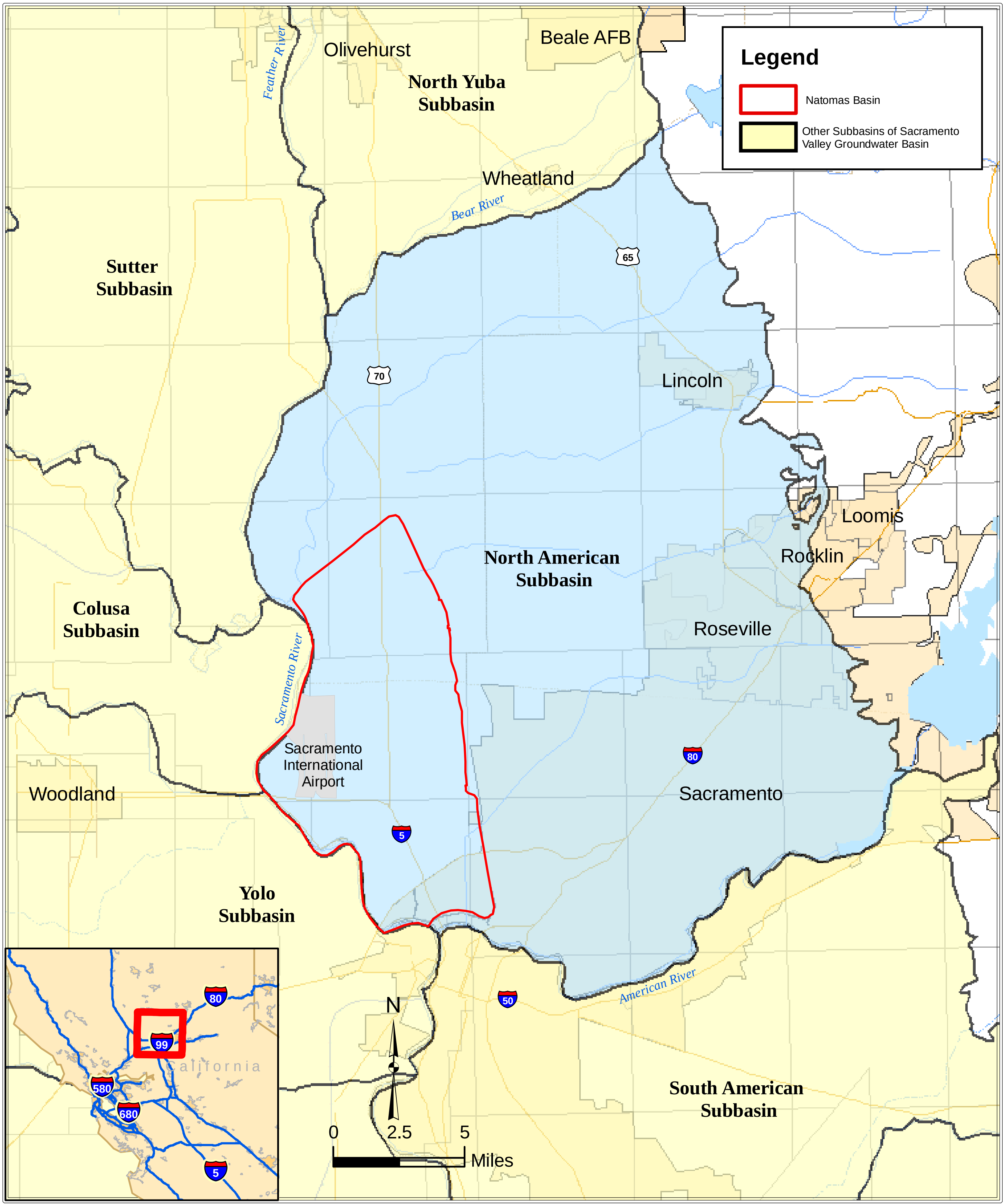

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Figure 2-1
Location of North American Subbasin and Adjoining Subbasins of the Sacramento Valley Groundwater Basin

3.0 Groundwater Levels and Flow

3.1 Sacramento River East Levee Piezometers

DWR has conducted groundwater level monitoring at a number of wells in the Natomas Basin since 1948. DWR monitored approximately 20 wells in 2003 but only 7 wells in 2007. In addition to the wells monitored by DWR, a series of shallow piezometers was constructed along the Sacramento River East Levee in the Natomas Basin to collect groundwater level data for previous investigations of seepage beneath the levee. A total of 38 piezometers has been installed along the levee since 1991, and at least some groundwater level data are available for 27 of these. Groundwater elevations measured in these piezometers have been plotted in order to determine the location and seasonal fluctuations of gaining and losing reaches along the Sacramento River East Levee. The 27 piezometers with water level data include four installed by Kleinfelder in 1998, 13 installed by USACE in 2001, and ten installed by Kleinfelder in 2004. The construction of the piezometers is summarized in **Table 3-1**, and the piezometer locations are shown on **Figure 3-1**. The piezometers range in depth from 12 to 90 feet, but most are between 25 and 50 feet deep. Many of the piezometers are paired based either on depth (shallow vs. deep) or location (closer to the River vs. further away). The latter pairings are particularly useful to show the direction and magnitude of the hydraulic gradient near the River.

Water level measurements at the piezometers have been intermittent, resulting in varying periods of record for water level data between 1999 and 2007. Data from the USACE piezometers are the most useful because the wellhead elevations have been surveyed and manual water level measurements are available. The USACE piezometers have a period of record from January 2002 to October 2003.

The Kleinfelder piezometers were not surveyed at the time of installation, and those installed in 1998 have a short period of record (December 2005 to April 2006). The piezometers installed by Kleinfelder in 2001 have a longer period of record (October 2004 to July 2006). There are no manual measurements available for these piezometers, however, and some of the transducer data are questionable as discussed below. The Kleinfelder piezometers were surveyed by LSCE on February 28 and 29, 2008 using survey-grade Global Positioning System (GPS) equipment with a vertical accuracy of at least one inch. The survey results are shown in **Table 3-1**. No bollards were installed to protect these piezometers, and two of them (PZ-4 and PZ-7) had been destroyed (apparently by farm equipment) by the time of the survey.

Data from the shallow levee piezometers were combined with other water level data to prepare contour maps of equal groundwater elevation for the North American Subbasin and more detailed maps for the Natomas Basin. The contour maps were prepared prior to the GPS survey of the Kleinfelder piezometers; therefore, data from these piezometers were not used to create the contour maps. Hydrographs were also prepared showing groundwater elevations in 23 piezometers and estimated stage in the Sacramento River adjacent to the piezometers. These contour maps and hydrographs were used to evaluate gaining and losing conditions along the

Sacramento River and to estimate the hydraulic gradient between the River and the shallow aquifer.

3.2 Groundwater Elevation Contour Maps

Groundwater elevations and flow directions in the study area are illustrated on groundwater elevation contour maps. DWR (1997) includes spring water level contour maps for the years 1950, 1960, 1965, 1970, 1977, 1980, 1985, 1990, and 1992. As noted by DWR, groundwater generally flowed in a southwesterly direction (from the foothills toward the axis of the valley) under pre-development conditions. Groundwater levels began to decline during the 1940s (or earlier), and the 1960 water level contour map shows three pumping depressions. From north to south, these were located east of Nicolaus, near Pleasant Grove, and near the eastern edge of the Natomas Basin along the Sutter-Sacramento County line. By 1965, the pumping depression east of Nicolaus had largely disappeared, but the pumping depression near Pleasant Grove had deepened and merged with that along the eastern edge of the Natomas Basin. The 1980 DWR contour map shown on **Figure 3-2** indicates that, by 1980, the pumping depression southeast of Pleasant Grove had deepened to about –30 feet msl and merged with a deeper pumping depression beneath McClellan Air Force Base (AFB) in Sacramento County. These pumping depressions are centered about three miles east of the eastern edge of the Natomas Basin. Note that elevations shown on **Figures 3-2** and **3-3** are based on the NGVD 1929 vertical datum. These are copies of historical water level contour maps that cannot be converted to a newer datum. All other elevations in this report are based on the NAVD 1988 datum.

A fall 1997 groundwater elevation contour map for all of Sacramento County prepared by the Sacramento County Water Resources Division and reproduced in NCMWC (2002) is shown on **Figure 3-3**. This contour map indicates that the McClellan AFB pumping depression was linked with two other pumping depressions centered beneath the City of Elk Grove and east of the City of Galt. The Elk Grove pumping depression is the largest and deepest of the three, with a groundwater elevation below –70 feet msl at the center. The Pleasant Grove and McClellan AFB pumping depressions are located in the North American Subbasin; the other two depressions are located in the South American Subbasin.

The DWR and Sacramento County groundwater elevation contour maps were developed using data from wells of variable and often unknown perforated intervals. These composite maps must be considered approximations that do not reflect the fact that groundwater elevations can be significantly different in wells of different depths. Hydrographs of DWR's multiple-completion monitoring wells show that deeper wells in the area typically have lower groundwater elevations than shallower wells because most groundwater pumping occurs from deeper zones, which are more confined. Upper zone groundwater elevation contour maps were prepared for this study, as discussed below.

Water level data for wells completed in the upper zone in the North American Subbasin were evaluated to select recent periods with sufficient data for contouring purposes. Because the primary focus of this investigation is on groundwater flow in the Natomas Basin, contour maps were prepared for periods for which data from the USACE levee piezometers (the only piezometers with surveyed wellhead elevations prior to 2008) were available, and spring and fall contour maps were prepared for 2003. Two versions of the 2003 contour maps were created, one showing the entire subbasin and another showing a more detailed view of the Natomas Basin. Data from about 90 wells were used to prepare each map. The subbasin-scale groundwater elevation contour maps have a contour interval of ten feet; the more detailed maps have a two-foot contour interval. The periods selected for groundwater elevation contour maps, area of coverage, and the number of wells used for each map are as follows:

- **Figure 3-4:** Spring 2003 (North American Subbasin),
- **Figure 3-5**: Spring 2003 (Natomas Basin),
- **Figure 3-6**: Fall 2003 (North American Subbasin),
- **Figure 3-7**: Fall 2003 (Natomas Basin).

The spring 2003 groundwater elevation contour map for the North American Subbasin (**Figure 3-4**) shows that the direction of groundwater flow in the upper zone in most of the subbasin is toward the pumping depression centered in the McClellan AFB area, which had a minimum elevation of about –40 feet msl based on data from McClellan AFB monitoring wells. The northeastern portion of the subbasin is the only area where the groundwater flow direction was not toward the McClellan AFB pumping depression on **Figure 3-4**. The direction of groundwater flow in the northeastern area is toward the Bear and Feather Rivers, which indicates that both rivers were gaining in the spring of 2003. A gaining reach occurs when groundwater levels are higher than the river stage, creating a gradient for groundwater to flow to the river. Losing conditions occur when the river stage is higher than groundwater levels adjacent to the river, which results in recharge from the River to the aquifer.

The Sacramento River west of the Natomas Basin appeared to be a losing reach in spring 2003. Groundwater elevations shown on **Figure 3-4** range from about 20 feet msl in the northern and northwestern portions of the Natomas Basin to about –15 feet msl in the southeastern corner. The direction of groundwater flow was easterly toward the McClellan AFB pumping depression. The hydraulic gradient was relatively flat especially in the northern half of the study area (about three ft/mile) but became much steeper along the eastern edge (up to 20 ft/mile).

In order to provide additional detail on groundwater elevations and flow directions in the Natomas Basin, the spring 2003 water level data were re-contoured with a contour interval of two feet. The resulting map, shown on **Figure 3-5**, confirms that the direction of groundwater flow was easterly across most of the Natomas Basin. All reaches of the Sacramento River appeared to be losing in the spring of 2003, but the magnitude of the hydraulic gradient near the River gradually increases from north to south. In the northern portion of the Natomas Basin, the hydraulic gradient for flow away from the River was less than three ft/mile. In the southern portion, the easterly hydraulic gradient increased to about nine ft/mile.

The fall 2003 groundwater elevation contour map shown on **Figure 3-6** is generally similar to the spring 2003 map, and the direction of groundwater flow was essentially the same during both periods. Comparison of the two contour maps indicates that fall groundwater levels along the Sacramento River were five to ten feet lower than in the spring, but levels at these two times were similar in the eastern portion of the Natomas Basin. Fall 2003 groundwater levels were also similar to spring levels in the McClellan AFB pumping depression but were about ten feet lower than in the spring in the pumping depression in southwestern Placer County.

Figure 3-7 shows fall 2003 groundwater levels in the Natomas Basin re-contoured with a contour interval of two feet. Although groundwater levels in fall 2003 were lower along the Sacramento River than in the spring, the general direction of groundwater flow was still easterly in most of the study area. The only exception is the northern portion of the Natomas Basin where the direction of groundwater flow was to the south-southwest parallel to the Sacramento River. These reaches of the River appear to be neutral (no significant gain or loss) in fall 2003. Losing conditions prevailed in the southern reaches, but the gradient for flow away from the River was less steep than in the spring.

3.3 Hydrographs of Groundwater Levels and River Stage

Water level hydrographs were prepared for the shallow piezometers along the Sacramento River East Levee in order to evaluate seasonal variations in gaining and losing conditions. In addition to groundwater elevation data from the levee piezometers, river stage estimates are also shown on the hydrographs. Under separate contract for SAFCA, MBK Engineers (MBK) used stage data from the Verona, Bryte, and I Street gages (**Figure 3-8**) to estimate the daily average stage at each piezometer location based on a linear interpolation (Mike Archer, MBK, pers. comm., January 22, 2008). One source of error in the stage estimates is that tidal effects at the Bryte and I Street gages do not propagate upstream to the Verona gage. However, MBK checked the estimates against stage profiles simulated with a calibrated Hydrologic Engineering Center (HEC) surface water model, and concluded that the stage estimates were reasonable.

Hydrographs of groundwater elevations in the shallow piezometers and estimated Sacramento river stage are shown from north to south on **Figures 3-9** through **3-16**. Where piezometers are paired based on distance from the River, data from both piezometers are plotted on the same hydrograph using different symbols. As discussed above, losing conditions occur when groundwater elevations are lower than river stage. For the paired piezometers, a gradient away from the River indicates losing conditions, while a gradient toward the River indicates gaining conditions. The groundwater level data are color coded on the hydrographs, with data showing losing conditions plotted in red and data showing gaining conditions plotted in blue. For the piezometers with surveyed elevations, stage estimates can also be compared with measured groundwater elevations to indicate gaining or losing conditions at unpaired piezometer locations. The groundwater level data plotted on these hydrographs are also color coded to show gaining or losing conditions. Uncertainty in the data is highlighted by the fact that a number of hydrographs show gaining conditions in the spring and fall of 2003 even in the southern half of the Natomas Basin, while the groundwater elevation contour map (**Figure 3-8**) shows losing conditions in this area.

During the winter when the river stage is high, all hydrographs show losing conditions and steep gradients for groundwater flow away from the River. The results are much more variable during the rest of the year when the river stage is lower. Hydraulic gradients are relatively flat during periods of low stage, and gradient reversals appear to be common. Gaining conditions are most likely to occur during the summer and fall when the river stage is lowest. There is more uncertainty about the determination of gaining or losing conditions during the summer and fall because groundwater levels and river stage are similar during these periods. There is also uncertainty during periods of rapidly declining stage because groundwater levels decline at a slower rate than river stage. Continuous data would be needed during these periods to accurately determine the fluctuations between gaining and losing conditions.

Gaining and losing reaches vary by both location and time. URS (2003) indicated that river stage was approximately nine to ten feet above groundwater levels at high stage and one to three feet below groundwater levels at low stage at the northernmost USACE piezometer (2F-01-15N). At the southernmost USACE piezometer (2F-01-19S), river stage was approximately four to five feet above groundwater levels at high stage and one to 1.5 feet below groundwater levels at low stage. For USACE paired piezometers 2F-01-26N and 28N, URS noted that groundwater levels were about 1.25 feet higher in the piezometer closer to the River during high stage and generally similar during low stage. For paired piezometers 2F-01-68N and 69N, URS indicated that groundwater levels were about three feet higher in the piezometer closer to the River during high stage and generally similar during low stage. URS also noted that groundwater levels tended to lag river stage by several days (URS, 2003). The individual hydrographs are discussed below.

Figure 3-9 shows hydrographs of the northernmost piezometers. This includes USACE piezometer 2F-01-15N in Reach 2 and paired Kleinfelder piezometers PZ-7 and PZ-8 in Reach 4a. The hydrograph of 2F-01-15N shows losing conditions during periods of high stage in the winter and spring and gaining conditions during the rest of the year. This is the deepest of the levee piezometers with a screened interval of 80 to 90 feet. This makes the comparison with river stage less valid, but there are no nearby shallow piezometers to show the head difference between shallow and deeper zones. Paired piezometers PZ-7 and PZ-8 show losing conditions during a limited period of record (intermittent from October 13, 2004 to July 12, 2006). The fact that the groundwater elevations were notably lower than the stage estimates for all periods suggests inaccuracies in either the stage estimates, the wellhead elevation, or the water level measurements. The indication of consistently losing conditions should be considered questionable since most other piezometers show a mix of gaining and losing conditions.

Figure 3-10 shows hydrographs of paired USACE piezometers 2F-01-26N and 28N in Reach 4b and paired Kleinfelder piezometers PZ-5D and PZ-6D in Reach 6b. Both piezometer pairs show generally losing conditions during the winter and spring and consistently gaining conditions during the summer and fall. The continuous transducer data from the Kleinfelder piezometers clearly show losing conditions at high stage and gaining conditions at low stage during the winter and spring. This effect is especially noticeable from December 2004 to May 2005 but also occurred during the winter and spring of 2005-2006.

Figure 3-11 show hydrographs of unpaired USACE piezometers 2F-01-51N in Reach 8 and 2F-01-49N in Reach 9a, and **Figure 3-12** show hydrographs of unpaired USACE piezometers 2F-01-56N in Reach 9b and 2F-01-62N in Reach 11b. Compared against estimated river stage, all four piezometers show mostly losing conditions except during periods of rapidly fluctuating stage in the spring and periods of very low stage during the fall. The spring of 2003 was the longest period of gaining conditions during the 22-month period of record.

Figure 3-13 shows hydrographs of paired Kleinfelder PZ-3 and PZ-4 and USACE piezometers 2F-01-68N and 69N in Reach 11b. Piezometers PZ-3 and PZ-4 show losing conditions based on groundwater level data during the entire period of record (October 13, 2004 to October 7, 2006). As for piezometers PZ-7 and PZ-8, the fact that the groundwater elevations were notably lower than the stage estimates for all periods suggests inaccuracies in either the stage estimates, the wellhead elevation, or the water level measurements. The indication of consistently losing conditions should be considered questionable since most other piezometers show a mix of gaining and losing conditions. The data from paired USACE piezometers 2F-01-68N and 69N in Reach 11b are more similar to piezometers in other reaches, with losing conditions occurring during periods of high stage and a mixture of gaining and losing conditions during the rest of the year. Gaining conditions occurred primarily in the spring of 2002 and during periods of lowest stage.

Figure 3-14 shows hydrographs of unpaired USACE piezometers 2F-01-05S in Reach 13 and 2F-01-15S in Reach 15 compared with estimated stage. Most of the data from 2F-01-05S appear to be questionable, with low groundwater levels in the spring and higher levels during the summer, especially in 2002. The data from USACE piezometer 2F-01-15S in Reach 13 track the estimated stage much more closely, but the estimated stage appears to be low relative to the groundwater levels. In particular, the indication of gaining conditions during almost all of 2002 is probably incorrect. The stage estimates appear to be more accurate from December 2002 through October 2003, with losing conditions during periods of high or rising stage and gaining conditions during periods of low or declining stage.

Figure 3-15 shows hydrographs of unpaired USACE piezometers 2F-01-17S and 2F-01-19S in Reach 16 compared with estimated stage. Both piezometers have similar hydrographs, and the estimated stage tracks the groundwater data closely. The hydrographs generally show losing conditions during periods of high or rising stage and gaining conditions during periods of low or declining stage.

Figure 3-16 shows hydrographs of paired Kleinfelder piezometers in Reaches 18b and 19a. The transducers in Kleinfelder piezometers PZ-1 and PZ-2 were not working during most of the monitoring period. Almost all of the data that were collected in January and June-August 2005 show gaining conditions, which is inconsistent with the other piezometers. Water level measurements in paired Kleinfelder piezometers LMW-1 and LMW-4 were made manually, but the measurements made prior to January 2006 appear to be too high when compared with the estimated stage. The measurements made from December 2005 to April 2006 appear to be more reasonable but were made only during periods of high stage. The groundwater level data indicate losing conditions throughout this period.

Depths to water measured in the USACE piezometers located on the land side levee toe typically range from about six feet during the winter to about 18 feet during the summer and fall. This represents a seasonal fluctuation of only about 12 feet. Similarly high groundwater levels and small seasonal fluctuations have been observed at DWR's multiple-completion wells elsewhere in the Natomas Basin. The small seasonal fluctuations are due to a combination of the buffering effect of recharge from the River and from rice fields throughout the Natomas Basin and the fact that most pumping is from deeper zones. Recharge from rice irrigation in the summer months keeps shallow groundwater levels high and is a primary factor in the gaining conditions observed at many of the levee piezometers during periods of low stage.

3.4 Hydraulic Gradient Estimates

The differences in hydraulic head between the paired piezometers and also between the unpaired piezometers and the estimated River stage are tabulated in **Table 3-2**, and these head differences were used to estimate the hydraulic gradient. Losing conditions are indicated by positive head differences and hydraulic gradients, and negative values indicate gaining conditions. Head differences were calculated for the entire period of record and range from about –3 feet to more than 11 feet. For paired piezometers that have been surveyed, head differences were calculated based on both groundwater data and stage estimates.

Average annual head differences and hydraulic gradients were calculated for each individual or paired piezometer based on the most recent 12-month period for which data are available. Due to the problems with some of the piezometer data discussed above, hydraulic gradients were not calculated for USACE piezometer 2F-01-15S and Kleinfelder piezometers PZ-1, PZ-2, LMW-1, and LMW-4. For the two sets of paired USACE piezometers, gradients were estimated by comparing the estimated stage with head in the piezometer closest to the River. Because more data were available from the USACE piezometers during the winter and spring, an average hydraulic gradient was calculated for each month. The monthly gradients were then averaged to determine the average hydraulic gradient for the 12-month period.

As shown in **Table 3-2**, the minimum hydraulic gradient at each piezometer location ranged from –0.0098 to 0.0003 ft/ft, with an average of –0.0039 ft/ft. The minimum hydraulic gradient was negative at all but one site, which indicates gaining conditions. The maximum hydraulic gradient ranged from 0.0054 to 0.0239 ft/ft, with an average of 0.0161 ft/ft. The magnitude of the average maximum hydraulic gradient (0.0239 ft/ft) is more than twice as large as the average minimum gradient (–0.0098 ft/ft) because the gradient is steeper during periods of high stage.

Average monthly hydraulic gradients were calculated for 13 piezometer locations (individual or paired), and an average annual gradient was calculated by averaging the monthly values. As shown in **Table 3-2**, the average annual hydraulic gradient at each piezometer ranged from 0.0006 to 0.0089 ft/ft. All of the average annual hydraulic gradients were positive, which indicates that all reaches exhibited losing conditions over the 12-month period. Although the groundwater elevation contour maps show steeper gradients in the southern portion of the Natomas Basin, there are too many sources of error in the gradient estimates to allow quantification of these spatial variations.

The average annual hydraulic gradient for all piezometers shown in **Table 3-2** was 0.0032 ft/ft or about 17 ft/mile. This represents the estimated average annual gradient for seepage loss from the River to the shallow aquifer based on a combination of piezometer data and estimated stage. This gradient is almost twice as steep as the maximum gradient east of the Sacramento River shown on the spring and fall 2003 groundwater elevation contour maps for the Natomas Basin (**Figures 3-5** and **3-7**). The groundwater contour maps are based on groundwater data only and have too large a scale to show the gradient between these closely spaced piezometers. The steeper gradient near the River calculated above is also due to the low permeability of the riverbed and the fact that the greatest head differences between surface water and groundwater occur during periods of high stage.

Table 3-1
Construction of Sacramento River East Levee Piezometers in Natomas Basin

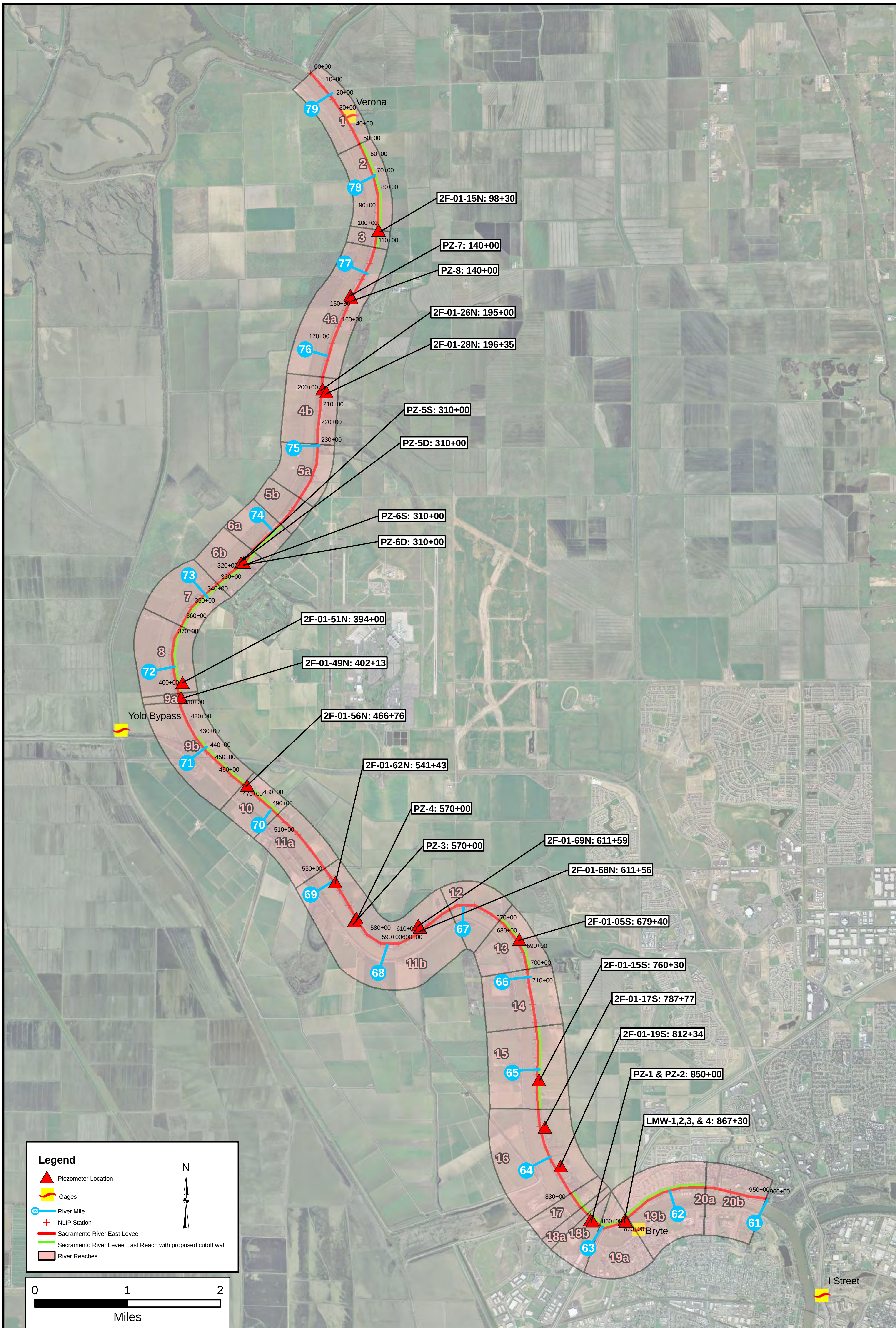
Well ID	NLIP Station	River Mile (Approx)	Levee Mile (Approx)	Land Side Offset (Approx.) (ft)	Ground Surface Elevation (ft msl)[1]	Wellhead Elevation (ft msl)[1]	Screened Interval (ft)	Northing (ft)[2]	Easting (ft)[2]	Installed By	Date Drilled
2F-01-15N	98+30	76.8	1.9	0	27.38	29.18	80 - 90	2037443	6678210	USACE	2001
2F-01-26N	195+00	74.9	3.7	0	28.44	31.26	45 - 46	2028392	6675030	USACE	2001
2F-01-28N	196+35	74.9	3.7	250	29.79	31.03	38 - 48	2028227	6675252	USACE	2001
2F-01-51N	394+00	71.0	7.5	200	25.66	25.36	30 - 37	2011639	6667053	USACE	2001
2F-01-49N	402+13	70.9	7.6	0	27.67	27.29	40 - 60	2010756	6666969	USACE	2001
2F-01-56N	466+76	69.7	8.8	100	25.43	27.79	30 - 40	2005770	6670729	USACE	2001
2F-01-62N	541+43	68.2	10.3	50	27.16	29.34	33 - 43	2000269	6675756	USACE	2001
2F-01-68N	611+56	67.0	11.6	50	24.95	24.78	30 - 40	1997685	6680572	USACE	2001
2F-01-69N	611+59	67.0	11.6	200	23.99	23.79	26 - 36	1997813	6680474	USACE	2001
2F-01-05S	679+40	65.9	12.9	100	24.03	23.50	25 -35	1996993	6686228	USACE	2001
2F-01-15S	760+30	64.3	14.4	0	26.78	29.33	25 - 35	1988983	6687344	USACE	2001
2F-01-17S	787+77	63.7	14.9	100	21.81	21.56	30 - 40	1986284	6687689	USACE	2001
2F-01-19S	812+34	63.2	15.4	250	22.55	25.16	35 - 45	1984077	6688570	USACE	2001
LMW-1	867+30	62.2	16.5	Land Side	23.28	40.06	20 - 25	1980996	6692226	Kleinfelder	Oct. 1998
LMW-4	867+30	62.2	16.5	Water Side	22.28	40.36	20 - 25	1980918	6692285	Kleinfelder	Oct. 1998
LMW-2	867+30	62.2	16.5	Land Side	20.68	40.06	40 - 45	1980996	6692226	Kleinfelder	Oct. 1998
LMW-3	867+30	62.2	16.5	Water Side	21.88	40.36	40 - 45	1980918	6692285	Kleinfelder	Oct. 1998
PZ-7[3]	140+00	76.1	2.7	0	23.78	-	32 - 33	2033745	6676601	Kleinfelder	Oct. 2004
PZ-8	140+00	76.1	2.7	100	21.88	23.91	32 - 33	2033576	6676663	Kleinfelder	Oct. 2004
PZ-5S	310+00	72.7	5.9	0	36.28	37.71	11 - 12	2018478	6670369	Kleinfelder	Oct. 2004
PZ-5D	310+00	72.7	5.9	0	36.28	37.71	34 - 35	2018478	6670369	Kleinfelder	Oct. 2004
PZ-6S	310+00	72.7	5.9	100	32.48	33.78	12 - 13	2018489	6670533	Kleinfelder	Oct. 2004
PZ-6D	310+00	72.7	5.9	100	32.48	33.78	30.5 - 31.5	2018489	6670533	Kleinfelder	Oct. 2004
PZ-3	570+00	67.8	10.8	0	27.28	28.56	29.5 - 30.5	1998067	6676831	Kleinfelder	Oct. 2004
PZ-4[3]	570+00	67.8	10.8	100	25.68	-	32 - 33	1998216	6676951	Kleinfelder	Oct. 2004
PZ-1	850+00	62.5	16.1	0	23.28	25.81	32 - 33	1981001	6690265	Kleinfelder	Oct. 2004
PZ-2	850+00	62.5	16.1	100	21.48	24.11	31 - 32	1980925	6690401	Kleinfelder	Oct. 2004

1. Vertical datum = NAVD88
2. Horizontal datum = NAD83, California State Plane Zone 2.
3. Destroyed.

Table 3-2
Hydraulic Gradients Along Sacramento River East Levee Based on Groundwater Elevations in Shallow Piezometers and Estimated Stage

Reach	NLIP Station	Monitoring Location		Distance[1] (ft)	Period of Record	Period for Annual Average	Head Difference (ft)[2]			Hydraulic Gradient (ft/ft)[2]		
		River Side	Land Side				Min	Max	Annual Average[3]	Min	Max	Annual Average[3]
2	98+30	River	2F-01-15N	370	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-2.70	8.83	0.47	-0.0073	0.0239	0.0013
4a	140+00	PZ-7	PZ-8	100	10/13/04 - 07/05/06	08/01/05 - 07/31/06	-0.35	1.31	0.89	-0.0035	0.0131	0.0089
4b	195+00 196+35	2F-01-26N	2F-01-28N	220	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-0.40	1.26	0.20	-	-	-
		River	2F-01-26N	260		11/01/02 - 10/31/03	-0.35	5.40	1.29	-0.0014	0.0208	0.0050
6b	310+00	PZ-5D	PZ-6D	100	10/14/04 - 07/12/06	08/01/05 - 07/31/06	-0.42	2.03	0.37	-0.0042	0.0203	0.0037
8	394+00	River	2F-01-51N	600	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-1.83	9.92	1.82	-0.0030	0.0165	0.0030
9a	402+13	River	2F-01-49N	260	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-1.47	6.28	0.99	-0.0057	0.0241	0.0038
9b	466+76	River	2F-01-56N	330	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-1.34	4.98	0.77	-0.0041	0.0151	0.0023
11b	541+43	River	2F-01-62N	300	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-2.95	3.45	0.33	-0.0098	0.0115	0.0011
	570+00	PZ-3	PZ-4	100	10/13/04 - 10/07/06	10/01/05 - 09/30/06	0.03	1.54	0.60	0.0003	0.0154	0.0060
	611+56 611+59	2F-01-68N	2F-01-69N	160	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-0.53	2.94	0.44	-	-	-
		River	2F-01-68N	500		11/01/02 - 10/31/03	-1.95	7.13	0.54	-0.0039	0.0143	0.0011
13	679+40	River	2F-01-05S	520	03/05/02 - 09/30/03	10/01/02 - 09/30/03	-2.14	10.71	2.30	-0.0041	0.0206	0.0044
15	760+30	River	2F-01-15S	270	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-0.97	1.92	-0.11	-	-	-
16	787+77	River	2F-01-17S	370	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-0.76	2.90	0.29	-0.0020	0.0078	0.0008
	812+34	River	2F-01-19S	550	01/07/02 - 10/28/03	11/01/02 - 10/31/03	-0.97	2.96	0.32	-0.0018	0.0054	0.0006
18b	850+00	PZ-1	PZ-2	100	01/20/05 - 08/19/05	01/20/05 - 08/19/05	-1.21	1.06	-0.78	-	-	-
19a	867+30	LMW-4	LMW-1	100	02/03/99 - 04/24/06	11/01/05 - 10/31/06	-1.73	8.86	1.80	-	-	-
						Average	**-1.22**	**4.64**	**0.70**	**-0.0039**	**0.0161**	**0.0032**

1. Approximate distance between paired piezometers or between unpaired piezometers and Sacramento River.
2. Positive head differences and gradients indicate losing conditions (flow away from the River); negative values indicate gaining conditions.
3. The annual average was calculated from monthly averages to adjust for seasonal variations in the measurement frequency.



FILE: \public\SAFCA\GIS\Wells and Levee Location map.mxd DATE: 1/30/2008 4:01:06 PM

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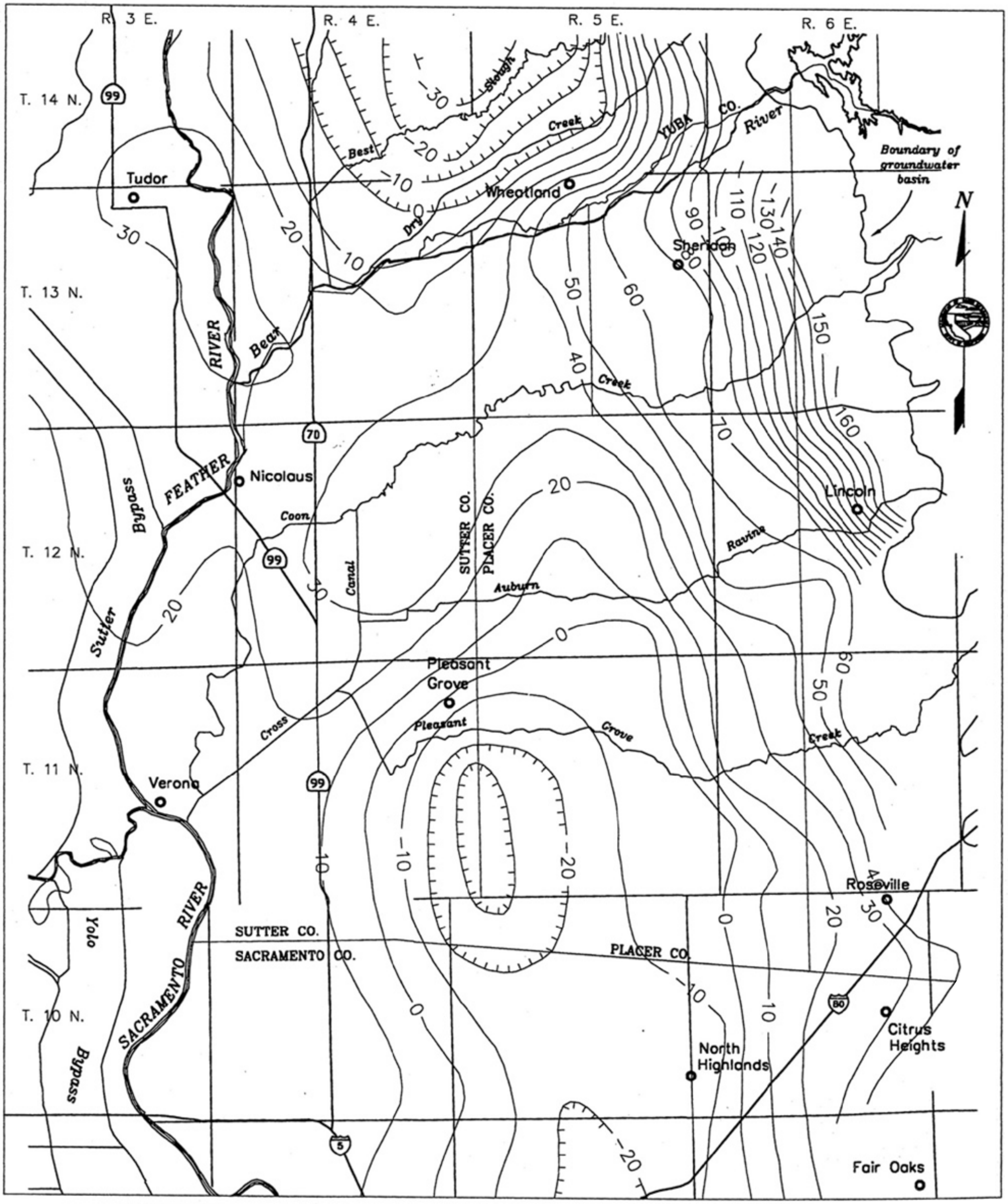
Figure 3-1
Piezometer Locations Along Sacramento River East Levee in Natomas Basin



EXPLANATION

10 Line of equal elevation of water surface in wells, feet. Contour interval 10 feet.

Source: Figure 28 (DWR, 1997)
(Elevations in NGVD29)

1 0 1 2 3
MILES

FILE: \\server_pe2900\Public\Sutter Pointe 07-1-012\GIS\Figure 4-4 Spring 1980 GWE contours.mxd Date: 4/3/2009

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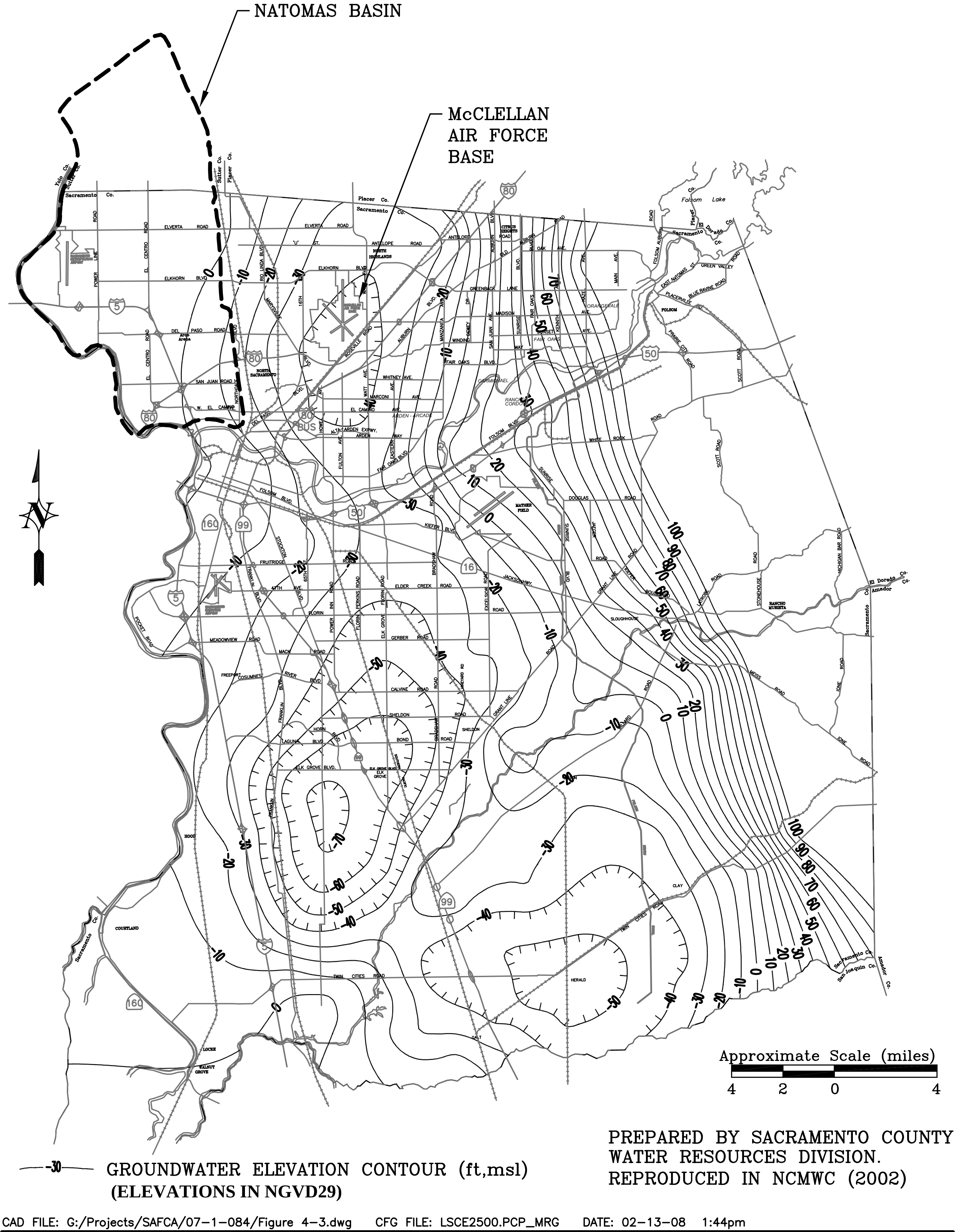
Figure 3-2
Spring 1980 Groundwater Elevation Contours
Multiple Zone Wells in North American Subbasin



PREPARED BY SACRAMENTO COUNTY WATER RESOURCES DIVISION. REPRODUCED IN NCMWC (2002)

CAD FILE: G:/Projects/SAFCA/07-1-084/Figure 4-3.dwg CFG FILE: LSCE2500.PCP_MRG DATE: 02-13-08 1:44pm

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Figure 3-3
Fall 1997 Groundwater Elevation Contours Multiple Zone Wells in Sacramento County

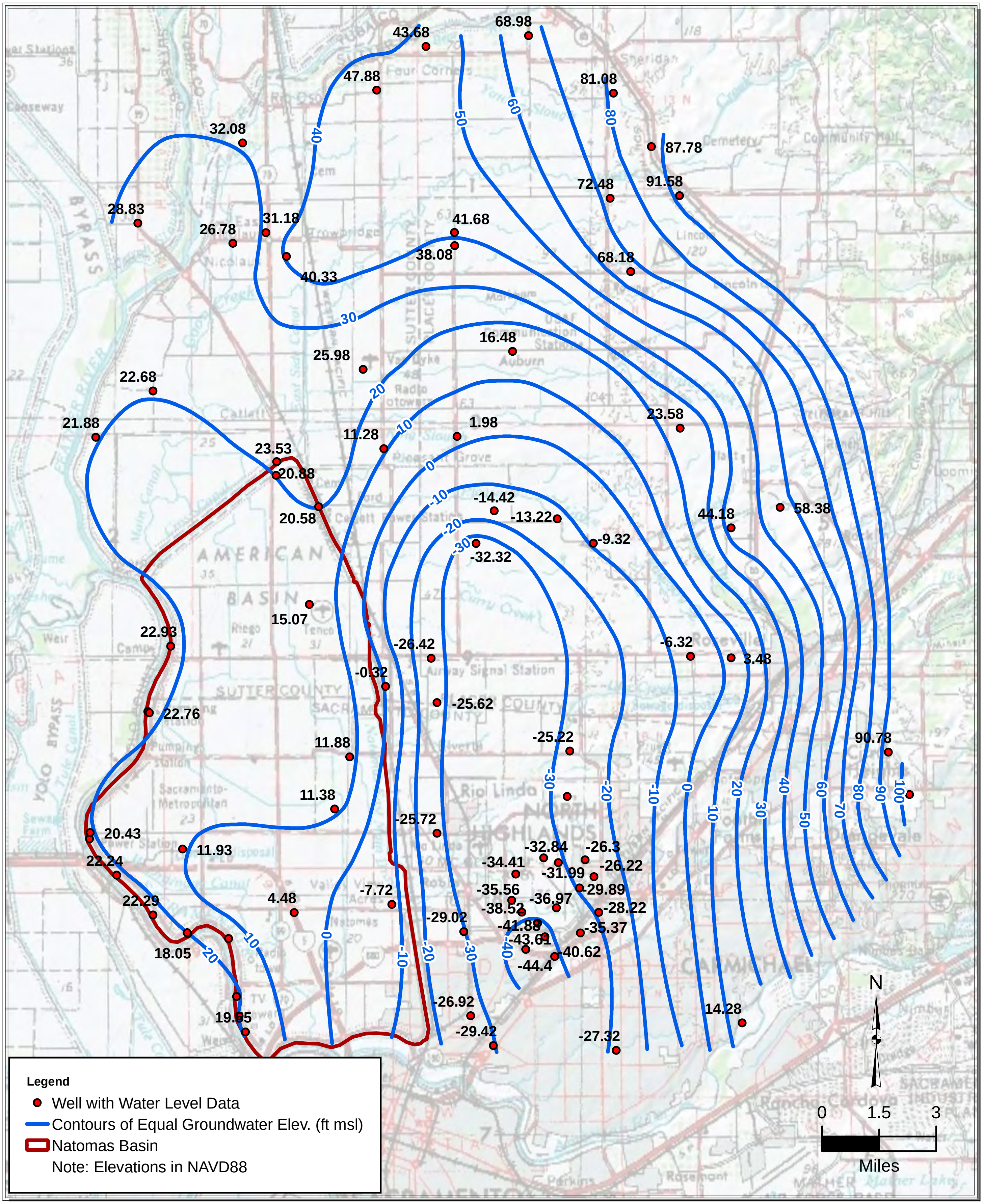

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Figure 3-4
Spring 2003 Groundwater Elevations Contours for Uppper Zone Wells in North American Subbasin

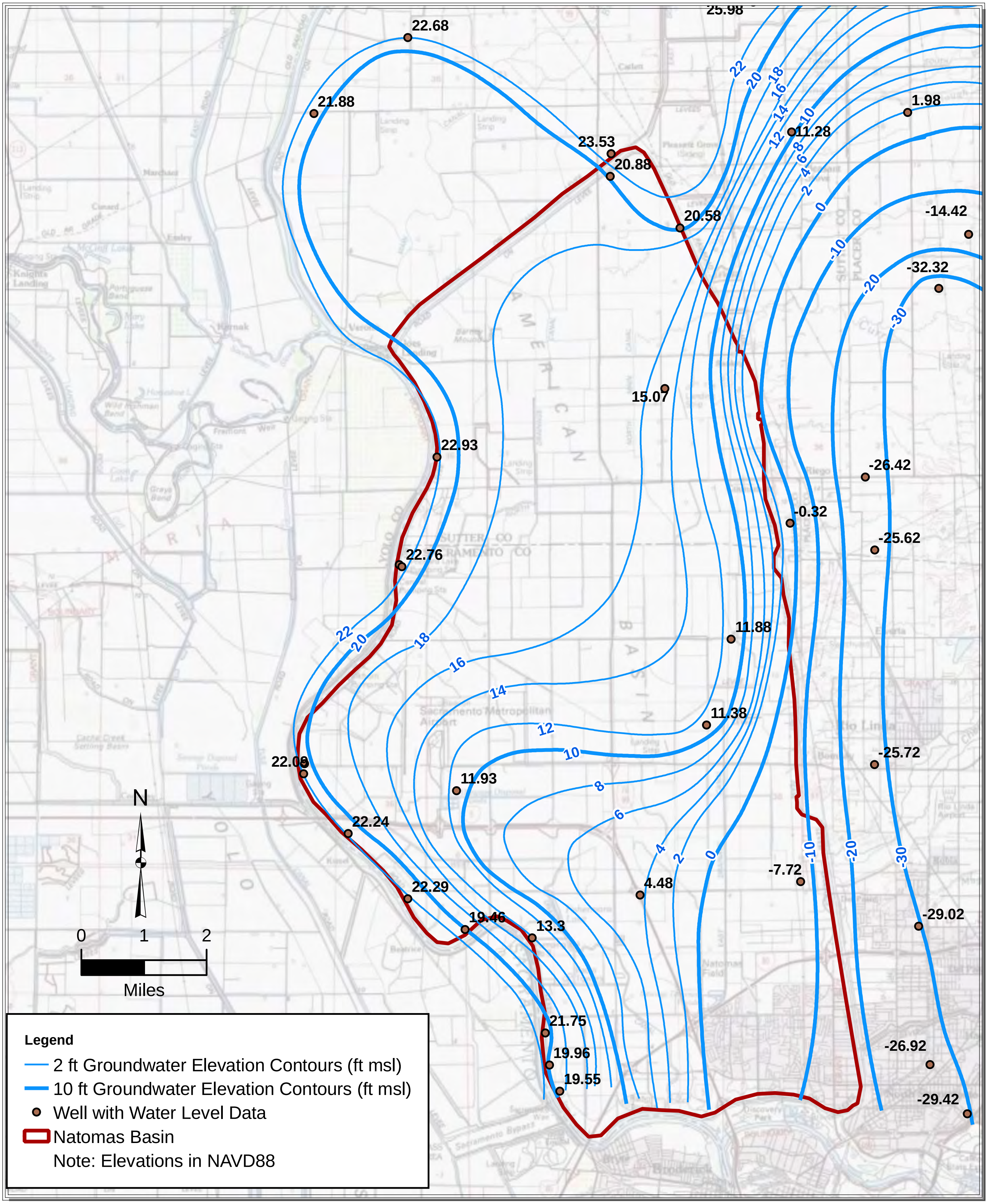

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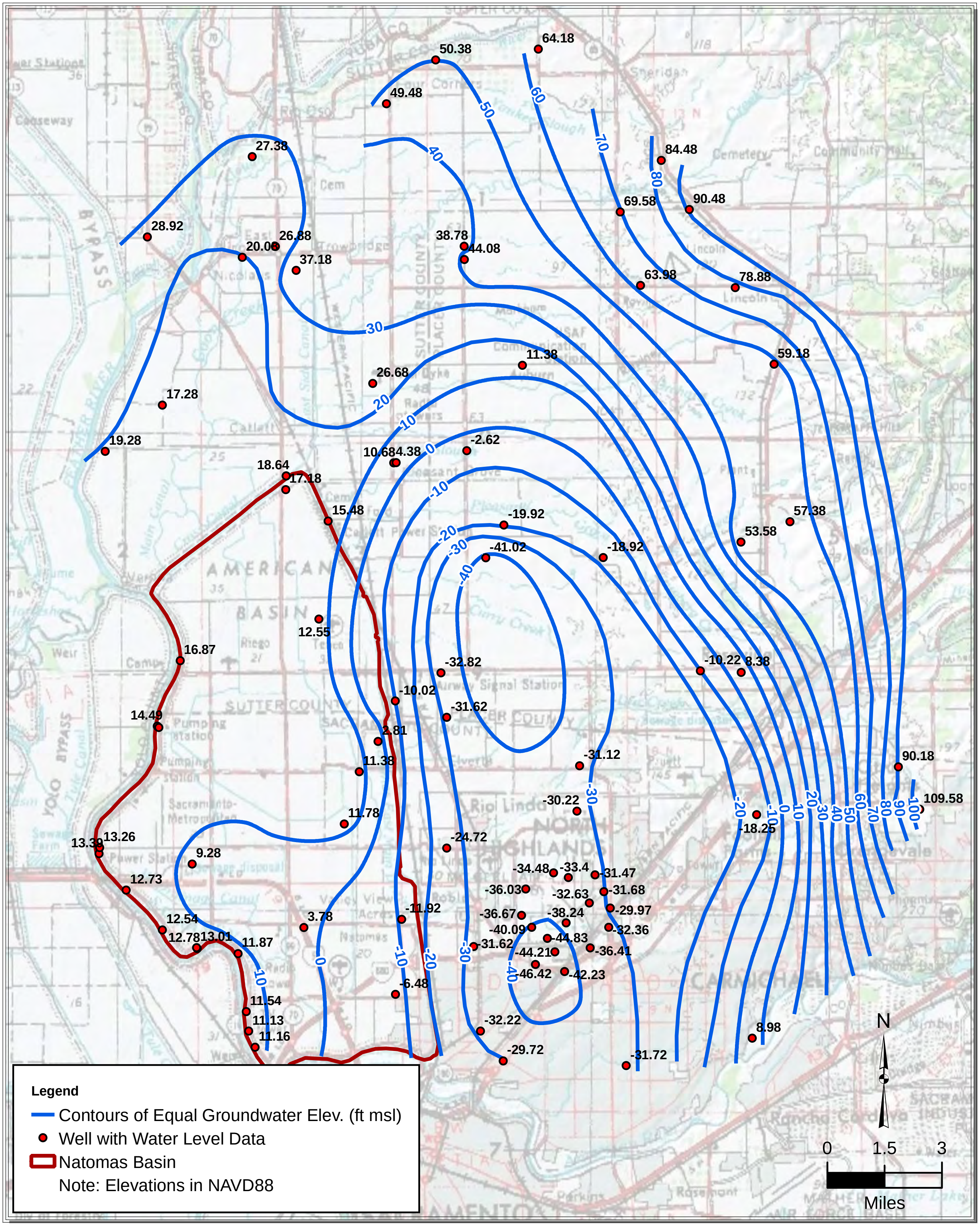
Figure 3-5
Spring 2003 Groundwater Elevation Contours for Upper Zone Wells in Natomas Basin



FILE: \\server_pe2900\Public\Sutter pointe 07-1-012\GIS\Fall 2003WLEContourMap_portrait_8.5x11JH.mxd Date: 4/15/2009

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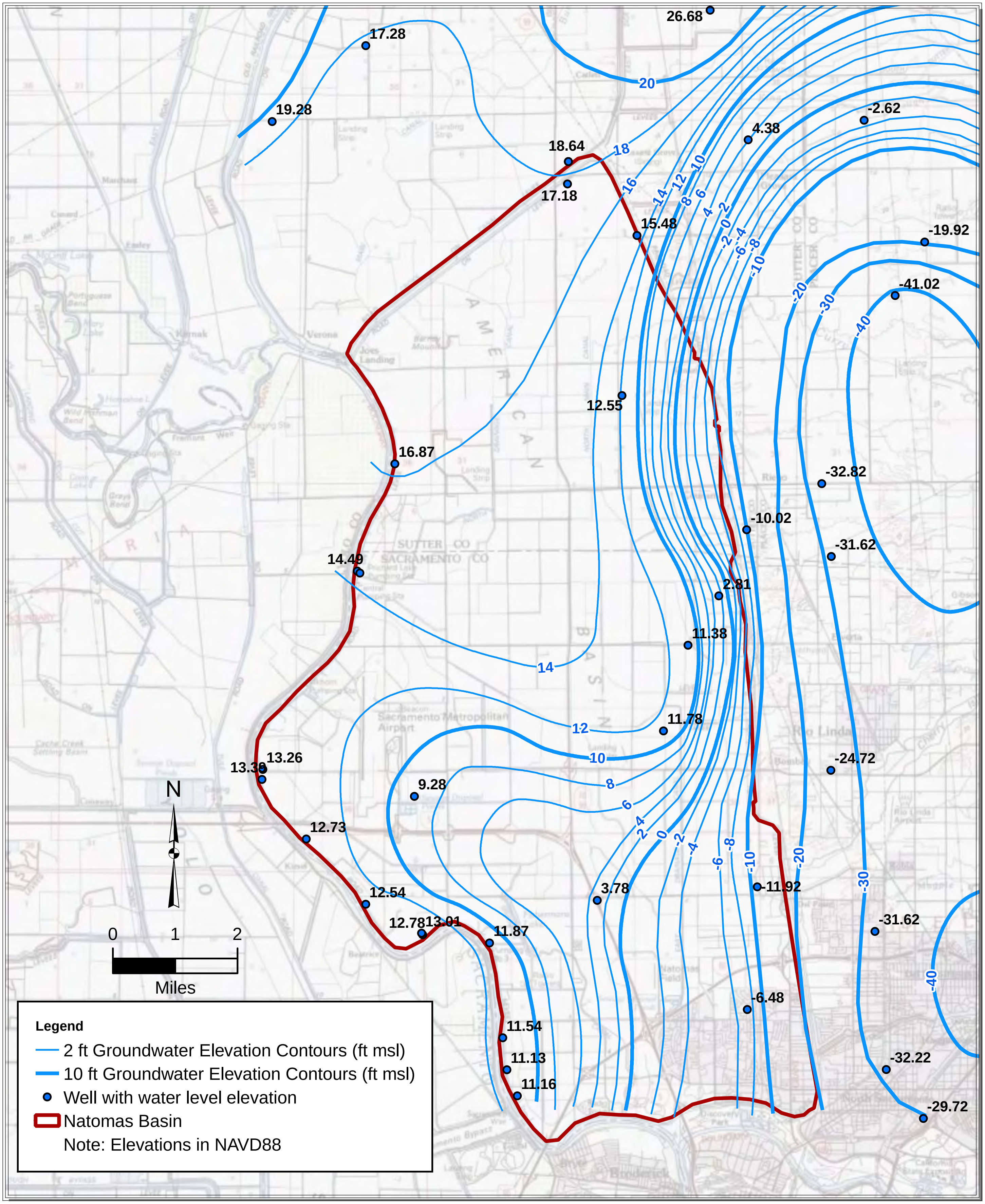
Figure 3-6
Fall 2003 Groundwater Elevations Contours for Upper Zone Wells in North American Subbasin



FILE: \\server_pe2900\Public\Sutter pointe 07-1-012\GIS\Fall 2003 WLENatomasContourMap_portraitJH.mxd Date: 4/13/2009

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Figure 3-7
Fall 2003 Groundwater Elevation Contours for Upper Zone Wells in Natomas Basin

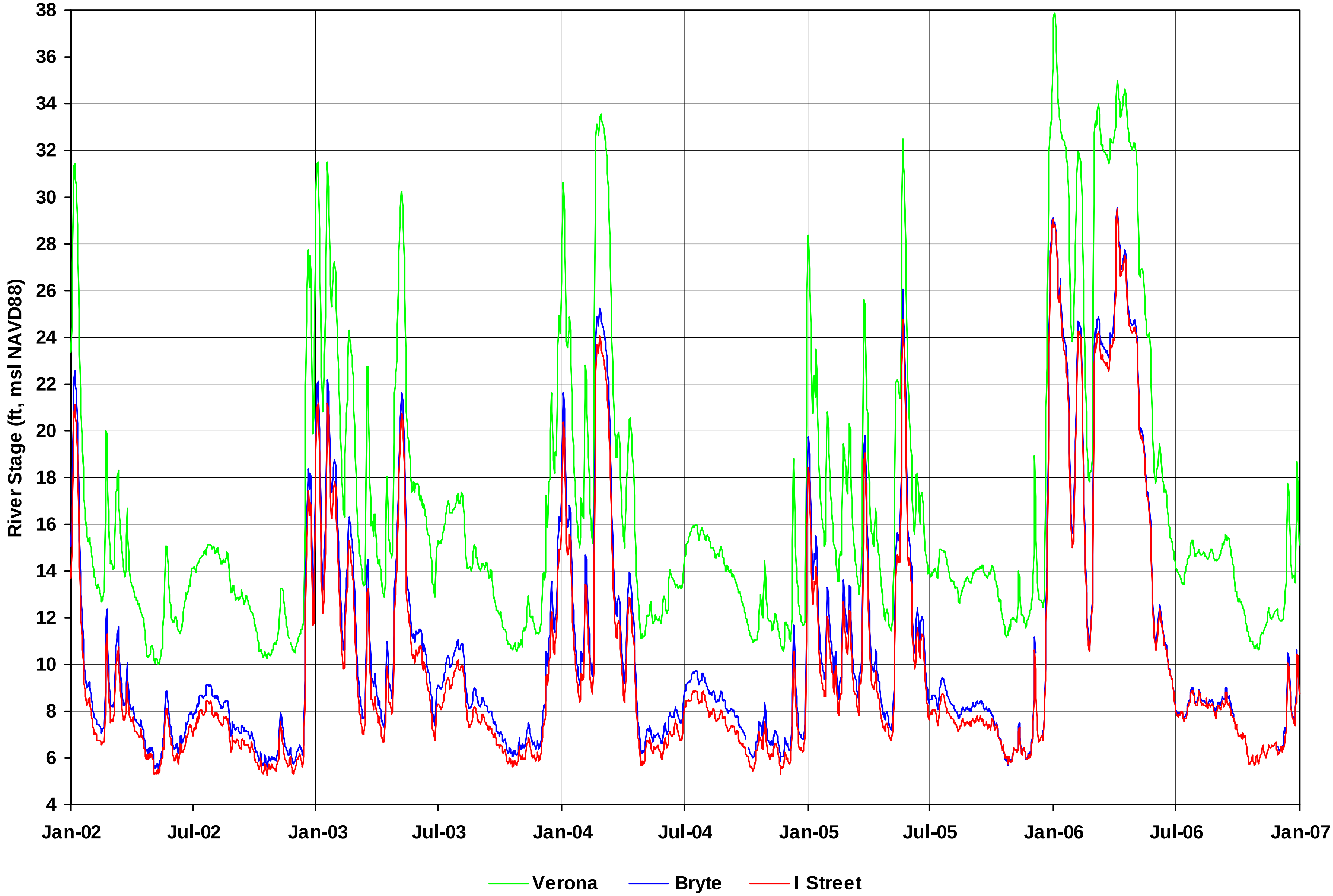

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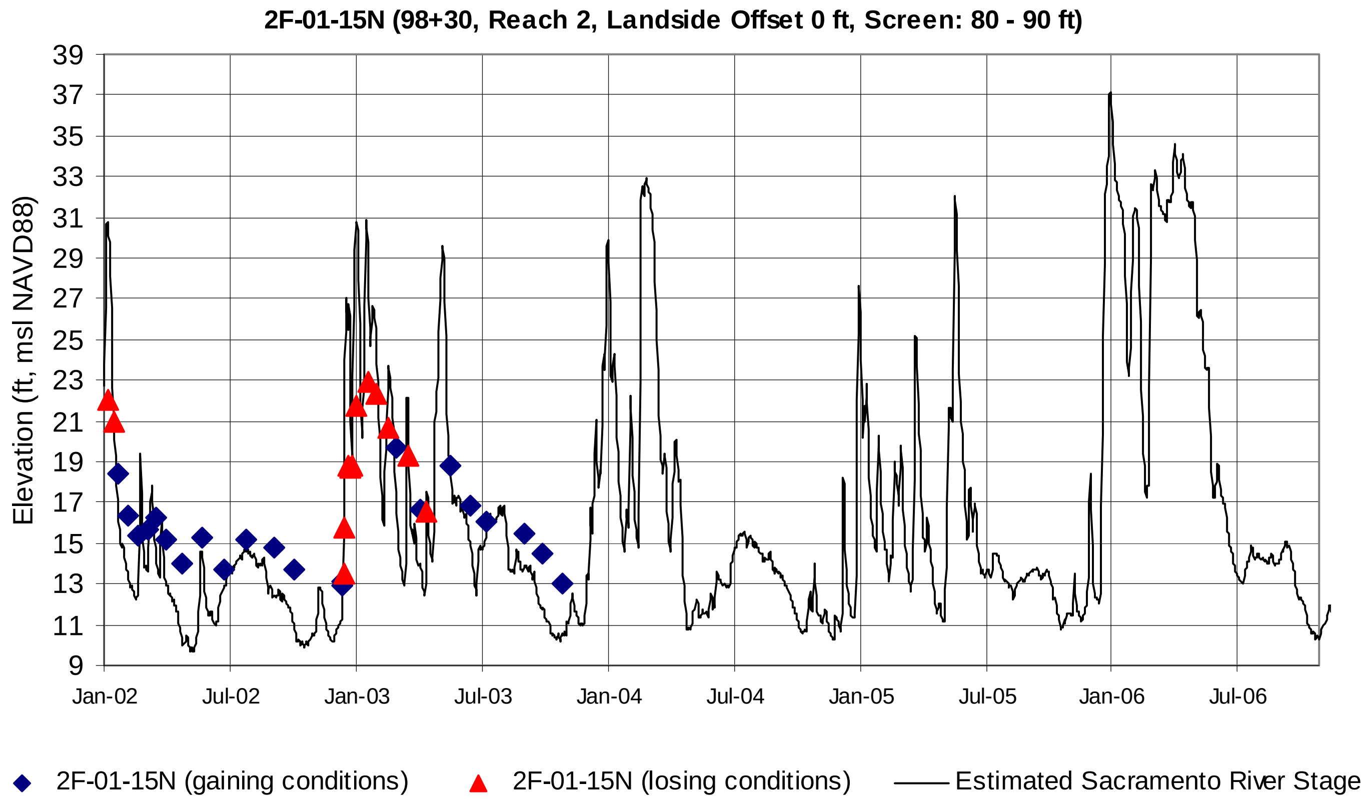
Figure 3-8
Hydrographs of Sacramento River Stage at the Verona, Bryte, and I Street Gages



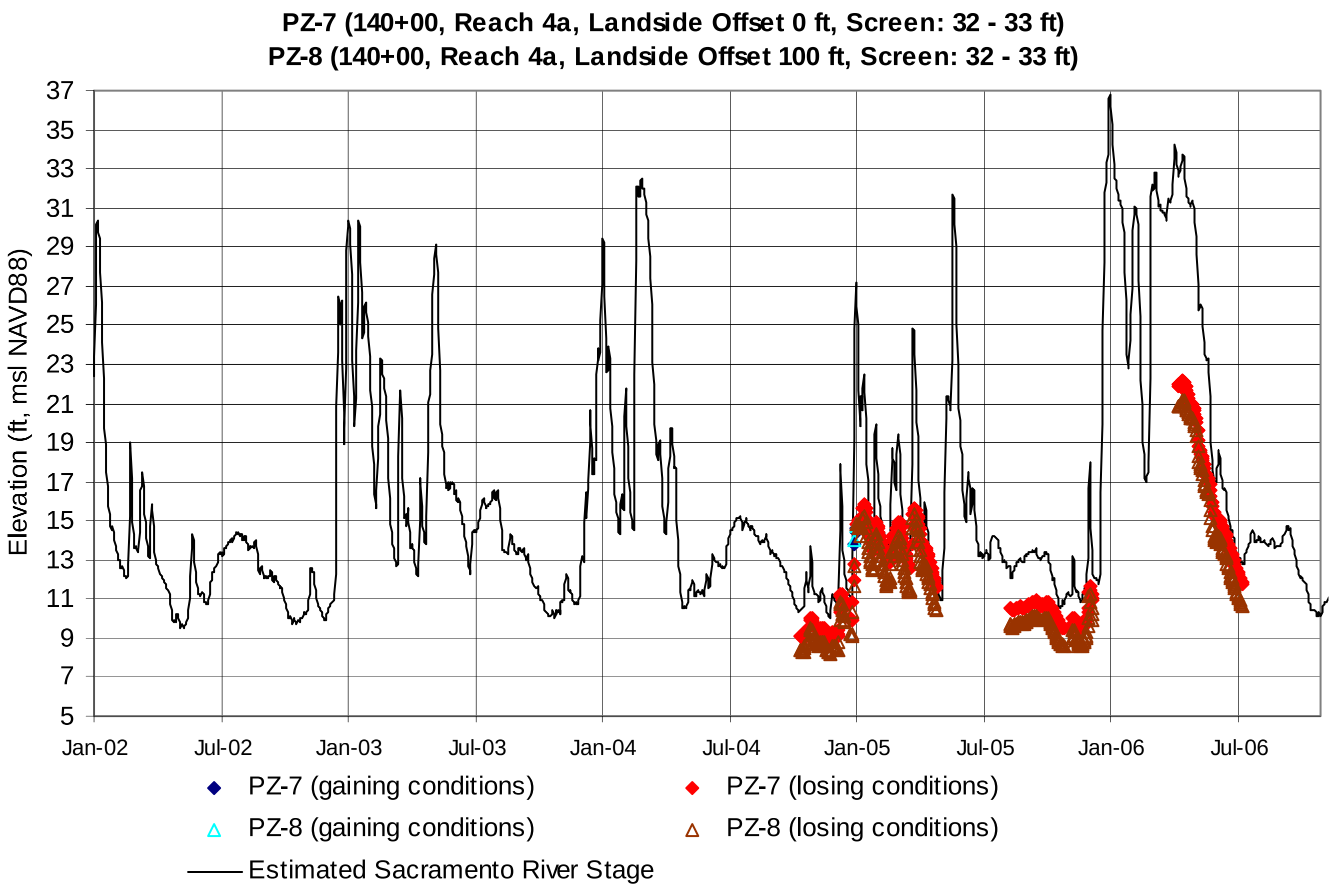


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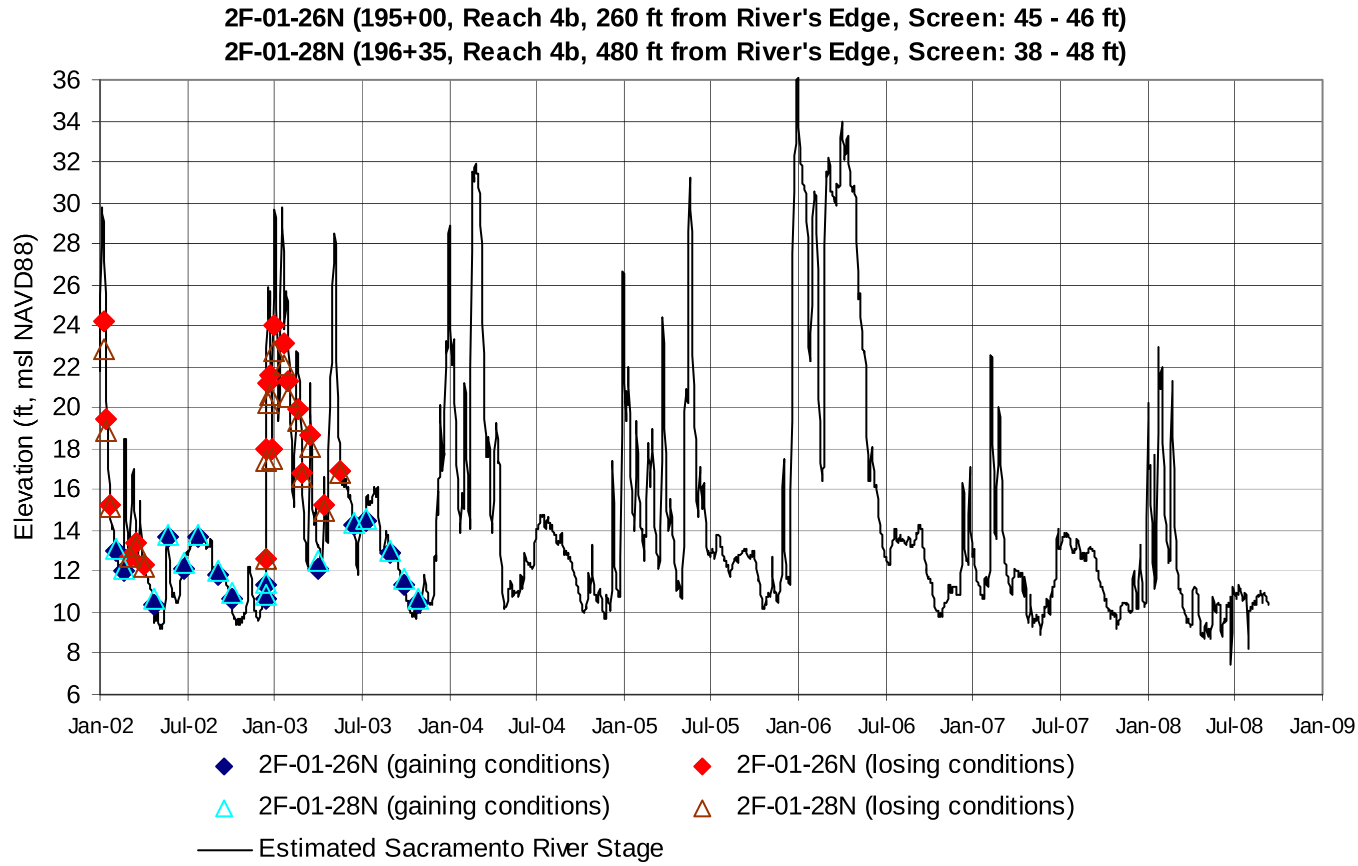
Figure 3-9
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 2 and 4a



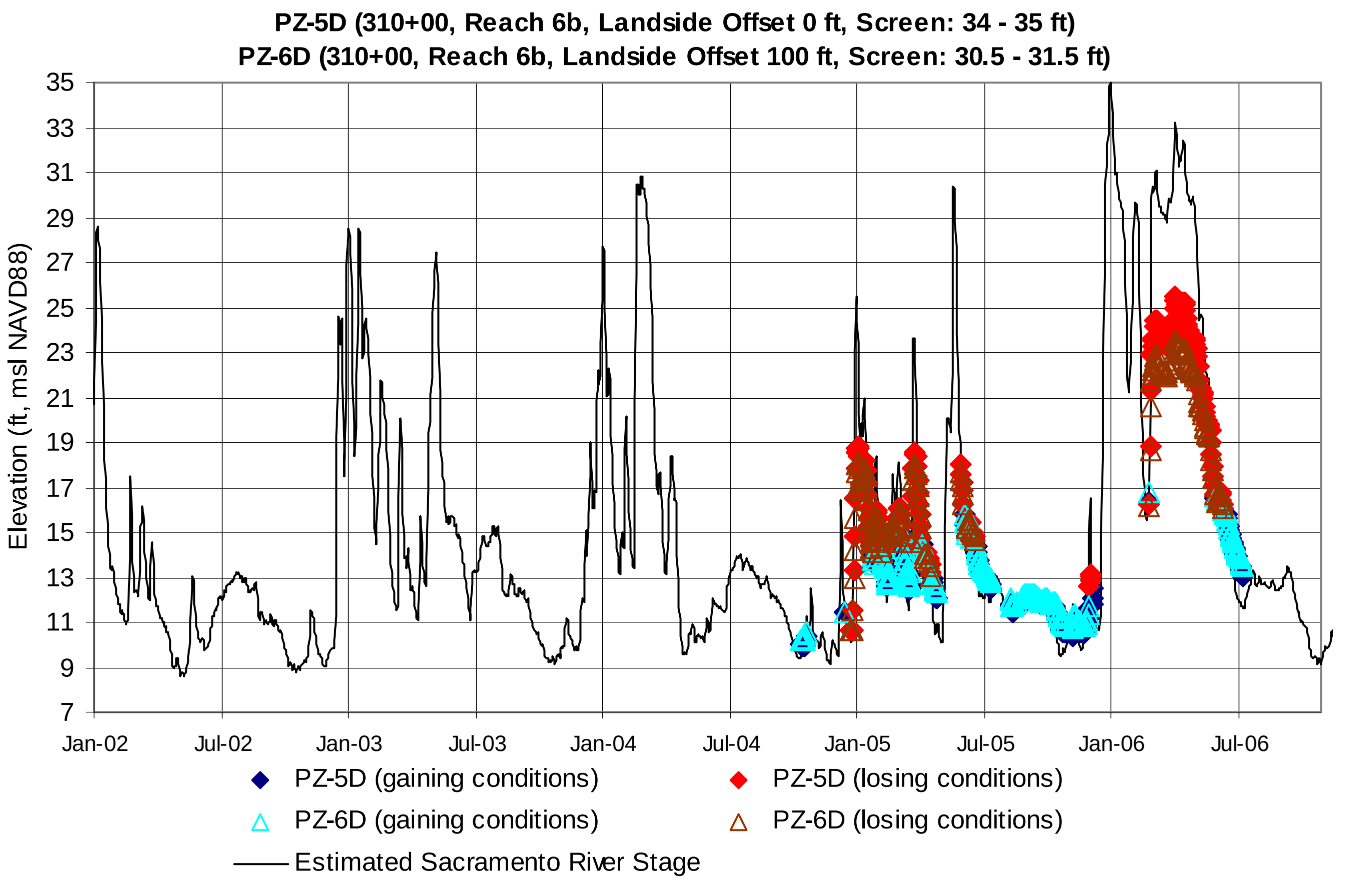


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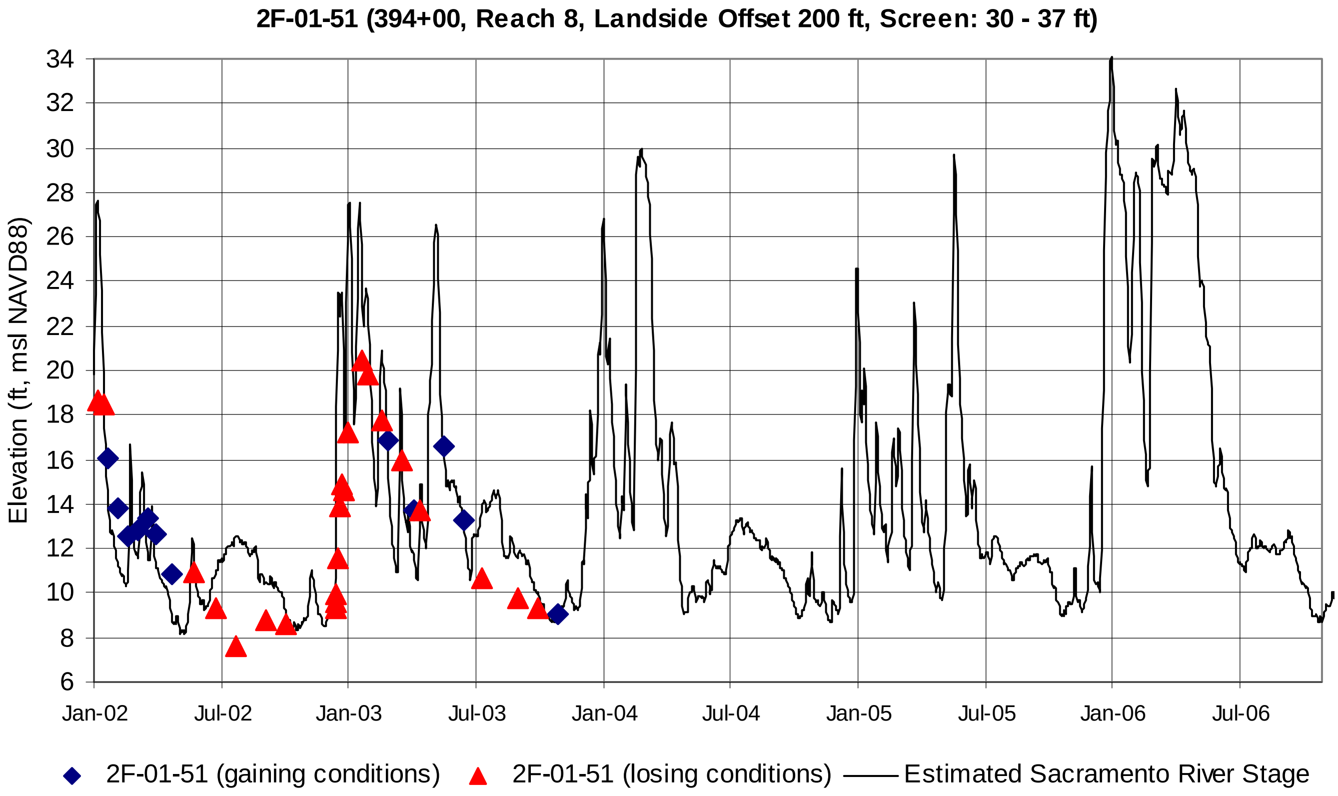
Figure 3-10
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 4b and 6b



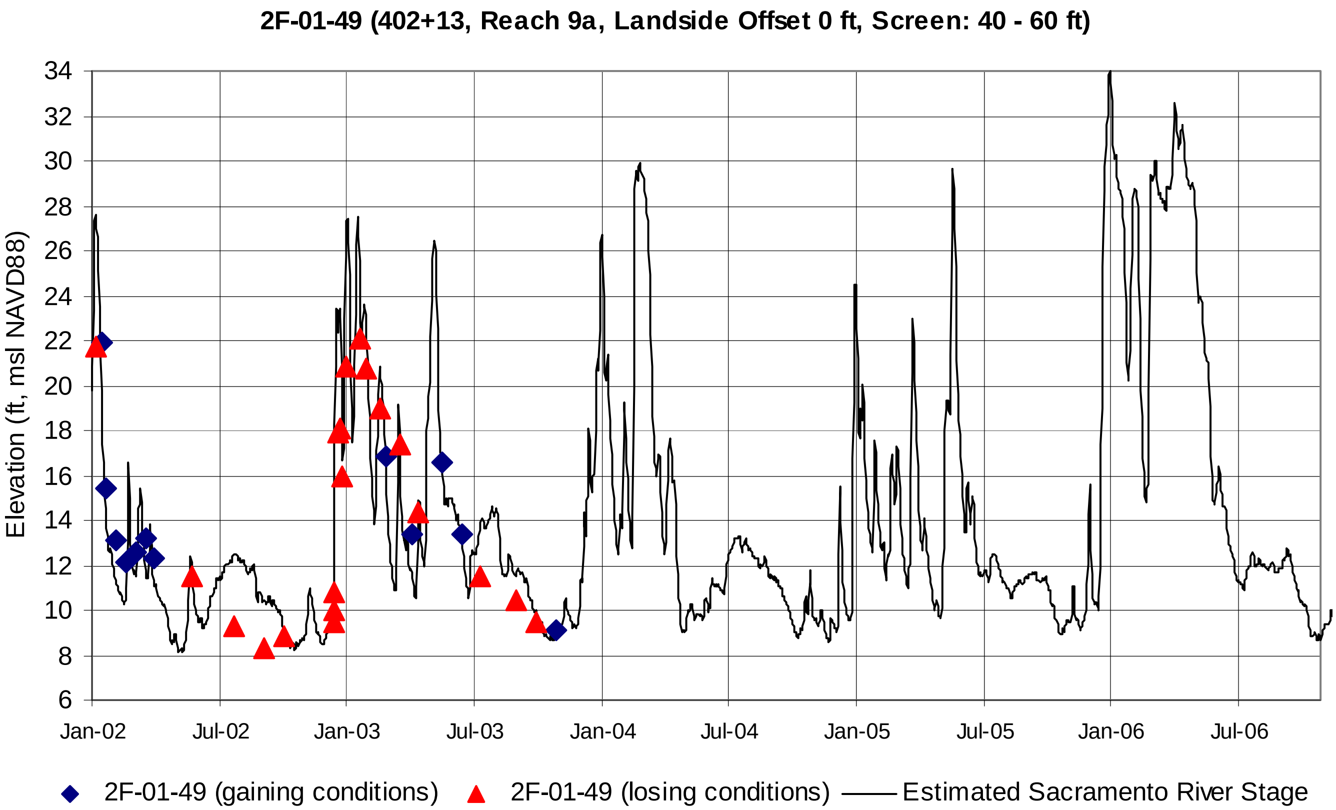


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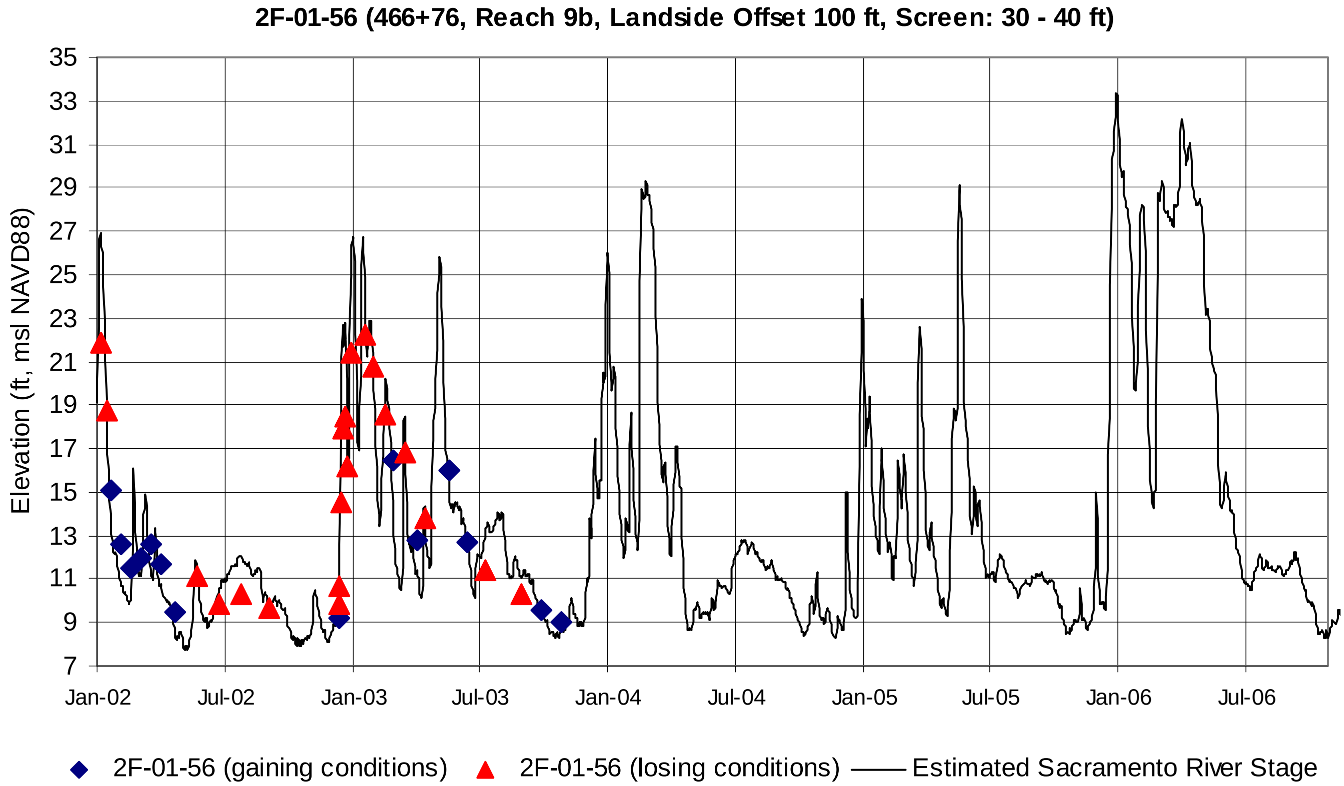
Figure 3-11
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 8 and 9a



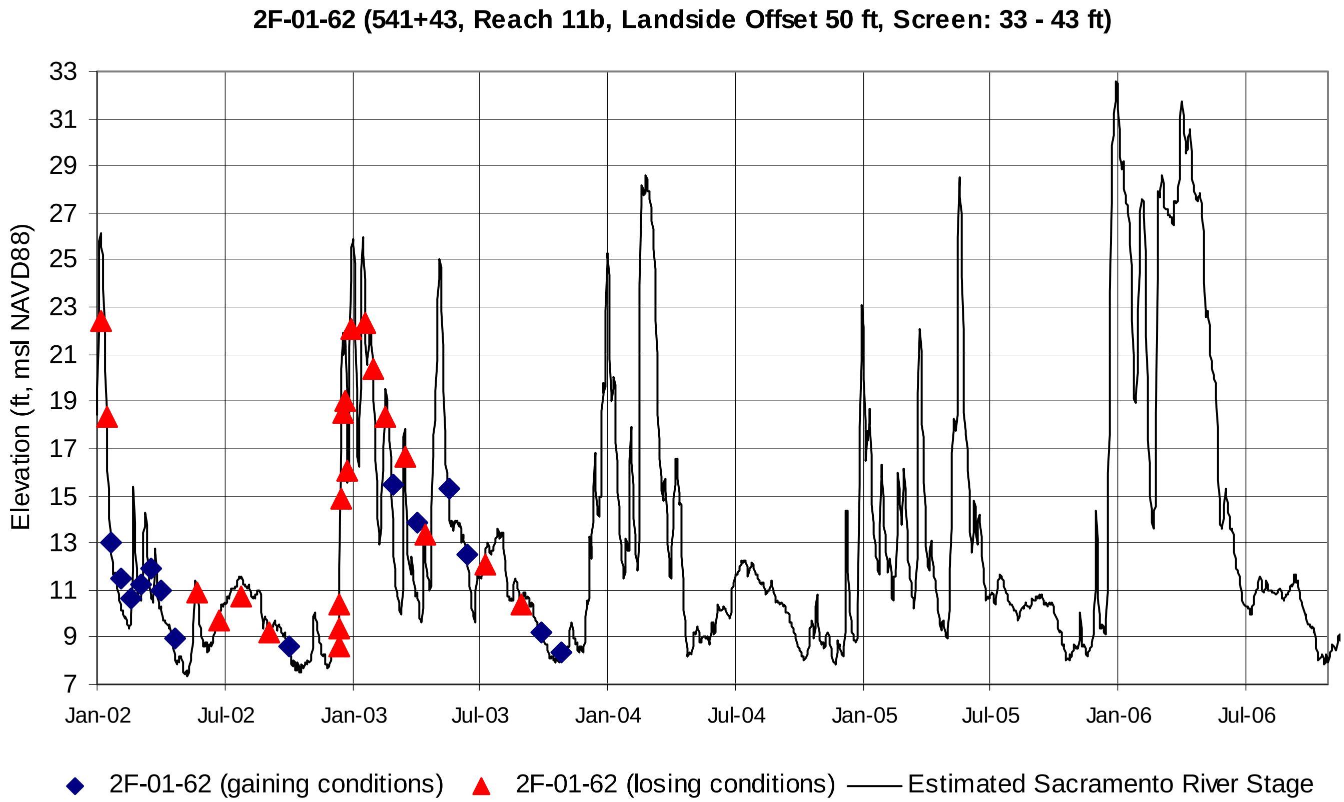


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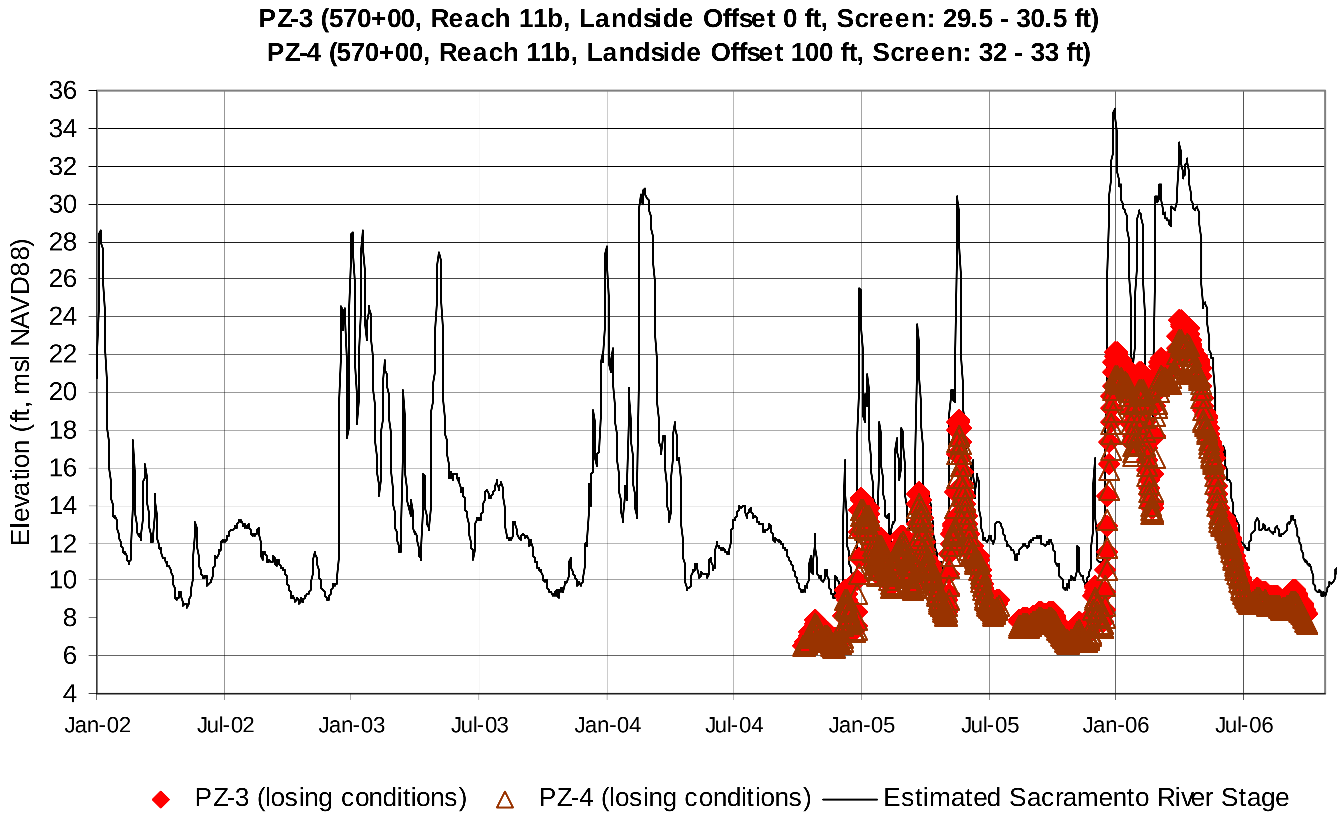
Figure 3-12
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 9b and 11b



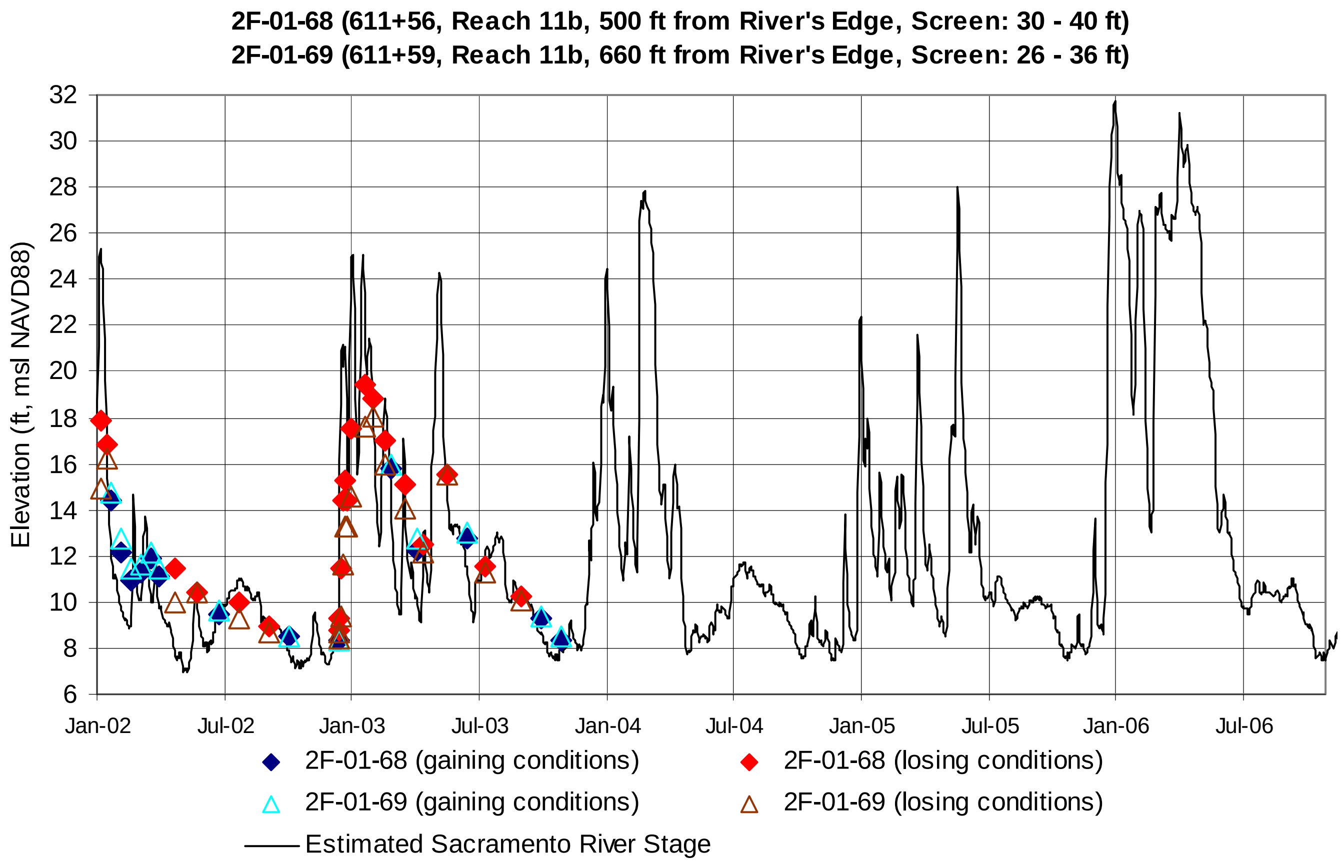


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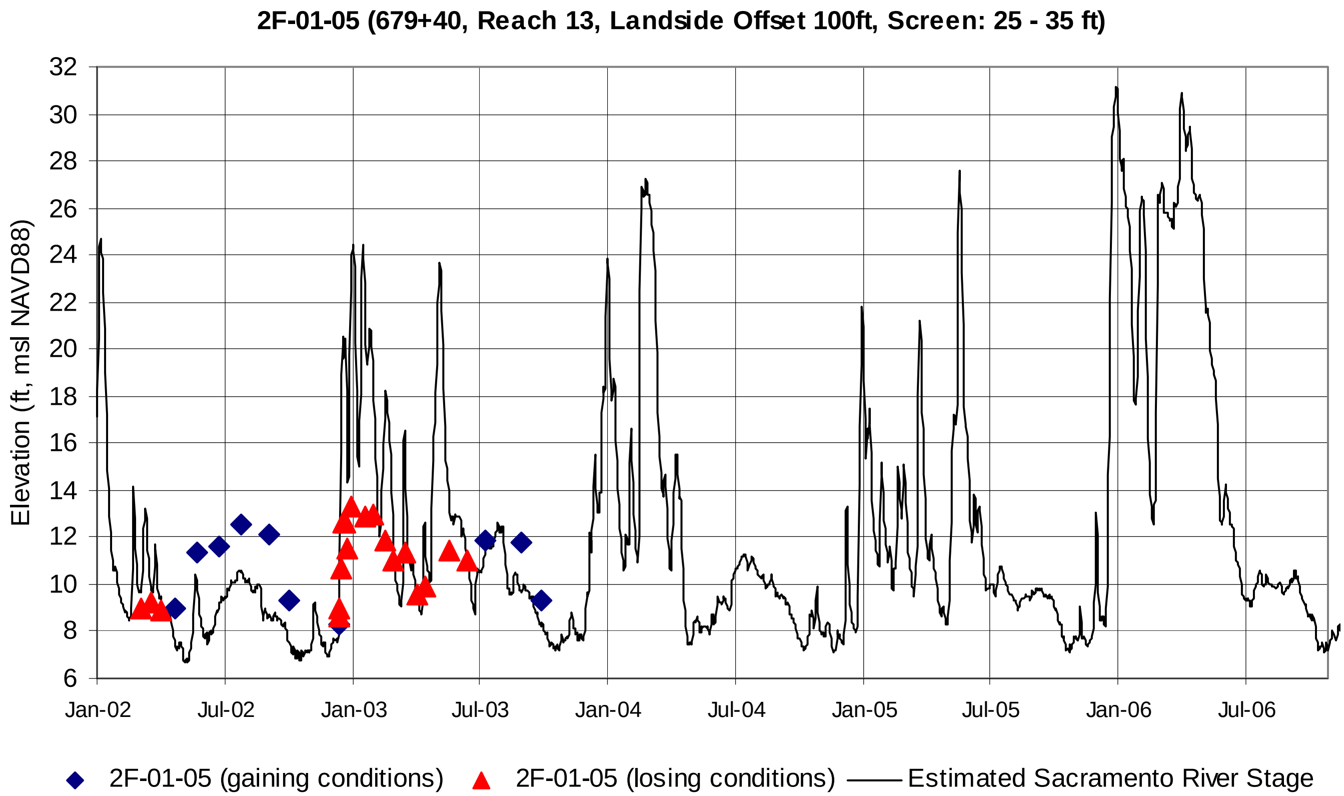
Figure 3-13
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reach 11b



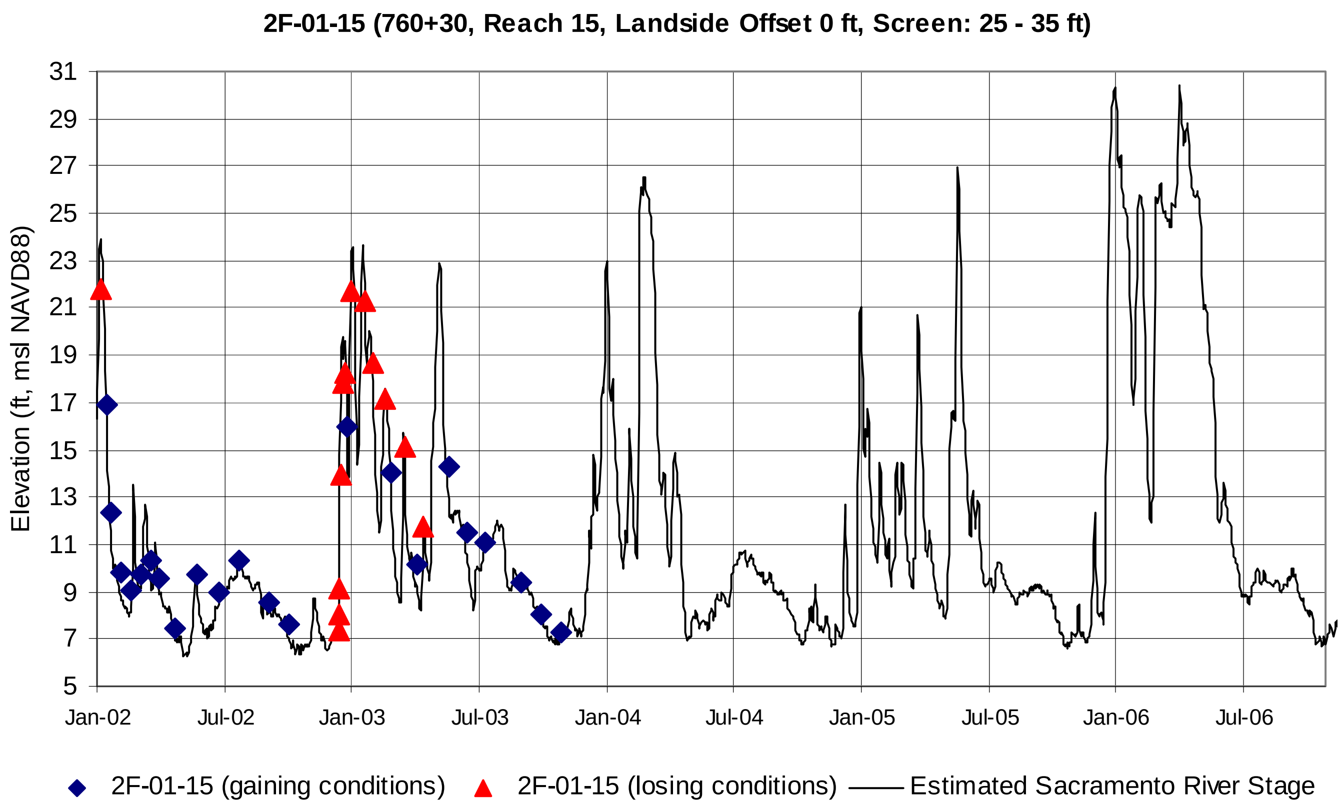


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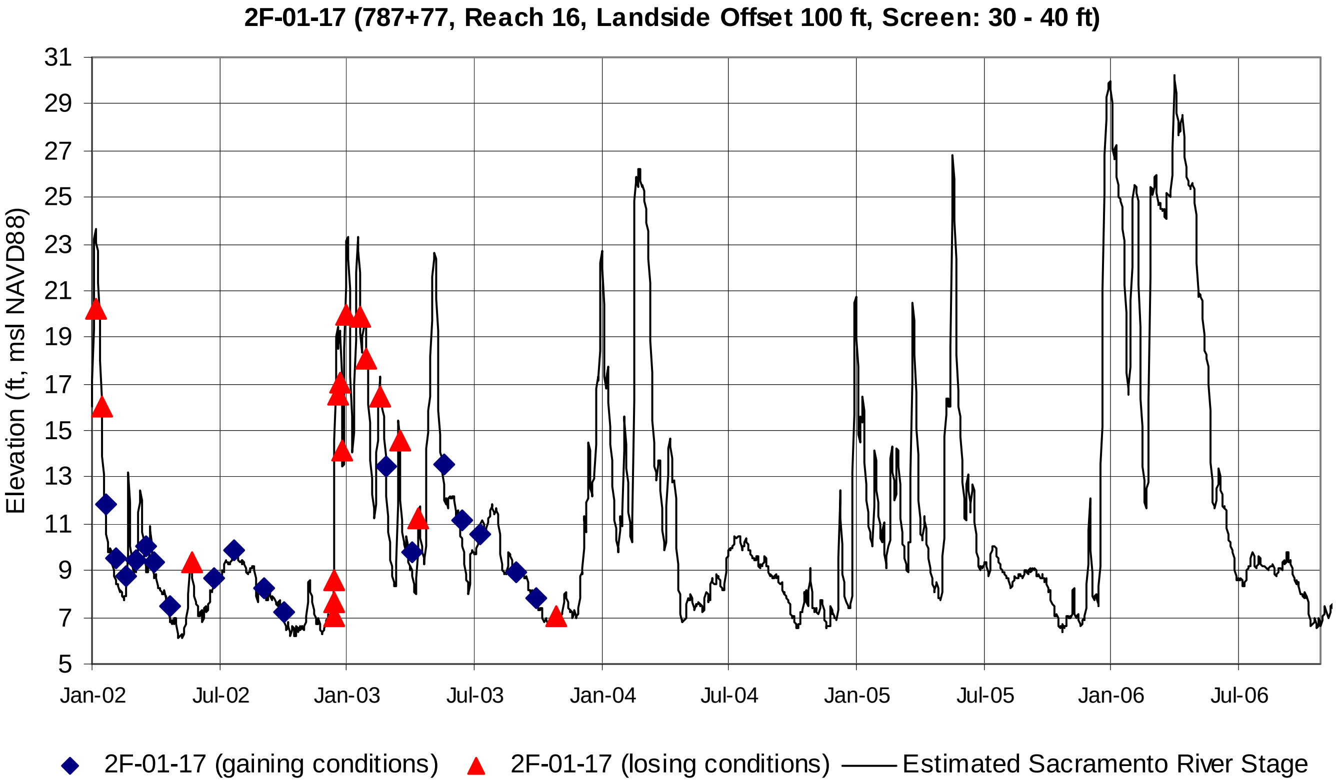
Figure 3-14
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 13 and 15



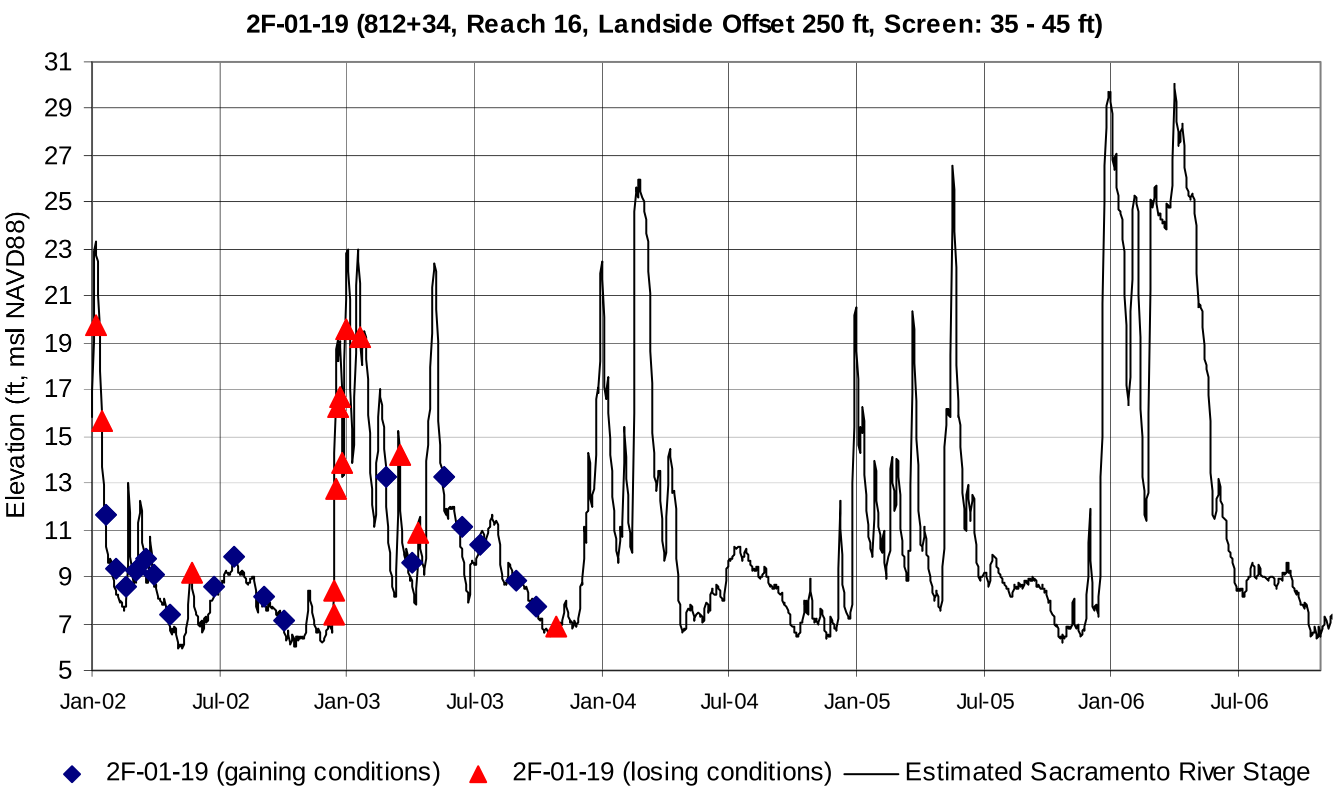


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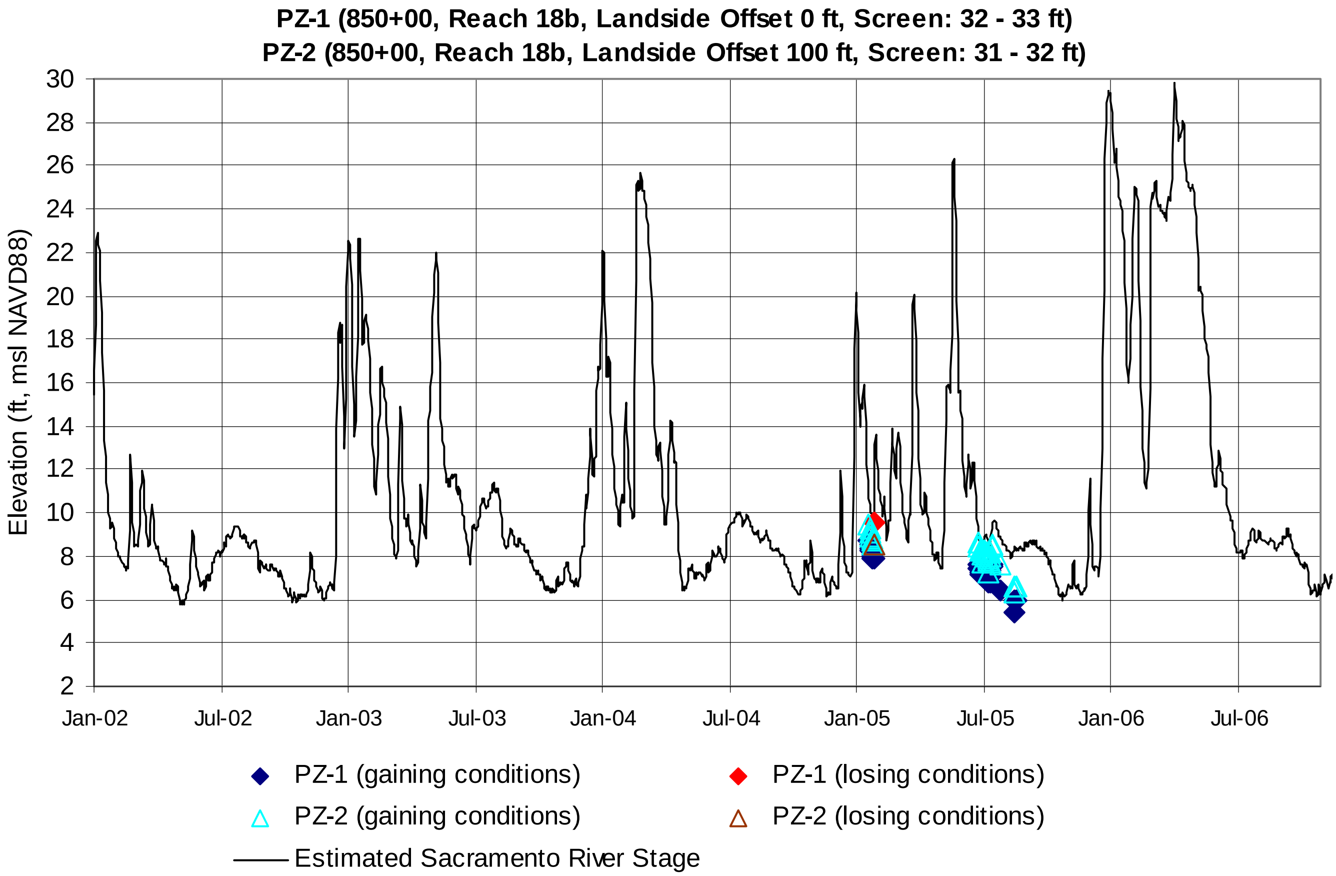
Figure 3-15
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reach 16



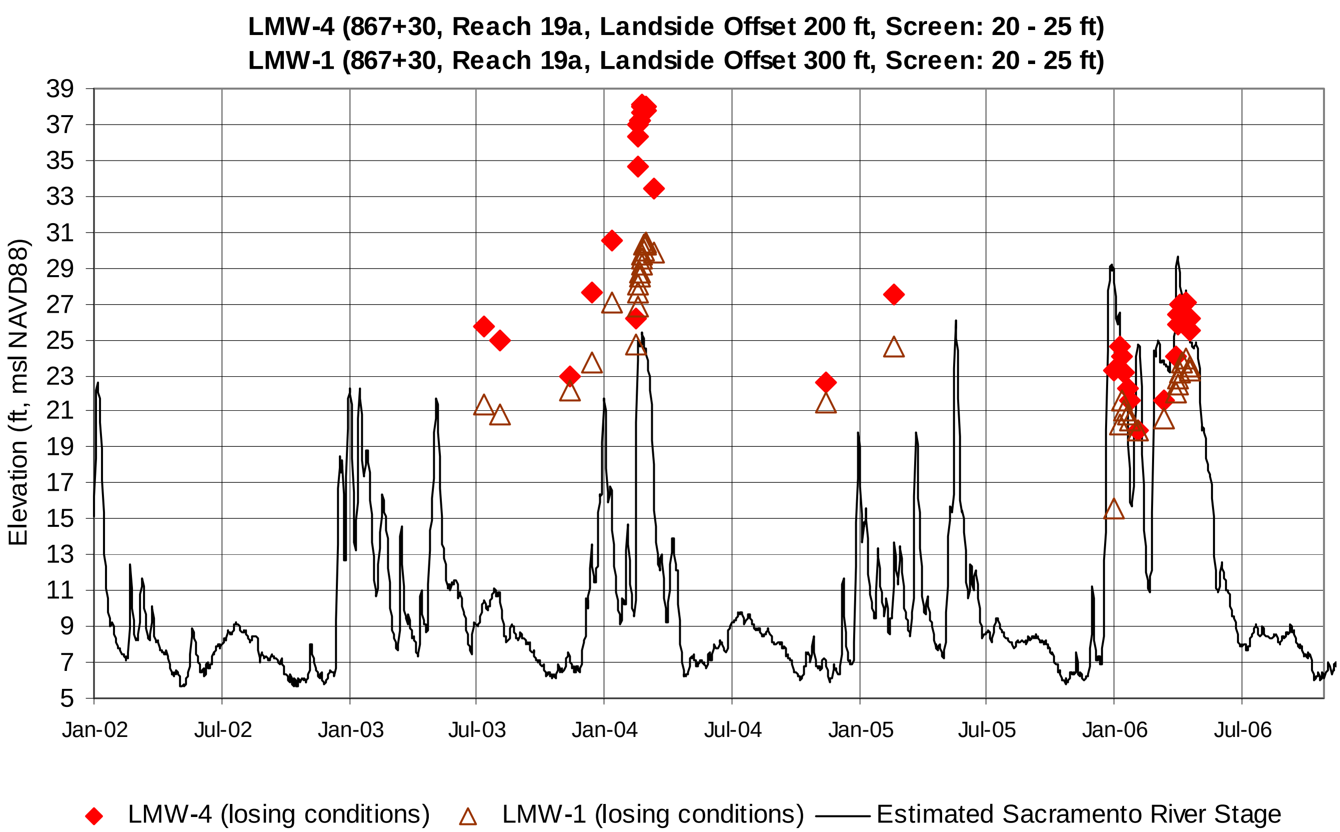


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Figure 3-16
Hydrographs of Groundwater Elevations in Levee Piezometers and Estimated Stage in Reaches 18b and 19a

4.0 Water Budgets for Existing and Future Groundwater Conditions in the Natomas Basin

4.1 IGSM Models

In order to evaluate the cumulative effects of SAFCA's proposed construction activities on groundwater conditions, a pair of existing numerical groundwater flow models were used to simulate groundwater conditions in the North American Subbasin and calculate groundwater budgets for the Natomas Basin. The models are based on the Integrated Groundwater and Surface Water Model (IGSM) platform developed by Montgomery Watson, Inc. (MW) in the 1990s. As discussed below, model results were used to calculate groundwater budgets for existing conditions (based on 2004) and future conditions (based on 2030).

The Sacramento County IGSM model is referred to as the SACIGSM and was originally developed by MW in 1993. The SACIGSM was updated by MW in 1995 and by WRIME in 2005, 2007, and 2008. The IGSM model for the Sutter/Placer County portion of the North American Subbasin is referred to as the North American River (NAR) IGSM and was originally developed by MW in 1995. The NARIGSM was subsequently updated by DWR (1997) and MW (2001). The grids used for both models are shown on **Figure 4-1**.

The IGSM models were updated most recently by WRIME in 2008 to reflect more current conditions in the Natomas Basin in order to simulate the groundwater impacts of the proposed Sutter Pointe Specific Plan development in southeastern Sutter County, which were summarized in the *Sutter Pointe Specific Plan Groundwater Supply Assessment* prepared by LSCE (2008b) . WRIME linked the NARIGSM and SACIGSM models and used them to simulate the effect of variations in the rate, timing, and location of pumping to supply the proposed Sutter Pointe development along with other land use and pumping projected for a 35-year simulation period that included different water year types.

IGSM is a finite element, quasi three-dimensional numerical groundwater flow model that simulates all major components of the hydrologic cycle. These include precipitation, runoff, evaporation, consumptive use, groundwater recharge, groundwater extraction and injection, and subsurface inflow and outflow along the model boundaries. As indicated in the model name, the simulation also includes interactions between surface water (streams and lakes) and groundwater. The primary components of the groundwater budget calculated by IGSM are:

Inflows

- Deep percolation from rainfall and irrigation applied water;
- Recharge due to stream seepage;
- Recharge from other sources such as irrigation canals and recharge ponds;
- Boundary inflows from outside the model area; and
- Subsurface inflows from adjacent model areas.

Outflows

- Groundwater pumping;
- Outflow to streams and rivers;
- Subsurface outflows to adjacent model areas; and
- Boundary outflows.

4.1.1 Sacramento County IGSM Model

The Sacramento County IGSM model covers most of Sacramento County and includes portions of northern San Joaquin County and western Amador County (**Figure 4-1**). The model is physically represented as a three-layer system consisting of the following layers: 1) the uppermost layer represents the unconfined or semi-confined aquifer system consisting of alluvial sediments that overlie the Mehrten Formation, 2) the middle layer represents the confined aquifer system of the Mehrten Formation, and 3) the lowermost layer represents groundwater of generally poorer quality in marine sediments underlying the Mehrten Formation. Near the southern boundary of the Natomas Basin, Layer 1 is about 200 feet thick and is overlain and underlain by aquitards with thicknesses of about 60 and 130 feet, respectively. Layer 2 starts at a depth of about 360 feet and is over 1,500 feet thick in this area. Layering of the SACIGSM model in the southern portion of the Natomas Basin is shown on **Figure 4-2** (see **Figure 4-1** for cross-section location). All groundwater pumping is simulated in the two upper layers.

Boundary conditions were established to designate heads for all boundary nodes and allow for surface and subsurface flows through the model boundaries. Boundary conditions reported by WRIME (2007) are as follows:

- The eastern boundary of the model is a no flow boundary but incorporates surface-water inflow to the model based on ungaged watersheds.

- General head conditions are used for the southern boundary (along the Mokelumne River). The heads for this boundary are obtained from the Stanislaus Basin IGSM, which has a simulation period ending in 1993, and values of head in nodes along this boundary in 1995 to 2004 use values from 1993.

- The western model boundary is along the Sacramento River. The northern section (north of Pocket Road) uses general head boundary conditions provided by the Central Valley IGSM (CVIGSM). The southern section of the western boundary (south of Pocket Road) is simulated as a constant head boundary. Both the general head and constant head conditions are interpolated from prior model nodes to the updated SACIGSM nodes for the western boundary. Because the general heads in the prior SACIGSM stop in 1995, the updated SACIGSM uses the 1995 values for subsequent years (1996 to 2004).

- General head conditions are used for the northern model boundary. These heads are provided by the NARIGSM, which was run concurrently with the SACIGSM. The linkage between the two models was done by correlating the boundary nodes of the models, updating the NARIGSM from monthly to daily time steps, and using the 1995 general heads in the NARISGM for subsequent years (1996 to 2004).

4.1.2 North American River IGSM Model

As shown on **Figure 4-1**, the NARIGSM includes the portions of eastern Sutter County and western Placer County that comprise the northern two-thirds of the North American Subbasin. This includes the Sutter County portion of the Natomas Basin. In 2001, the NARIGSM was refined to better assess groundwater impacts resulting from the water supply project and program alternatives being considered for the Regional Water Master Plan (MWH, 2001). The data sets that were updated included land use, streamflow, agricultural demand, surface-water diversions, urban water demand, groundwater pumping, precipitation, and groundwater levels.

The layering of the NARIGSM is similar to that of the SACIGSM. In the Sutter County portion of the Natomas Basin, Layer 1 extends from about 80 to 300 feet in depth and is overlain and underlain by aquitards. Layer 2 extends from about 420 to 1,400 feet in depth.

The boundaries for the NARIGSM were developed based on a combination of geological, hydrological, and political boundaries. MWH (1995) describes the original model boundaries as follows:

- The western model boundary is the Feather and Sacramento Rivers, which are an important source of recharge that create a groundwater divide in the upper aquifer system. General head conditions are used for this boundary based on the regional CVIGSM.

- The southern model boundary follows the Placer/Sacramento and Sutter/Sacramento County lines, and extends from the Sacramento River in the west to the eastern edge of the groundwater basin. This boundary is also the northern boundary of the SACIGSM. General head conditions are used for this boundary. As described above, the SACIGSM was linked to the NARIGSM to achieve consistent heads along this boundary.

- The eastern model boundary represents the geologic boundary between the Sacramento Valley Groundwater Basin and the Sierra Nevada foothills. No flow conditions are used for this boundary.

- The northern model boundary is the Bear River, which coincides with the Placer/Yuba and Sutter/Yuba County lines. General head conditions are used for this boundary based on the regional CVIGSM.

4.2 Model Inputs

Both the calibration and the future conditions simulations were run for a 35-year simulation period based on 1970-2004 hydrologic conditions. This was a period of approximately average precipitation, which included three single-dry years and three periods of multiple-dry years based on DWR’s Sacramento River Basin Index. Initial conditions (starting heads) for the beginning of the calibration period were established using historical groundwater levels published by DWR to generate regional groundwater level contour maps and assign initial (September/October

1969) groundwater levels to each model node. Initial conditions for the 2030 simulation are discussed in Section 4.4 below.

The IGSM models simulate transient conditions whereby hydraulic heads and groundwater flow can vary with time. Discretization over time occurs by dividing the continuous simulation period into time steps. Both models originally used monthly time steps, but have since been updated to use daily time steps (WRIME, 2007). Some model inputs such as streamflow and precipitation are daily, while others such as surface-water deliveries and municipal and industrial (M&I) groundwater pumping are monthly. Agricultural water demands are estimated by the model based on historical crop acreage, soil moisture requirements, effective rainfall, potential evapotranspiration (ET), and irrigation efficiency.

The aquifer properties required by the model include hydraulic conductivity, storage coefficient, and specific yield for each layer. In the Natomas Basin, the hydraulic conductivity used for Layer 1 ranges from 33 to 118 ft/day across the Natomas Basin. Hydraulic conductivities are lower in Layer 2 (15-20 ft/day) and Layer 3 (3-12 ft/day).

Specific yield values used in the models range from 0.08 to 0.12 for the NARIGSM and from 0.04 to 0.20 for the SACIGSM. Storage coefficients in the Natomas Basin area ranged from 1.4×10^{-4} to 1.4×10^{-3} in Layer 1 to 3.5×10^{-5} to 3.0×10^{-4} in Layer 2, and 3.0×10^{-5} to 3.0×10^{-3} in Layer 3.

4.2.1 Simulation of Streams

To simulate streamflow, the IGSM models calculate a water balance for each stream element. The stream elements are a series of one-dimensional line elements that are used to describe the stream system in the model area. The gain or loss due to stream-aquifer interaction is computed based on head in the stream (stage) and head in the underlying aquifer (WRIME, 2006). The stream stage is computed using stage-discharge relationships at the corresponding stream node. Input data for the stream system include:

- Stream configuration;
- Stream node elevation;
- Stream channel cross section;
- Stage-discharge relationship;
- Stream inflows at boundary (including surface-water flow entering the model area and also gains or losses of the stream system due to stream-aquifer interaction);
- Tributary inflows;
- Wastewater discharges to streams; and
- Streamflow diversions that remove water from the stream system.

In the Natomas Basin, only the Sacramento and American Rivers are simulated as streams (recharge from smaller streams and canals is included in areal recharge estimate discussed below).

4.2.2 Areal Recharge

The IGSM models account for a number of processes in the soil zone, including ET, direct runoff, infiltration, and deep percolation from rainfall and applied water (WRIME, 2006). ET is computed based on crop consumptive use requirements and available soil moisture. Direct runoff from rainfall and applied water is computed using a modified Soil Conservation Service (SCS) runoff curve number method. Input data for simulation of hydrologic processes in the soil zone include (MW, 1995; WRIME, 2006):

- Initial soil moisture;
- Rainfall;
- Land use category;
- SCS hydrologic soil group;
- Minimum soil moisture requirements for each crop type;
- Crop consumptive use (amount of applied water consumptively used to satisfy ET or soil moisture requirements);
- Root zone depth for each crop; and
- Surface drainage pattern.

The two primary sources of water to the soil zone in agricultural and urban areas are precipitation and applied water. Agricultural areas in the NARIGSM area tend to have the largest amount of deep percolation due to the volume of irrigation water applied to rice fields in addition to the natural rainfall, while the amount of deep percolation from non-irrigated areas is relatively small (MW, 1995).

Water infiltrating beyond the soil zone (deep percolation) results in groundwater recharge. IGSM models simulate the vadose zone with the mathematical equation of unsaturated flow solved numerically at every time step (WRIME, 2006). The vadose zone is divided into a number of discrete layers of specified thickness; the water passing through the soil zone becomes the inflow to the uppermost vadose zone layer. This process repeats until the outflow from the last vadose zone layer becomes inflow to the first layer of the aquifer system. As discussed further in Chapter 5, deep percolation is a significant inflow component of the overall groundwater budget.

4.2.3 Model Calibration

Calibration is the process of adjusting parameters used in the model so that the model approximates the observed behavior of the aquifer system, especially measured groundwater levels. After the model is calibrated, it can be used to evaluate the response of the aquifer system to new or changing stresses. The original model calibration period for both IGSM models was water years 1970-1990. For the current versions of the models, the calibration period has been extended to water years 1970-1995 for the NARIGSM (MWH, 2001) and to 1970-2004 for the SACIGSM (WRIME, 2007).

During the calibration process, model generated heads were compared against measured water levels at selected calibration wells. In total, 81 calibration wells were used for the NARIGSM, and 138 wells were used for calibration of the SACIGSM. The models were found to generally produce simulated water levels that were in good agreement with observed values under various hydrologic conditions. For the northern portion of the SACIGSM model, including the Sacramento County portion of the Natomas Basin, WRIME (2007) reported that 76 percent of the simulated heads fell within ten feet of observed heads.

Since they were last calibrated (2001 for the NARIGSM and 2007 for the SACIGSM), a number of changes have been made to both models. A check of the calibration was performed in fall 2007 after the refinement of the hydraulic conductivity values in the Natomas Basin to match recent aquifer test data provided by LSCE. Additional updates and refinements were made to the models through late 2007 and early 2008, but were considered to have only a minor effect on the calibration.

Since the models are an approximation of the physical system, they do not exactly reproduce observed groundwater levels. Although the calibration was considered acceptable for the primary intended purpose of the model (regional planning), there are notable differences between measured and simulated heads in the Natomas Basin. In particular, calibration hydrographs included in LSCE (2008b) and WRIME (2007) show declining heads at some of the Natomas Basin calibration wells over the 1970-2004 period. This is not supported by actual data, which generally show stable or increasing water levels since the early 1980s except for small seasonal fluctuations.

4.3 Water Budget for Existing Conditions

The groundwater budget for existing conditions in the Natomas Basin is based on the final water year of the 1970-2004 calibration period for the SACIGSM model. For the NARIGSM model, the calibration period ended in 1995, but the simulation period was extended to 2004 to create the water budget. Although a number of other IGSM simulations have been conducted for different purposes, the calibration period simulation was considered the best available representation of existing groundwater conditions in the Natomas Basin.

The groundwater budget for the end of the calibration simulation (2004) is shown in **Table 4-1** and summarized below The results are grouped into inflow and outflow components, and the change in storage represents the difference between the inflow and outflow.

<u>Inflow Components</u>

- Deep Percolation – This includes infiltration from precipitation, applied irrigation water, seepage from ditches and canals, and recharge from smaller streams. Deep percolation is assumed to be greatest from agricultural land planted to rice. A deep percolation rate of 1.32 acre-feet per acre per year (af/ac/yr), not including precipitation, was estimated for rice in the Natomas Basin (WRIME, 2008). The simulated deep percolation shown in **Table 4-1** totaled 31,429 af in 2004.

- Net Recharge from Streams – The direction of flow between streams and the underlying aquifer can vary seasonally or by reach. Flow from a stream to the aquifer system (losing conditions) is classified as inflow to the groundwater basin, and flow from the aquifer system to a stream (gaining conditions) is classified as outflow. For the Natomas Basin, only flow to and from the Sacramento and American Rivers is included in this component. Although there is some seasonal variation, all reaches of the Sacramento and American Rivers were simulated as losing in 2004. The simulated net recharge from streams shown in **Table 4-1** was 6,469 afy for the Sacramento River and 1,086 afy for the American River.

- Net Boundary Inflow – This represents groundwater inflow or outflow through model boundaries. The Sacramento River forms the western boundary of both IGSM models, and positive values of boundary inflow represent groundwater flow from the west beneath the Sacramento River. Boundary inflow from the west shown in **Table 4-1** totaled 10,365 afy. Available water level data do not show a noticeable gradient for significant groundwater flow beneath the Sacramento River from the west. Therefore, some of this boundary inflow, especially that which occurs in Layer 1, may actually represent additional recharge from the Sacramento River.

- Subsurface Inflow – This component represents groundwater inflow from one model subregion to another. As shown in **Table 4-1**, there is a small amount of inflow from the north beneath the NCC (241 afy) and a larger amount of inflow from the south beneath the American River (2,714 afy).

<u>Outflow Components</u>

- Subsurface Outflow – This component represents groundwater outflow from one model subregion to another. For the 2004 simulation, there was a large amount of outflow from the Natomas Basin to the east (21,738 afy), as shown in **Table 4-1**.

- Groundwater Pumping – This represents the largest outflow component and, in the Natomas Basin, is primarily for agricultural use. The simulated groundwater pumping shown in **Table 4-1** is 35,537 afy.

<u>Change in Storage</u>

- Change in Storage – The basic equation for a water budget is:

  Inflow – Outflow = Change in Storage.

  A positive change in storage indicates rising groundwater levels while a negative change in storage indicates declining groundwater levels. As discussed above, hydrographs indicate that groundwater levels in the Natomas Basin are generally stable but show small fluctuations in response to climatic conditions. 2004 was classified as a normal year based on DWR's Sacramento River Basin Index, but precipitation in the Sacramento area was slightly below average. The simulated change in storage shown in **Table 4-1** is –4,971 afy.

This reduction in groundwater storage means that simulated heads were declining at the end of the calibration simulation. A decline in groundwater storage of almost 5,000 afy divided by the area of the Natomas Basin represents a small decrease in storage on a per acre basis (less than 0.1 af/ac/yr). As discussed above, the specific yield used in the model ranges from 0.04 to 0.20. Assuming a specific yield of 0.10, the simulated decrease in storage equates to an average decrease in head of about one foot.

4.4 Simulation of Future Conditions

The water budget for future conditions discussed below is based on a simulation conducted by WRIME to estimate the effect of proposed land and water use changes due to proposed developments in the North American Subbasin on groundwater conditions in 2030. For this scenario, the IGSM models were run for a 35-year simulation period based on 1970-2004 hydrologic conditions. As discussed above, this was a period of approximately average precipitation, which included three single-dry years and three periods of multiple-dry years based on DWR's Sacramento River Basin Index. This simulation represents proposed future land and water uses in the Natomas Basin, including the Sutter Pointe development at buildout (labeled Scenario 2B in LSCE, 2008b).

The 2030 simulation is based on estimated conditions in the groundwater basin in 2030 without SAFCA's construction activities. Future water supply conditions for northern Sacramento County were primarily based on Urban Water Management Plans for individual water districts in the area. As reported by WRIME (2007), most of the plans indicate a significant transition from groundwater to surface-water utilization to meet municipal water demands. Future water supply conditions for Placer County were based on several sources including the *Western Placer County Groundwater Management Plan* prepared by MWH (2007) on behalf of the City of Roseville, City of Lincoln, Placer County Water Agency, and California American Water. Water demand and supply data for proposed developments such as Placer Vineyards and Placer Ranch were obtained from the Specific Plan, EIR, or Notice of Preparation for each development.

The 2030 water budget presented below is based on Scenario 2B in LSCE (2008b), which includes full buildout of the Sutter Pointe development along with the other developments in the North American Subbasin discussed above. All agricultural land uses in the proposed development areas are simulated as being replaced by M&I land uses by 2030. Groundwater usage in the Sutter Pointe area is projected to be 13,072 afy in a normal year, which represents about 52 percent of the total demand M&I water demand, with the remainder supplied by surface water.

4.4.1 Water Budget for Future Conditions

The groundwater budget for the simulation of future conditions (2030) without SAFCA's planned construction is shown in **Table 4-1**. The future conditions water budget is based on the last 23 years of the simulation period (1982-2004). Precipitation during this period was approximately average, and this period includes nine wet years, four normal years, two single-dry years, and two multiple-dry periods (1987-1992 and 2001-2002) based on the Sacramento River 40-30-30 Index.

There are significant differences between the water budgets for the 2004 and 2030 simulations shown in **Table 4-1**. Many of these differences are due to much higher heads east of the Natomas Basin in 2030 due to the planned transition from groundwater to surface water to meet M&I demands in northern Sacramento County. Heads are also higher in most of the Natomas Basin due in part to reduced pumping outside of the Sutter Pointe area. Higher heads result in less recharge from streams, less boundary inflow, and less subsurface outflow for the Natomas Basin water budget.

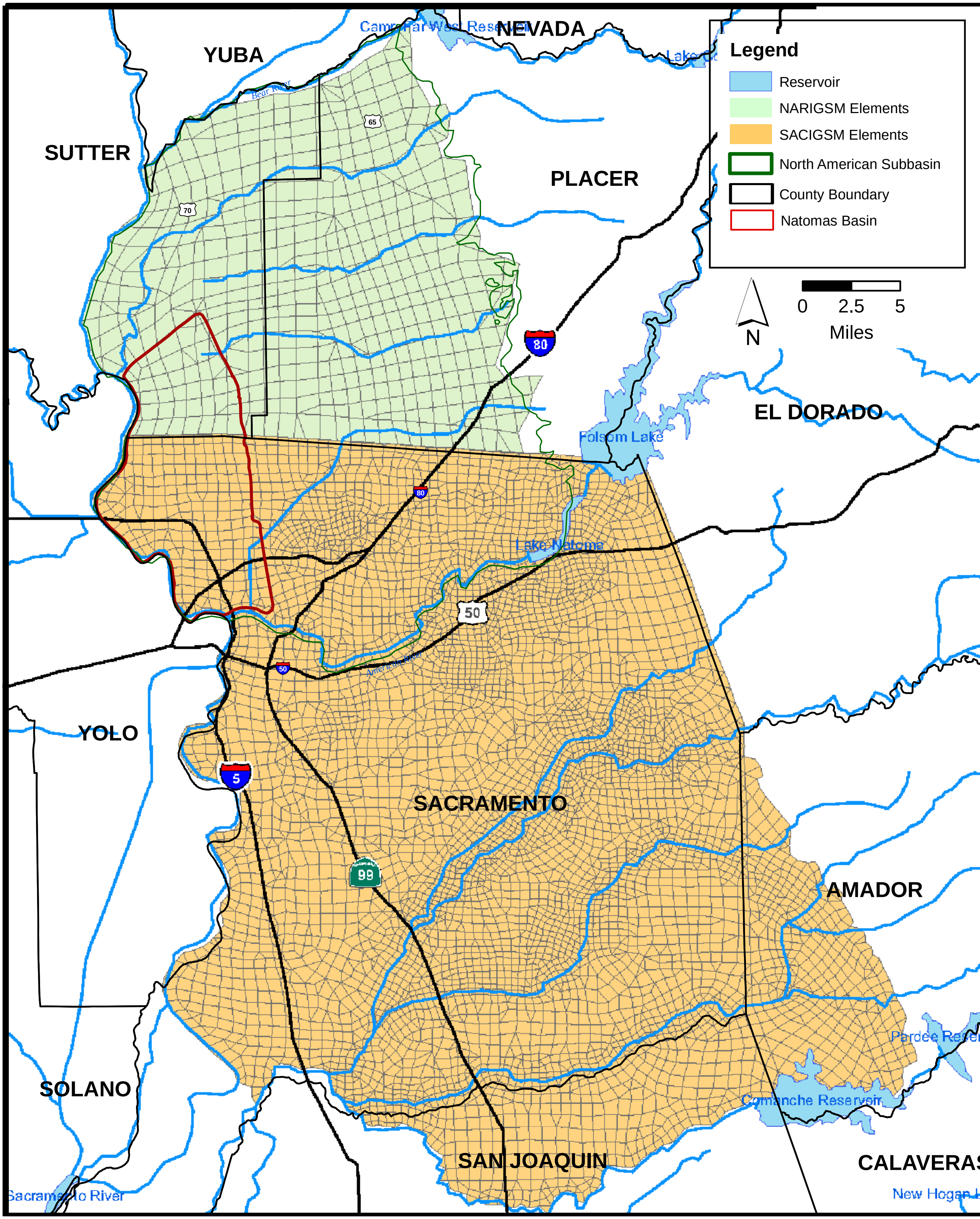
There are also differences between the values shown in **Table 4-1** for the 2030 simulation and the Scenario 2B results summarized in LSCE (2008b). These differences occurred because the latter simulation included an area of about 1,000 acres east of the Natomas Basin in southern Sutter County, which was removed from the area used for the water budget in **Table 4-1**. Due to the additional area, deep percolation and groundwater pumping were 2,300 and 3,000 afy higher, respectively, for the Scenario B water budget (LSCE, 2008b).

The inflow components shown in **Table 4-1** are deep percolation (27,187 afy), which represents a reduction of 4,242 afy from 2004 due to increased urbanization. Recharge from streams is 1,100 afy for the Sacramento River and –500 afy for the American River. The negative recharge for the American River indicates that it is simulated as a gaining reach for this model run. The total net recharge from streams (600 afy) is 6,955 afy lower than for the 2004 simulation. Boundary inflow from the west in 2030 (3,700 afy) is 6,665 afy lower than in 2004. Subsurface inflow from the north (3,700 afy) is 745 afy higher, however, due primarily to drawdown caused by proposed Sutter Pointe pumping in southern Sutter County. The 2030 simulation also shows only 1,200 afy of subsurface outflow to the east (20,538 afy less than in 2004) and 800 afy of subsurface outflow to the south due to expected pumping reductions in the southern portion of the Natomas Basin. The total pumpage in the 2030 simulation is 31,615 afy, which is 3,922 afy lower than in 2004. The average change in storage was 1,572 afy, which indicates generally increasing heads over the simulation period.

Table 4-1
Simulated Groundwater Budgets for Natomas Basin
(Not Including SAFCA Activities)

	Water Budget Component	2004 Simulation[1] (afy)	2030 Simulation[2] (afy)	Difference (afy)
Inflow	Deep Percolation (Including Canal Seepage)	31,429	27,187	4,242
	Recharge from Sacramento River	6,469	1,100	5,369
	Recharge from American River	1,086	-500	1,586
	Boundary Inflow from West	10,365	3,700	6,665
	Subsurface Inflow from North	241	3,700	-3,459
	Subsurface Inflow from South	2,714	0	2,714
	Total Inflow	**52,304**	**35,187**	**17,117**
Outflow	Groundwater Pumping	35,537	31,615	3,922
	Subsurface Outflow to East	21,738	1,200	20,538
	Subsurface Outflow to South	0	800	-800
	Total Outflow	**57,275**	**33,615**	**23,660**
Inflow minus Outflow	**Change in Storage**	**-4,971**	**1,572**	**-6,543**

1. Based on final year of calibration simulation (LSCE, 2008b).
2. Based on 1982-2004 average for Sutter Pointe Project Scenario 2B (LSCE, 2008b).



FILE: C:\Temp\SAFCA\Figure 7-1 Model Grids.mxd Date: 8/6/2008

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Figure 4-1
Model Grids for SACIGSM and NARIGSM
Groundwater Flow Models

5.0 Effects of SAFCA Construction Activities

Most of SAFCA's proposed levee improvements will have no effect on groundwater in the Natomas Basin, but the proposed slurry cutoff walls are intended to reduce seepage beneath the levees and will affect groundwater conditions. Some of SAFCA's construction activities will involve land use changes that will reduce groundwater recharge. This reduction will be at least partially offset by seepage from new and relocated canals, which will increase groundwater recharge. Finally, water supply changes at the Brookfield property borrow site will result in a large reduction in groundwater pumping. A summary of assumptions about proposed SAFCA construction activities used to prepare water budgets and evaluate impacts is provided in **Table 5-1**. The groundwater impacts of proposed slurry cutoff walls are addressed in Chapter 6; the groundwater impacts of SAFCA's other proposed construction activities are summarized below.

5.1 Deep Percolation from Irrigated Agricultural Land

Most groundwater recharge in the Natomas Basin results from deep percolation of applied irrigation water. As shown in **Table 5-2**, estimates of applied water for various crops range from 2.5 af/ac/yr for field crops, grains, and hay to 6.5 af/ac/yr for rice (LSCE, 2008b). Most of this water is consumed by ET but some goes to tailwater runoff and deep percolation. The amount of deep percolation is estimated to range from about ten percent of applied water for field crops (0.25 af/ac/yr) to 17 percent of applied water for orchards (0.68 af/ac/yr). These estimates represent deep percolation from irrigation only; they do not include deep percolation from direct precipitation in the winter and spring. Deep percolation from precipitation was estimated to be about 0.23 af/ac/yr and is not included in the estimates because it would occur regardless of land use (except for areas covered by pavement or other impermeable materials). Estimates of deep percolation from applied water for other crops include 0.77 af/ac/yr for rice, 0.41 af/ac/yr for grains and hay, and 0.61 af/ac/yr for pasture (LSCE, 2008b).

5.2 Land Use Changes Due to Levee Construction

Proposed levee construction activities that will affect land use include raising levees, modifying levee slopes, and adding seepage berms. As summarized in **Table 5-1**, planned improvements to the Sacramento River East Levee will require about 486.5 acres of land and will result in the loss of about 20 acres of rice, 175 acres of field crops, and five acres of orchard (EDAW, 2008). Proposed improvements to other levees are expected to result in the loss of an additional five acres of rice along the NCC South Levee and 50 acres of rice along the PGCC West Levee. Improvements to the NEMDC West Levee are still in the design phase, but irrigated crop land is limited to the northern portion of this levee and any changes in agricultural land use are expected to be small. No agricultural land would be affected by improvements to the American River North Levee, which is located within the City of Sacramento.

Table 5-3 shows existing and future agricultural land uses affected by proposed levee improvements and the resulting change in deep percolation from applied water. The estimated loss of deep percolation is 74 afy for the Sacramento River East Levee, seven afy for the NCC South Levee, and 66 afy for the PGCC West Levee.

5.3 Effects of Canal Improvements

Construction of the new GGS/Drainage Canal and relocation/improvement of three existing canals will increase groundwater recharge in the Natomas Basin. The new GGS/Drainage Canal and most of the relocated canals will be unlined, which will result in additional seepage from the canals to the underlying aquifer. Canal construction activities will also necessitate land use changes, including the loss of some irrigated agricultural land. The assumptions shown in **Table 5-1** were used to estimate the effects of land use changes and seepage from the canals for the water budget. For canals that would be relocated, this includes the total length of the existing and relocated canals, the length of any lined or piped segments, the approximate width of the canals at the waterline, existing land uses for the area where the relocated canal would be constructed, and the proposed future land uses for the existing canal that would be removed.

5.3.1 Giant Garter Snake/Drainage Canal

The new GGS/Drainage Canal will be about 23,200 feet (4.4 miles) long and will extend from the west end of the West Drainage Canal at the south to Pumping Plant No. 2 (east of the Pritchard Lake Pumping Plant) at the north (**Figure 1-1**). The new canal will be entirely unlined, with an average width at the waterline of about 50 feet including benches.

Construction of the GGS/Drainage Canal and associated infrastructure will require about 58.5 acres of land, as indicated in **Table 5-1**. Approximately 45 acres of this area is currently planted to field crops such as corn (EDAW, 2008). As shown in **Table 5-3**, the total amount of deep percolation that will be lost due to the removal of these field crops is estimated to be 11 afy.

The loss of deep percolation of applied water would be offset by increased seepage from the canal. Kleinfelder (2009) used the SEEP/W groundwater flow model to estimate seepage from a two-mile segment of the new GGS/Drainage canal. The canal was simulated with a ten-foot width and an underlying soil hydraulic conductivity of 10^{-5} cm/sec. The canal was simulated as being filled with about five feet of water from May through December, but some seepage was also assumed to occur during the winter. The Kleinfelder seepage estimate was 1.4 af/1,000 lf or 1.4×10^{-4} af per square foot of wetted canal area (af/ft^2). For the total length (23,200 lf) and average width (50 feet) of the GGS/Drainage Canal, this represents a seepage rate of 162 afy, as shown in **Table 5-4**. As discussed below, the estimated seepage rate per wetted area (1.4×10^{-4} af/ft^2) was also used to estimate increased seepage due to relocation or improvement of the West Drainage Canal, the Elkhorn Canal, and the Riverside Canal.

5.3.2 West Drainage Canal

The West Drainage Canal is located south of I-5 and the SIA (**Figure 1-1**) and is about 19,000 feet long. Approximately 4,700 lf of this canal is proposed to be relocated. The existing canal is unlined, and the relocated segment of the canal is also planned to be unlined. In addition to the partial relocation, SAFCA plans to widen the entire canal from about 30 feet to 72 feet, including a bench area that will be planted to tules (EDAW, 2008; M&H, 2008). As shown in **Table 5-1**, only about 1.5 acres of the area where the relocated canal will be constructed is currently planted to field crops. The loss of deep percolation from applied water due to the canal relocation is estimated to be 0.4 afy (**Table 5-3**).

Canal seepage was estimated using the seepage rate calculated from the Kleinfelder model for the GGS/Drainage Canal (1.4 x 10^{-4} af/ft^2). As shown in **Table 5-4**, seepage from the existing West Drainage Canal was estimated to be about 80 afy. Due to lengthening and widening of the canal, the future seepage rate is projected to be 208 afy, which represents an increase of 128 afy.

5.3.3 Elkhorn Canal

The existing Elkhorn Canal is located just east of the Sacramento River East Levee (**Figure 1-1**) and is about 19,850 feet (3.8 miles) long and 16 feet wide. Approximately one mile of the existing canal is concrete lined. The canal is being relocated farther east to make room for levee widening and other improvements. The relocated canal will be about 22,300 feet long and 32 feet wide. Approximately 6,100 lf of the relocated canal are planned to be lined, and another 2,950 lf would be piped. This includes the 2,050 lf alignment crossing the Teal Bend Golf Course and another 900 lf adjacent to an area of existing homes (M&H, 2008).

As shown in **Table 5-1**, relocation of the Elkhorn Canal and associated infrastructure will require about 30 acres of land. Most of the area where the new canal will be constructed is currently planted to irrigated crops. As shown in **Table 5-3**, there are about 15 acres of field crops, three acres of orchard, and 11 acres of grain, hay, and pasture. The loss of deep percolation due to removal of these crops is estimated to be 11 afy.

Canal seepage was estimated similarly to the West Drainage Canal, using the seepage rate calculated from the Kleinfelder model for the GGS/Drainage Canal (1.4 x 10^{-4} af/ft^2). As shown in **Table 5-4**, seepage from the existing Elkhorn Canal was estimated to be about 33 afy. The seepage rate of the relocated canal is projected to be 59 afy, which represents an increase of 27 afy.

5.3.4 Riverside Canal

The existing Riverside Canal is located just east of the southern portion of the Sacramento River East Levee in the Natomas Basin (**Figure 1-1**) and is about 19,600 feet (3.7 miles) long and seven feet wide. The Riverside Canal is also being relocated farther east to make room for levee improvements. The relocated canal is planned to be about 20,550 feet long and ten feet wide (M&H, 2008).

As shown in **Table 5-1**, relocation of the Riverside Canal and associated infrastructure will require about 54 acres of land. Most of the area where the new canal will be constructed is currently planted to irrigated crops. As shown in **Table 5-3**, there are about four acres of rice, 33 acres of field crops, six acres of orchard, and seven acres of grains, hay, and pasture. The loss of deep percolation due to removal of these crops is estimated to be 21 afy.

Canal seepage was again estimated using the seepage rate calculated from the Kleinfelder model for the GGS/Drainage Canal (1.4 x 10^{-4} af/ft^2). As shown in **Table 5-4**, seepage from the existing Riverside Canal was estimated to be 19 afy. The seepage rate of the relocated canal is projected to be 29 afy, which represents an increase of ten afy.

5.4 Effects of Borrow Sites

Excavation of the three borrow sites that will be the primary source of soil for SAFCA's proposed levee improvements and other construction activities will have effects on groundwater recharge in the Natomas Basin. **Table 5-1** includes a summary of assumptions about the borrow sites that were used for water budget estimates. These include the area of each borrow site and existing and proposed future land uses.

5.4.1 Airport North Bufferlands

The Airport North Bufferlands is a 737-acre site located north of the SIA (**Figure 1-1**). Approximately 630 acres of this site that had previously been planted to rice has recently been removed from rice cultivation or other land uses that would attract water fowl by the SIA. SAFCA plans to remove about four to six feet of borrow material from this site, which is currently considered non-irrigated grassland. Topsoil will be stockpiled and replaced after borrow operations are complete, and future land uses are not expected to change after reclamation of the site. As shown in **Table 5-3**, there will be no change in deep percolation from this site as a result of SAFCA's activities.

5.4.2 Brookfield Property

The Brookfield property consists of 353 acres at the northern tip of the Natomas Basin. Approximately 325 acres of this property is currently planted to rice, and SAFCA plans to restore most of this site to rice cultivation. Up to six feet of soil will be excavated, including one foot of topsoil that will be stockpiled and replaced after borrow operations are complete.

SAFCA plans to return about 286 acres of the Brookfield property to rice cultivation after construction activities are complete. The remaining 39 acres of rice fields would be lost due to construction along the PGCC West Levee and other factors. As shown in **Table 5-3**, an estimated 51 afy of deep percolation will be lost due to the conversion of rice land to other uses. The Brookfield property is currently irrigated entirely with groundwater, but SAFCA plans to provide the infrastructure so that most of the borrow site can be irrigated with surface water in the future. Engineering work is still in progress, but current estimates are that about 80 percent of the property would be irrigated with surface water rather than groundwater after reclamation (M&H, 2008). The current crop mix is about 50 percent regular rice and 50 percent wild rice (Jack DeWit, pers. comm., July 8, 2008). Regular rice and wild rice have estimated water demands of 6.5 and 6.0 af/ac/yr, respectively. Therefore, current groundwater pumpage to irrigate this property is estimated to be about 2,030 afy. This would be reduced by 1,625 afy due to the planned transition from groundwater to surface water.

In addition to increasing heads in the vicinity of the Brookfield site, the reduction in pumping would also result in increased groundwater outflow from the northern portion of the Natomas Basin. An analytical groundwater model based on the Theis (1935) equation for groundwater flow in a confined aquifer was used to estimate the amount of water level recovery that would occur due to the reduced pumping. An aquifer transmissivity of 7,620 ft^2/day and a storage coefficient of 0.001 were used for this simulation based on LSCE (2008b). The maximum simulated water level recovery beneath the Brookfield property was about 17 feet at the end of the irrigation season in September. At the midpoint of the PGCC West Levee (south of the Brookfield property), the simulated recovery ranged from 1.6 to 7.6 feet, with an average annual value of 3.8 feet. This would result in an average increase in the hydraulic gradient for flow to the east of about 4.4×10^{-5} ft/ft. The increase in subsurface outflow was estimated using Darcy's Law (Darcy, 1856), which can be written as:

$$Q = KAi$$

where:
Q = volumetric flow rate,
K = hydraulic conductivity of the porous medium,
A = cross-sectional area of the porous medium, and
i = hydraulic gradient.

The cross-sectional area was estimated based on the assumption that almost all of the flow would occur in the upper 400 feet of the aquifer system. Using this equation, the increase in subsurface outflow from the Natomas Basin was predicted to be 76 afy.

5.4.3 Fisherman's Lake

Fisherman's Lake – The Fisherman's Lake borrow site is located at the northern end of Fisherman's Lake in the southwestern portion of the Natomas Basin. Engineering work has not been completed for this site, but the current estimate is that about 400 acres of land would be used for borrow material.

As shown in **Table 5-1**, current land uses on this site are 49 acres of rice, 266 acres of field crops, and 85 acres of managed marsh. After reclamation, there would be about 175 acres of managed marsh and 225 acres of non-irrigated grassland or woodland. As shown in **Table 5-3**, the creation of managed marsh will result in an increase in deep percolation of 51 afy. Overall, however, there will be a net loss in deep percolation of 15 afy due to the conversion of field crops to non-irrigated grassland.

5.5 Summary

This chapter summarized the groundwater impacts of SAFCA's proposed construction activities, with the exception of slurry cutoff walls, which are addressed in Chapter 6. The above analysis included three types of groundwater impacts:

- Land use changes due to levee and canal improvements and borrow sites will result in the conversion of some irrigated agricultural land to non-irrigated land uses, which will reduce groundwater recharge from deep percolation of applied water. The total loss of deep percolation from applied water is estimated to be 256 afy, as shown in **Table 5-3**.
- The new and relocated canals would result in increased groundwater recharge due to additional canal seepage. The total estimated increase in canal seepage is 327 afy, as shown in **Table 5-4**.

- There will be a large reduction in groundwater pumping due to the planned shift in water supply from groundwater to surface water for 80 percent of the Brookfield property. The reduction in pumping is estimated to be about 1,625 afy. This will result in higher heads and increased groundwater outflow in the northern portion of the Natomas Basin.

Table 5-1
SAFCA Construction Assumptions for Water Budget Estimates

	Total Length (ft)	Slurry Cutoff Walls		Canals		Total Area (ac)	Existing Agricultural Land Uses	Future Land Uses	Notes/Sources
		Length (ft)	Average Depth (ft)	Length of Lined or Piped Segments (ft)	Average Width at Waterline (ft)				
Levees									
Sacramento River East Levee	96,000	53,450	65	-	-	486.5	20 ac rice, 175 ac field crops, 5 ac orchard	Levee	HDR (April 17, 2009); Land use based on EDAW Table 3
NCC South Levee	28,700	28,700	70	-	-	148.5	5 ac rice	Levee	Kleinfelder (2008), Land use based on EDAW Table 3
PGCC West Levee	17,400	14,010	38	-	-	89.5	50 ac rice	Levee	Wood Rodgers (2009), land use based on EDAW Table 3
NEMDC West Levee (North)	35,700	22,840	37	-	-	-	South NEMDC - none; North NEMDC - unknown	Levee	Wood Rodgers (2009)
NEMDC West Levee (South)	31,900	23,100	45	-	-	-	South NEMDC - none; North NEMDC - unknown	Levee	Wood Rodgers (2009)
American River North Levee	11,600	11,560	55	-	-	-	None	Levee	HDR (April 17, 2009)
Canals									
GGS/Drainage Canal	23,200	-	-	0	50	58.5	45 ac field crops	-	Width (M&H, 7-15-08); Land use based on EDAW Table 3
West Drainage Canal (Existing)	19,000	-	-	0	30	7	-	Managed grassland	4,700 LF section to be relocated
West Drainage Canal (Relocated)	20,600	-	-	0	72	8	1.5 ac field crops	-	Relocated section = 6,300 LF, rest widened to 72 ft.
Elkhorn Canal (Existing)	19,850	-	-	5,280	16	30	-	Levee	Length & width (M&H, 7-15-08)
Elkhorn Canal (Relocated)	22,300	-	-	9,050	32	34	15 ac field crops, 3 ac orchard, 11 ac other	-	Land use estimated by LSCE based on 2004 land use map from LSCE (2008b)
Riverside Canal (Existing)	19,600	-	-	0	7	50	-	Levee	
Riverside Canal (Relocated)	20,550	-	-	0	10	54	12 ac rice, 102 ac field crops, 17 ac orchard, 24 ac other	-	Land use estimated by LSCE based on 2004 land use map from LSCE (2008b)
Borrow Sites									
Airport North Bufferlands	-	-	-	-	-	737	Previously planted to rice but currently non-irrigated at request of FAA.	Managed grassland	Acreage (M&H, 7-15-08); current land uses per SAFCA
Brookfield Property	-	-	-	-	-	353	325 ac rice irrigated w/ 100% groundwater (1/2 & 1/2 reg. & wild rice)	286 ac rice irrigated w/ 20% groundwater, 80% surface water	Assumption of 286 ac in rice in future based on work on adjacent PGCC west levee (M&H, 2008)
Fisherman's Lake	-	-	-	-	-	400	49 ac rice, 266 ac field crops, 85 ac marsh	175 ac managed marsh, 225 ac grass-land or woodland	Acreage, land use from Marieke Armstrong, M&H (7-18-08)

Table 5-2
Deep Percolation from Applied Water in the Natomas Basin

Crop	Applied Water[1] (af/ac/yr)	Deep Percolation from Applied Water[2]	
		(af/ac/yr)	(%)
Rice or managed marsh	6.5	0.77	12%
Field and Row Crops	2.5	0.25	10%
Orchard	4.0	0.68	17%
Grains and Hay	2.5	0.41	16%
Pasture	4.8	0.61	13%

1. Source: LSCE (2008b).
2. Source: LSCE 2008b. Estimated as total deep percolation minus deep percolation from precipitation.

Table 5-3
Effects of Land Use Changes Due to Proposed SAFCA Construction on Deep Percolation

SAFCA Construction Activity	Existing Agricultural Land Uses (ac)				Future Agricultural Land Uses (ac)		Loss of Deep Percolation from Applied Water (afy)				Total Loss of Deep Percolation from Applied Water (afy)
	Rice[1]	Field Crops	Orchard	Grains, Hay, and Pasture	Rice or Managed Marsh	Other	Rice[2]	Field Crops[3]	Orchard[4]	Grains, Hay, and Pasture[5]	
Levee Improvements:											
Sacramento River East Levee	20	175	5	0	0	0	15	44	3	0	63
NCC South Levee	5	0	0	0	0	0	4	0	0	0	4
PGCC West Levee	50	0	0	0	0	0	39	0	0	0	39
NEMDC West Levee[6]	0	0	0	0	0	0	0	0	0	0	0
American River North Levee	0	0	0	0	0	0	0	0	0	0	0
Subtotal	**75**	**175**	**5**	**0**	**0**	**0**	**58**	**44**	**3**	**0**	**105**
Canals:											
GGS/Drainage Canal	0	45	0	0	0	0	0	11	0	0	11
West Drainage Canal	0	1.5	0	0	0	0	0	0.4	0	0	0.4
Elkhorn Canal	0	15	3	11	0	0	0	4	2	5	11
Riverside Canal	4	33	6	7	0	0	3	8	4	3	19
Subtotal	**4**	**95**	**9**	**18**	**0**	**0**	**3**	**24**	**6**	**8**	**41**
Borrow Sites:											
Airport North Bufferlands	0	0	0	0	0	0	0	0	0	0	0
Brookfield Property	325	0	0	0	286	0	30	0	0	0	30
Fisherman's Lake	134	266	0	0	173	0	-30	67	0	0	36
Subtotal	**459**	**266**	**0**	**0**	**459**	**0**	**0**	**67**	**0**	**0**	**67**
Total	**538**	**536**	**14**		**459**	**0**	**61**	**134**	**10**	**8**	**213**

1. Includes 85 ac of managed marsh at the Fisherman's Lake borrow site.
2. Deep percolation from applied water estimated to be 0.77 af/ac/yr for rice and managed marsh by LSCE (2008b).
3. Deep percolation from applied water estimated to be 0.25 af/ac/yr for field crops by LSCE (2008b).
4. Deep percolation from applied water estimated to be 0.68 af/ac/yr for orchards by LSCE (2008b).
5. Deep percolation from applied water estimated to be 0.41 af/ac/yr for grains/hay and 0.61 af/ac/yr for pasture by LSCE (2008b). A weighted average of 0.47 af/ac was used above.
6. Design of NEMDC levee improvements is in the early stages, and there is no current estimate of land use changes due to levee constructiion. An estimate of 50 ac of rice based on the PGCC was also used for the NEMDC because land uses west of the northern portion of the NEMDC are similar to the PGCC. Land uses west of the southern portion of the NEMDC are urbanized or vacant.

Table 5-4
Effects of SAFCA's Proposed Canal Construction on Canal Seepage

Canal Name		Total Length (ft)	Length of Lined or Piped Segments (ft)	Length of Unlined Portion (ft)	Width at Waterline (ft)	Area at Waterline[1] (ft^2)	Seepage Rate per Sq. Foot[2] ($af/ft^2/yr$)	Total Seepage Rate (afy)	Seepage Increase (afy)
GGS/Drainage Canal	New	23,200	0	23,200	50	1,160,000	1.4E-04	162	162
West Drainage Canal	Existing	19,000	0	19,000	30	570,000	1.4E-04	80	
	Relocated	20,600	0	20,600	72	1,483,200	1.4E-04	208	128
Elkhorn Canal	Existing	19,850	5,280	14,570	16	233,120	1.4E-04	33	
	Relocated	22,300	9,050	13,250	32	424,000	1.4E-04	59	27
Riverside Canal	Existing	19,600	0	19,600	7	137,200	1.4E-04	19	
	Relocated	20,550	0	20,550	10	205,500	1.4E-04	29	10
Total	**Existing**	**58,450**	**5,280**	**53,170**		**940,320**		**132**	
	New or Relocated	**86,650**	**9,050**	**77,600**		**3,272,700**		**458**	**327**

1. Area of unlined portion only.
2. Based on results of Kleinfelder (2009) seepage model for portion of GGS/Drainage Canal.

6.0 Effects of Slurry Cutoff Walls

Slurry cutoff walls are currently proposed for a total of about 29 miles of the levees surrounding the Natomas Basin. This includes about ten miles of the Sacramento River East Levee, all (5.4 miles) of the NCC South Levee, 2.7 miles of the PGCC West Levee, 4.3 miles of the northern NEMDC West Levee, 4.1 miles of the southern NEMDC West Levee, and all (2.2 miles) of the American River North Levee. Proposed seepage mitigation including slurry cutoff walls is summarized in **Table 6-1** for the Sacramento River East Levee and in **Table 6-2** for the NCC South Levee, the PGCC West Levee, the NEMDC West Levee, and the American River North Levee. The proposed cutoff wall locations are shown on **Figure 6-1**.

Groundwater flow beneath the levees with and without the proposed cutoff walls was estimated by various methods. These methods and the resulting estimates are discussed in this section. Groundwater flow beneath the Sacramento River East Levee and the NCC South Levee with and without slurry cutoff walls was estimated by both URS and Kleinfelder using the SEEP/W groundwater flow model. The most recent estimates were made by Kleinfelder and are summarized below. LSCE used a spreadsheet model to develop a revised estimate for the Sacramento River East Levee.

No modeling has been done to estimate the impacts of proposed slurry cutoff walls along the other three levees that surround the Natomas Basin. For these areas, groundwater flow without slurry cutoff walls was estimated based on the IGSM models discussed in Chapter 4. Two different simulations were used for this purpose: one representing existing conditions based on 2004 data, and the other representing future conditions in 2030. Based on the model results, estimates of groundwater flow per cross-sectional area were developed. For the reaches where slurry cutoff walls are proposed, the estimated flow per cross-sectional area was reduced by a fixed percentage based on the Kleinfelder model results for the Sacramento River East Levee.

6.1 Sacramento River East Levee

Measures proposed to mitigate seepage problems beneath the Sacramento River East Levee are shown in **Table 6-1**. The current plan includes some form of mitigation for all reaches. Slurry cutoff walls are currently proposed for 13 reaches, seepage berms are proposed for 13 reaches, relief wells are proposed for ten reaches, and jet grouting is proposed at one reach. The reaches where cutoff walls are proposed are shown in **Figure 6-1**.

6.1.1 Kleinfelder Model

Kleinfelder (2009) used the SEEP/W groundwater flow model to estimate seepage beneath the Sacramento River East Levee with and without slurry cutoff walls and summarized the results in a report entitled *Evaluation of Cutoff Walls Impact on Groundwater Recharge, Sacramento River East Levee, Natomas Levee Improvement Project, Sacramento and Sutter Counties, California*. SEEP/W is a two-dimensional, finite-element model based on Darcy's Law (Darcy, 1856). As discussed in Chapter 5, the inputs to Darcy's equation are the hydraulic conductivity, the hydraulic gradient, and the cross-sectional area for groundwater flow. SEEP/W has the capability to simulate flow in multiple layers, and a separate hydraulic conductivity is required for each layer. Hydraulic conductivities used in the Kleinfelder model ranged from 0.028 ft/day for clay to 283 ft/day for gravel. The maximum hydraulic conductivity used for the permeable layers in most reaches was 14 ft/day (representing sand). The Kleinfelder model was based on a previous mitigation plan that included a total of 42,300 lf of slurry cutoff walls in 12 reaches.

The SEEP/W model allows both steady-state and transient simulations to be conducted. As discussed below, a transient simulation was conducted for one station, but the results were not used in the overall seepage estimate. The reported model results were based on steady-state simulations conducted for four stations, which were considered to be representative of the different geologic conditions observed on geologic profiles created from borehole data. The modeled stations were located at Stations 27+00 in Reach 1, 70+00 in Reach 2, 217+00 in Reach 4b, and 353+00 in Reach 7b. Model results from these stations were applied to other reaches with similar geology. The percentage of the entire length of the Sacramento River East Levee represented by each modeled station was 11 percent for Station 27+00, 23 percent for Station 70+00, 42 percent for Station 217+00, and 24 percent for Station 353+00.

Kleinfelder used an “average” groundwater elevation of 17.25 ft msl for all simulations. This was compared against river stage at the Verona gage ranging from 17.25 to 34.25 ft msl in one-foot increments to calculate the gradient between the River and shallow groundwater. The steady-state model was run separately for each stage height, and the estimated seepage was multiplied by the number of days that the stage was calculated to be at each elevation based on data from 1995-2007. The lowest stage height (17.25 ft msl) had the longest duration (20 days/year), and the three highest stage heights (32.25, 33.25, and 34.25 ft msl) each had a duration of ten days/year.

Since almost all of the groundwater flow occurs in the sand layers, the model is very sensitive to the hydraulic conductivity used for sands. A hydraulic conductivity of 14 ft/day was used for sand layers in three of the four modeled reaches, and the calculated seepage rate was relatively low (2.6 to 13.4 afy/1,000 lf) in these reaches. Hydraulic conductivities of 56 and 283 ft/day were used for sand and gravel, respectively, at Station 217+00, and the resulting seepage rate was much higher (129 afy/1,000 lf). These seepage estimates were multiplied by the length of each reach to estimate the total seepage, and the results are shown in **Table 6-3**. The total seepage was estimated to be about 5,650 afy without slurry cutoff walls using this approach.

The model was rerun for Stations 70+00 and 353+00 with the slurry cutoff walls in place to estimate the effect of the cutoff walls. A hydraulic conductivity of 2.8×10^{-3} ft/day was estimated for the cutoff walls. For Station 70+00, the cutoff wall was assumed to fully penetrate the permeable sand layer and a seepage reduction of 85 percent was calculated. At Station 353+00, the cutoff wall was assumed to not fully penetrate the permeable sand layer and was calculated to reduce seepage by only 40 percent. The model results for the four stations were multiplied by one of these percentages to estimate the impacts of the other cutoff walls. The 85 percent reduction was used for reaches where the cutoff wall was considered to fully penetrate the permeable sand layer, and the 40 percent reduction was used for reaches where the wall would not be fully penetrating. As shown in **Table 6-3**, the total amount of groundwater flow that would be blocked by the eight miles of proposed slurry cutoff walls is about 1,320 afy.

A transient version of the model was created for Station 70+00 to check the results of the steady-state simulations. The transient model was run with and without the slurry cutoff walls for a one-year period divided into 34 time steps. Groundwater elevations and river stage were allowed to fluctuate based on stage measured at the Verona gage and groundwater levels at USACE piezometer 2F-01-15N. Seepage without the cutoff wall calculated with the transient model was three times higher than that calculated with the steady-state model. Seepage through the cross-sectional area where the cutoff wall would be constructed was about four times higher with the transient model as compared to the steady-state model. On a percentage basis, the calculated flow reduction for the transient model was about 70 percent, which is less than the 85 percent reduction calculated with the steady-state model.

Overall, the Kleinfelder transient model results appear to be more realistic than the steady-state results. This would be expected since steady-state models require an assumption of equilibrium conditions and cannot simulate conditions that vary with time. For this reason, transient model results are considered more accurate for most applications. However, steady-state model results had to be used for Kleinfelder's overall seepage estimate shown in **Table 6-3** because only one station was simulated with the transient model. As discussed below, some of the Kleinfelder transient model results were used for LSCE's evaluation of cutoff wall impacts on seepage from the River and head changes in private wells along the east levee.

On a percentage basis, the transient and steady-state models showed varying results for flow reductions caused by the cutoff walls. Based on the transient model, a flow reduction of 70 percent due to horizontal flow through a fully-penetrating cutoff wall was considered to be a reasonable estimate. This estimate is considered to be conservative in that it does not account for increased vertical flow beneath the cutoff walls or horizontal flow around the cutoff walls. A three-dimensional model would be expected to show a somewhat smaller flow reduction due to the cutoff walls.

6.1.2 LSCE Seepage Estimates

Since almost all of the groundwater flow beneath the levees occurs in the permeable sand and gravel layers, a seepage estimate equivalent to the SEEP/W model can be obtained by simply calculating groundwater flow in the sand and gravel layers using Darcy's equation. An updated version of the estimate made by LSCE (2008a) is summarized in **Table 6-4** and discussed in this section. As noted above, Darcy's equation states that the volumetric rate of groundwater flow is equal to the product of the hydraulic conductivity, the cross-sectional area, and the hydraulic gradient (Darcy, 1856). Groundwater flow for 57 reaches or sub-reaches was estimated separately and then summed to estimate the total net recharge from the River. The term "net recharge" is used because the hydraulic gradient used for the simulations is an average value that accounts for the fact that the Sacramento River fluctuates between gaining and losing conditions over the course of the year. On an annual basis, however, all reaches of the Sacramento River in the Natomas Basin appear to be losing, as discussed above in Chapter 3.

For these seepage estimates, groundwater flow in fine to medium sands was estimated separately from that in coarse sands and gravels. For each category, the hydraulic conductivity and gradient were assumed to be constant for all reaches. Hydraulic conductivities used in the model are based on estimates summarized in **Table 2-1**. A hydraulic conductivity of 28 ft/day was used for the fine to medium sands, which is higher than the estimate used by Kleinfelder for three of the stations simulated with the SEEP/W model (14 ft/day). A hydraulic conductivity of 140 ft/day was used for coarse sands and gravels, which is within the range of estimates used by Kleinfelder for similar materials at Station 217+00 (56 to 283 ft/day).

The hydraulic gradient used for the Darcy's Law estimate was 0.0032 ft/ft based on the average annual value estimated in LSCE (2008a). As discussed in Section 4, this hydraulic gradient accounts for the large seasonal fluctuations observed in the hydrographs of groundwater levels and estimated stage. Steep positive gradients (losing conditions) occurring during periods of rising and high stage are partially offset by shallow negative gradients (gaining conditions) during periods of declining and low stage. Although the groundwater contour maps show that the gradient is steeper in the southern portion of the Natomas Basin, the piezometer data and stage estimates were not accurate enough to allow this spatial variability to be quantified.

For each reach, the saturated thickness of permeable sands and gravels was estimated from the geologic profiles, which contain data for the upper 100 to 120 feet of the aquifer system. The permeable saturated thickness for fine to medium sands ranged from eight to 80 feet, with an average of 46 feet. The permeable saturated thickness for coarse sands and gravels ranged from zero to 53 feet, with an average of seven feet. These thicknesses were multiplied by the length of each reach to estimate the cross-sectional area for groundwater flow. Because the overall length of the Sacramento River East Levee is about 18 miles, the total cross-sectional area is very large (about 5.8 million square feet or 134 acres).

As shown in **Table 6-4**, the estimated groundwater flow in each reach ranges by several orders of magnitude, from one to about 2,200 afy. The total estimated groundwater flow in the shallow aquifer without slurry cutoff walls is 8,450 afy. Although the coarse sand and gravel layers account for only 23 percent of the total saturated thickness, groundwater flow in these layers accounts for 60 percent of the total estimated flow. The total flow is about 50 percent more than was estimated by Kleinfelder using the steady-state SEEP/W model but is less than would be expected had Kleinfelder applied its transient model to all reaches.

The estimated effect of the slurry cutoff walls was partially based on the Kleinfelder transient model results. The estimate of a 70 percent reduction in groundwater flow obtained with the transient model was used for reaches where the cutoff wall fully penetrated the permeable sand layer. LSCE's interpretation of the geologic profiles indicates that the slurry cutoff walls will only be fully penetrating for portions of five of the 13 reaches where cutoff walls are proposed. For the other eight reaches, a 70 percent flow reduction was assumed for the depth of the cutoff wall and no flow reduction below the bottom of the cutoff wall. Using this approach, the effect of the cutoff walls is estimated to range from two to 70 percent of the total flow in these reaches. The estimated flow reduction due to all proposed cutoff walls is 884 afy, as shown in **Table 6-4**. This represents a reduction of about ten percent of the total estimated recharge from the Sacramento River.

The estimate of slurry cutoff wall impacts in **Table 6-4** is based on existing groundwater conditions in the Natomas Basin. In order to estimate impacts in 2030, the hydraulic gradient was increased to reflect the steeper gradient that would occur in the northern portion of the Natomas Basin primarily due to pumping to supply the proposed Sutter Pointe development. As shown in **Table 6-5**, the magnitude of the predicted increase ranges from a maximum of 0.0018 ft/ft in Reaches 2 and 3 to zero in Reaches 14 through 20. The total estimated recharge from the River without slurry cutoff walls would increase to 9,340 afy, and the estimated flow reduction due to all proposed cutoff walls would increase to 992 afy. These flow reductions are also summarized in **Table 6-6**, which shows the estimated groundwater flow through the cross-sectional area of the proposed slurry cutoff walls with and without the walls for all levees surrounding the Natomas Basin based on existing/2004 and future/2030 conditions.

Like the Kleinfelder model results, the reduction in flow due to the proposed slurry cutoff walls calculated by LSCE is conservative because the model only accounts for horizontal flow through the cutoff walls. Increased vertical flow beneath the cutoff walls and increased horizontal flow around the ends of the cutoff walls are not included in the model, which means that the actual flow reduction would be less than simulated. The reduction in groundwater flow beneath the levee due to the cutoff walls equates to reduced recharge from the Sacramento River to the Natomas Basin. During periods when the River is losing, heads will be lower on the land side of the levee and higher on the river side due to the impedance caused by the cutoff walls and the resultant reduction in groundwater flow. Flow that would be impeded by the cutoff walls would be expected to remain in the River, which will provide a benefit to downstream users.

6.2 Natomas Cross Canal South Levee

6.2.1 Kleinfelder Model

Slurry cutoff walls are currently under construction along the NCC South Levee as summarized in **Table 6-2**. Seepage beneath the NCC South Levee with and without slurry cutoff walls was estimated by Kleinfelder using the SEEP/W groundwater flow model. The model results are included in a report entitled *Evaluation of Cutoff Walls Impact on Groundwater Recharge, Natomas Cross Canal South Levee, Natomas Levee Improvement Project, Sacramento and Sutter Counties, California* (Kleinfelder, 2008) and are summarized below.

Hydraulic conductivities used in the model ranged from 0.028 ft/day for clay to 28 ft/day for sand. The maximum hydraulic conductivity is an order of magnitude less than the 283 ft/day used for some reaches of the Sacramento River East Levee because boreholes drilled along the NCC South Levee did not encounter significant gravel lenses. However, the permeable sand layers were assigned a hydraulic conductivity of 28 ft/day, which is double that used for the model of the Sacramento River East Levee.

Kleinfelder conducted both steady state and transient simulations were conducted for the NCC South Levee, but the results of the transient simulations were not used for the overall seepage estimate. The reported model results were based on steady-state simulations conducted for three stations, which were considered to be representative of the different geologic conditions observed on geologic profiles created from borehole data. The modeled stations were located at Stations 135+00 (Reach 4), 183+00 (Reach 5), and 213+00 (Reach 6). Stations 135+00 and

183+00 were modeled as having two relatively thin sand layers separated by a clay layer. Station 213+00 was modeled as having a single thicker sand layer. Model results from these stations were applied to other reaches with similar geology. The percentage of the entire length of the NCC South Levee represented by each modeled station was 35 percent for Station 135+00, 40 percent for Station 183+00, and 25 percent for Station 213+00.

An "average" depth to water of 7.5 feet was used for all simulations. This equates to a groundwater elevation of about 27.6 to 34.6 ft msl and was compared against NCC stage ranging from about 19.6 to 36.6 ft msl in one-foot increments to calculate the gradient between the canal and shallow groundwater. The steady-state model was run separately for each stage height, and the estimated seepage was multiplied by the number of days that the stage was calculated to be at each elevation based on data from the Sacramento River Verona gage for 1995-2007. The lowest stage height (19.6 ft msl) had the longest duration (about 20 days/year), and the three highest stage heights (34.6, 35.6, and 36.6 ft msl) each had a duration of about ten days/year.

Unlike its seepage model of the Sacramento River East Levee, Kleinfelder modeled all three stations of NCC South Levee using the same hydraulic conductivity (28 ft/day) for the most permeable layers. Therefore, the simulated seepage for the NCC was much less variable. Station 135+00 had the lowest estimated seepage rate (3.1 afy/1,000 lf). Station 183+00 had a seepage rate of 9.8 afy/1,000 lf, and Station 213+00 had a seepage rate of 9.1 afy/1,000 lf. These seepage estimates were multiplied by the length of each reach, and the total seepage was estimated to be about 218 afy without slurry cutoff walls using this approach.

The model was rerun for all three stations with the slurry cutoff walls in place to estimate the effect of the cutoff walls on seepage from the NCC. A hydraulic conductivity of 2.8×10^{-3} ft/day was assumed for the cutoff walls. For Station 135+00, the cutoff wall was assumed to fully penetrate both sand layers, resulting in an estimated seepage reduction of 90 percent. For Station 183+00, however, the cutoff wall was assumed to penetrate only the upper sand layer, which resulted in an estimated seepage reduction of 30 percent. For Station 213+00, the cutoff wall was assumed to fully penetrate the single sand layer, which also resulted in an estimated seepage reduction of 90 percent. The model results for the four stations were multiplied by one of these percentages to estimate the impacts of the other cutoff walls, and the total amount of groundwater flow that would be blocked by the slurry cutoff walls along the NCC South Levee under existing conditions was estimated to be 126 afy. This represents 90 percent of the flow through the cutoff wall cross section and 58 percent of the total flow calculated by the model. A flow reduction of 90 percent is considered to be high, and the flow reduction estimated from Kleinfelder's transient simulation for the Sacramento River East Levee was used for LSCE's seepage estimates discussed below.

6.2.2 LSCE Seepage Estimates

The Kleinfelder model of the NCC provides an estimate of canal seepage by does not include groundwater flow from the north into the Natomas Basin (beneath the NCC). As discussed in Chapter 4, this flow was estimated to be 241 afy based on the 2004 IGSM simulation. As shown in **Table 6-6**, the total flow into the Natomas Basin from the north is estimated as the sum of the groundwater flow estimated by the IGSM model and canal seepage estimate with the SEEP/W model (218 afy). Approximately 80 afy of this flow is estimated to pass through the cross-sectional area of the proposed slurry cutoff walls, and a flow reduction of 70 percent was assumed due to the cutoff walls. The total estimated flow reduction shown in **Table 6-6** is 56 afy, or 12 percent of the total flow.

The impacts of slurry cutoff walls along the NCC South Levee were estimated similarly for 2030 conditions in **Table 6-6**. Seepage from the NCC was assumed to be relatively constant in future years, but groundwater flow beneath the NCC South Levee was estimated to be much larger (about 3,700 afy) in 2030 (**Table 4-1**) due primarily to steeper gradients caused by proposed M&I pumping in the Sutter County portion of the Natomas Basin. It is assumed that almost all of this flow would occur in the upper 400 feet of the aquifer system. Flow through the cross-sectional area where cutoff walls are proposed was estimated to be 686 afy, and a 70 percent flow reduction due to the slurry cutoff walls was again assumed. The estimated flow reduction for the 2030 simulation is 480 afy.

6.3 Pleasant Grove Creek Canal West Levee

Proposed slurry cutoff walls along the PGCC West Levee are summarized in **Table 6-2**, and the cutoff wall locations are shown on **Figure 6-1**. As discussed above, no modeling has been done to estimate the impacts of proposed slurry cutoff walls along the PGCC West Levee, the NEMDC West Levee, and the American River North Levee. For these levees, groundwater flow without slurry cutoff walls was estimated based on the IGSM groundwater model results discussed in Chapter 4. Based on the model results, an estimate of groundwater flow per cross-sectional area was developed for the 2004 and 2030 simulations (**Table 6-6**). For the reaches where slurry cutoff walls are proposed, flow through the cross-sectional area of the cutoff walls was reduced by a fixed percentage (70 percent) based on the Kleinfelder transient model results for the Sacramento River East Levee.

As discussed in Chapter 4, the IGSM model results show relatively large volumes of groundwater outflow from the Natomas Basin to the east beneath the PGCC and NEMDC for the 2004 simulation. The model results indicate much less outflow in 2030 due to higher heads east of the Natomas Basin resulting from the planned transition from groundwater to surface water to meet M&I demands in northern Sacramento County.

Flow beneath the PGCC West Levee with and without slurry cutoff walls is estimated in **Table 6-6**. Groundwater flow to the east beneath the levee without cutoff walls was estimated to be 4,512 afy based on the 2004 IGSM simulation and 233 afy based on the 2030 simulation. It was assumed that almost all of this flow occurs in the upper 400 feet of the aquifer system, which corresponds to Layer 1 and the upper portion of Layer 2 of the IGSM models. The slurry cutoff walls along the PGCC West Levee were assumed to be about 14,000 feet long with an average depth of 38 feet. Groundwater flow through this cross section without the cutoff walls was estimated to be 341 afy and 19 afy, based on the 2004 and 2030 simulations, respectively. The estimated flow reduction due to the slurry cutoff walls is assumed to be 70 percent or 238 afy for the 2004 simulation and 13 afy for the 2030 simulation. These flow reductions will be at least partially offset by the estimated increase in groundwater outflow beneath the PGCC due to pumping reductions planned for the Brookfield borrow site.

6.4 Natomas East Main Drainage Canal West Levee

Proposed slurry cutoff walls along the NEMDC West Levee are summarized in **Table 6-2**, and the cutoff wall locations are shown on **Figure 6-1**. The impacts of proposed slurry cutoff walls along the NEMDC West Levee were estimated similarly to the PGCC West Levee in **Table 6-6**. Groundwater flow to the east beneath the northern and southern portions of the NEMDC West Levee was estimated separately. For the northern NEMDC West Levee, groundwater flow to the east beneath the levee without cutoff walls was estimated to be 9,132 afy based on the IGSM 2004 simulation and 504 afy based on the 2030 simulation. As for the PGCC, it was assumed that almost all of this flow occurs in the upper 400 feet of the aquifer system. The slurry cutoff walls along the northern NEMDC West Levee were assumed to be 22,800 feet long and an average of 37 feet deep. Groundwater flow through this cross-sectional area without the cutoff walls was estimated to be 541 afy and 30 afy, based on the 2004 and 2030 simulations, respectively. A 70 percent flow reduction due to the slurry cutoff walls was again assumed based on the Kleinfelder transient simulation for the Sacramento River East Levee. The estimated flow reduction is 378 afy for the 2004 simulation and 21 afy for the 2030 simulation.

For the southern NEMDC West Levee, groundwater flow to the east beneath the levee without cutoff walls was estimated to be 8,156 afy based on the IGSM 2004 simulation and 450 afy based on the 2030 simulation, as shown in **Table 6-6**. The slurry cutoff walls along the southern NEMDC West Levee were assumed to be 23,100 feet long and an average of 45 feet deep. Groundwater flow through this cross-sectional area without the cutoff walls was estimated to be 665 afy and 37 afy, respectively, based on the 2004 and 2030 simulations. The estimated flow reduction is 466 afy for the 2004 simulation and 26 afy for the 2030 simulation.

6.5 American River North Levee

Slurry cutoff walls are currently proposed for the entire length of the American River North Levee, as shown on **Table 6-2** and **Figure 6-1**. The impacts of these slurry cutoff walls were estimated similarly to the PGCC and NEMDC West Levees in **Table 6-6**. This was assumed to be a generally losing reach under current conditions, and recharge from the American River to the Natomas Basin was estimated to be 1,086 afy based on the IGSM 2004 simulation. For the 2030 simulation, the direction of groundwater flow is indicated to be toward the River (gaining conditions), and simulated groundwater flow to the River was 500 afy. For both simulations, it was assumed that almost all of the flow to and from the River occurs in the upper 200 feet of the aquifer system. Planning for slurry cutoff walls along the American River North Levee is in the early stages, but cutoff walls are currently proposed to extend the entire length of the levee (11,560 lf) and average 55 feet deep.

Groundwater flow through the cross-sectional area where cutoff walls are proposed was estimated to be 301 afy away from the River for the 2004 simulation and –139 afy toward the River for the 2030 simulation. A 70 percent flow reduction due to the slurry cutoff walls was again assumed based on the Kleinfelder transient simulation for the Sacramento River East Levee. The estimated reduction in flow from the River was 211 afy for the 2004 simulation as shown in **Table 6-6**. The estimated reduction in flow to the River was 97 afy for the 2030 simulation.

6.6 Summary

The proposed slurry cutoff walls are expected to reduce groundwater flow beneath the levees as intended. Cutoff wall impacts shown in **Table 6-6** were estimated separately based on simulations of existing (or 2004) and future (2030) conditions. Estimates were based on models by Kleinfelder (2009) and LSCE (2008a) and IGSM model results (WRIME, 2007 and LSCE, 2008b). The predicted impacts of cutoff walls beneath each of the five levees surrounding the Natomas Basin are based on both the existing/2004 and future/2030 results because the impact varies both by location and simulation period. The results show that the impact to groundwater supplies in the Natomas Basin is greatest due to proposed cutoff walls along the Sacramento River East Levee. For the entire Natomas Basin, reduced recharge from the Sacramento and American Rivers is largely offset by reduced groundwater outflow to the east for the 2004 simulation. The total predicted impact of all slurry cutoff walls is only 68 afy based on "existing" or 2004 conditions.

The impact of slurry cutoff walls is predicted to be greater based on future/2030 conditions due to several factors. Gradients are expected to be steeper in the northern portion of the Natomas Basin due to pumping to supply the proposed Sutter Pointe development. This will increase groundwater flow beneath the Sacramento River East Levee and the NCC South Levee, and there will be a corresponding increase in flow reductions caused by slurry cutoff walls. At the same time, the IGSM model predicts less groundwater outflow to the east beneath the PGCC and NEMDC West Levees due to reduced pumping east of the Natomas Basin. The total predicted impact of all slurry cutoff walls increases to 1,315 afy for the future/2030 scenario.

There are also potential groundwater impacts east of the Natomas Basin, primarily because the proposed slurry cutoff walls beneath the PGCC and NEMDC West Levees will reduce groundwater outflow to the east. These impacts are predicted to occur primarily under existing conditions (based on the 2004 simulation) because the gradient for groundwater flow to the east is estimated to be much steeper under existing/2004 conditions. As shown in **Table 6-6**, the reduction in groundwater outflow beneath the PGCC and NEMDC West Levees is estimated to be 1,082 afy based on the 2004 simulation. The predicted reduction in groundwater outflow to the east decreases to 60 afy for the 2030 simulation.

As discussed above, these estimates of slurry cutoff wall impacts are conservative in that they do not account for increased vertical flow beneath the cutoff walls or horizontal flow around the cutoff walls. A three-dimensional model would be expected to show somewhat smaller flow reductions due to the cutoff walls.

Table 6-1
Proposed Mitigation for Seepage Beneath Sacramento River East Levee

Reach	Stations	Proposed Mitigation[1]	Length of Reach (ft)	Length of Cutoff Wall[1] (ft)	Cutoff Wall Platform Elevation[2] (ft msl)	Cutoff Wall Bottom Elevation[2] (ft msl)	Depth of Cutoff Wall (ft)
1	0+00 to 2+00	None	200	-	-	-	-
	2+00 to 26+00	Cutoff Wall	2,400	2,400	34	7	27
	26+00 to 46+00	Cutoff Wall	2,000	2,000	34	12	22
	46+00 to 48+00	Cutoff Wall	200	200	34	-27	61
2	48+00 to 98+00	Cutoff Wall	5,000	5,000	34	-27	61
	98+00 to 100+00	Cutoff Wall	200	200	33	-15	48
3	100+00 to 105+00	Cutoff Wall	500	500	33	-15	48
	105+00 to 109+00	Cutoff Wall	400	400	33	10	23
	109+00 to 110+00	Cutoff Wall 100-foot Berm	100	100	33	10	23
4a	110+00 to 142+00	Cutoff Wall 100-foot Berm	3,200	3,200	33	10	23
	142+00 to 187+00	Cutoff Wall 100-foot Berm	4,500	4,500	32	-5	37
	187+00 to 190+00	Cutoff Wall 300-foot Berm	300	300	32	-5	37
4b	190+00 to 201+50	Cutoff Wall 300-foot Berm	1,150	1,150	32	-25	57
	201+50 to 214+00	Cutoff Wall 300-foot Berm	1,250	1,250	32	18	14
	214+00 to 224+00	Cutoff Wall 500-foot Berm	1,000	1,000	32	18	14
	224+00 to 228+00	Cutoff Wall 300-foot Berm	400	400	32	18	14
5a	228+00 to 231+00	Cutoff Wall 300-foot Berm	300	300	35	-40	75
	231+00 to 250+00	Cutoff Wall	1,900	1,900	35	-40	75
	250+00 to 263+00	Cutoff Wall	1,300	1,300	35	-30	65
5b	263+00 to 280+00	Cutoff Wall	1,700	1,700	35	-5	40
6a	280+00 to 303+00	Cutoff Wall	2,300	2,300	35	-80	115
6b	303+00 to 320+00	Cutoff Wall	1,700	1,700	35	-80	115
	320+00 to 330+00	Cutoff Wall	1,000	1,000	35	-85	120
7	330+00 to 345+00	Cutoff Wall	1,500	1,500	35	-85	120
	345+00 to 362+00	Cutoff Wall	1,700	1,700	35	-50	85
8	362+00 to 373+00	Cutoff Wall	1,100	1,100	35	-50	85
	373+00 to 402+00	Cutoff Wall	2,900	2,900	35	-60	95
9a	402+00 to 407+00	Cutoff Wall	500	500	35	-50	85
9b	407+00 to 425+00	Cutoff Wall	1,800	1,800	35	-60	95
	425+00 to 438+00	Cutoff Wall	1,300	1,300	35	-55	90
	438+00 to 456+00	Cutoff Wall	1,800	1,800	35	-50	85
	456+00 to 464+00	Cutoff Wall	800	800	35	-60	95
	464+00 to 468+00	Cutoff Wall 100-foot Berm w/ Relief Wells	400	400	35	-60	95

Table 6-1 (continued)
Proposed Mitigation for Seepage Beneath Sacramento River East Levee

Reach	Stations	Proposed Mitigation[1]	Length of Reach (ft)	Length of Cutoff Wall[1] (ft)	Cutoff Wall Platform Elevation[2] (ft msl)	Cutoff Wall Bottom Elevation[2] (ft msl)	Depth of Cutoff Wall (ft)
10	468+00 to 495+00	100-foot Berm w/ Relief Wells	2,700	-	-	-	-
11a	495+00 to 535+00	100-foot Berm w/ Relief Wells	4,000	-	-	-	-
11b	535+00 to 635+00	500-foot Berm	10,000	-	-	-	-
12a	635+00 to 650+00	500-foot Berm	1,500	-	-	-	-
	650+00 to 655+00	Cutoff Wall	500	500	35	-35	70
12b	655+00 to 667+00	Cutoff Wall	1,200	1,200	35	-35	70
13	667+00 to 671+00	Cutoff Wall	400	400	35	-35	70
	671+00 to 678+00	Cutoff Wall Relief Wells	700	700	35	-35	70
	678+00 to 681+50	Cutoff Wall 100-foot Berm w/ Relief Wells	350	350	35	-35	70
13	681+50 to 698+00	100-foot Berm w/ Relief Wells	1,650	-	-	-	-
	698+00 to 700+00	Cutoff Wall 100-foot Berm w/ Relief Wells	200	200	35	-40	75
14	700+00 to 701+00	Cutoff Wall 100-foot Berm w/ Relief Wells	100	100	35	-40	75
	701+00 to 732+00	Cutoff Wall	3,100	3,100	35	-40	75
15	732+00 to 735+00	Cutoff Wall 100-foot Berm w/ Relief Wells	300	300	35	-40	75
	735+00 to 769+50	100-foot Berm w/ Relief Wells	3,450	-	-	-	-
	769+50 to 780+00	100-foot Berm w/ Relief Wells	1,050	-	-	-	-
16	780+00 to 832+00	Relief Wells	5,200	-	-	-	-
17	832+00 to 842+00	100-foot Berm w/ Relief Wells	1,000	-	-	-	-
18a	842+00 to 848+00	100-foot Berm w/ Relief Wells	600	-	-	-	-
18b	848+00 to 857+00	100-foot Berm w/ Relief Wells	900	-	-	-	-
19a	857+00 to 875+00	100-foot Berm w/ Relief Wells	1,800	-	-	-	-
19b	875+00 to 925+00	Relief Wells	5,000	-	-	-	-
20a	925+00 to 925+50	Jet Grouting at Pump Plant	50	-	-	-	-
20b	925+50 to 960+00	None	3,450	-	-	-	-
			96,000	53,450			

1. Proposed mitigation and length of cutoff walls based on HDR Technical Memorandum (April 17, 2009).
2. Vertical datum = NAVD88.

Table 6-2
Proposed Slurry Cutoff Wall Locations Along Natomas Cross Canal, Pacific Grove Creek Canal, Natomas East Main Drainage Canal, and American River

Levee	Reach	Stations	Proposed Mitigation	Length of Reach (ft)	Length of Cutoff Wall (ft)	Cutoff Wall Bottom Elevation (ft msl)	Depth of Cutoff Wall (ft)
Natomas Cross Canal South Levee	1	00+00 to 5+70	Cutoff Wall	570	570	-28	70
	2	5+70 to 105+00	Cutoff Wall	9,930	9,930	-28	70
	3	105+00 to 123+00	Cutoff Wall	1,800	1,800	-28	70
	4	123+00 to 173+00	Cutoff Wall	5,000	5,000	-38	70
	5	173+00 to 195+00	Cutoff Wall	2,200	2,200	-38	70
	6	195+00 to 280+00	Cutoff Wall	8,500	8,500	-38	70
	7	280+00 to 287+00	Cutoff Wall	700	700	-38	70
		Subtotal		28,700	28,700		
Pacific Grove Creek Canal West Levee	1	287+37 to 356+20	Cutoff Wall	6,883	6,883	-10	45
	2	356+20 to 390+00	None	3,380	-	-	-
	3a	390+00 to 430+00	Cutoff Wall	4,000	4,000	15	20
	3b	430+00 to 461+31	Cutoff Wall	3,131	3,131	-15	50
		Subtotal		17,394	14,014		
Natomas East Main Drainage Canal (North)	8	645+00 to 675+65	None	3,065	-	-	-
	7	576+00 to 645+00	Cutoff Wall	6,900	6,900	10-15	35-40
	6	555+00 to 576+00	None	2,100	-	-	-
	5	505+00 to 555+00	Cutoff Wall	5,000	5,000	15	30
	4	467+00 to 505+00	None	3,800	-	-	-
	3	425+00 to 467+00	Cutoff Wall	4,200	4,200	0	45
	2	386+17 to 425+00	None	3,883	-	-	-
	1	318+75 to 386+17	Cutoff Wall	6,742	6,742	10	35
		Subtotal		35,690	22,842		
Natomas East Main Drainage Canal (South)	7c	305+65 to 318+75	Cutoff Wall	1,310	1,310	-10	53
	7b	265+50 to 305+65	None	4,015	-	-	-
	7a	235+00 to 265+50	None	3,050	-	-	-
	6	196+00 to 235+00	Cutoff Wall	3,900	3,900	-10	53
	5	154+00 to 196+00	Cutoff Wall	4,200	4,200	13	30
	4	114+00 to 154+00	Cutoff Wall	4,000	4,000	-10	53
	3	71+00 to 114+00	Cutoff Wall	4,300	4,300	13	30
	2	17+00 to 71+00	Cutoff Wall	5,400	5,400	-10	53
	1	00+00 to 17+00	None	1,700	-	-	-
		Subtotal		31,875	23,110		
American River North Levee	4	73+10 to 115+60	Cutoff Wall	4,250	4,250		80
	3	63+10 to 73+10	Cutoff Wall	1,000	1,000		80
	2	16+10 to 63+10	Cutoff Wall	4,700	4,700		35
	1	0+00 to 16+10	Cutoff Wall	1,610	1,610		35
		Subtotal		11,560	11,560		
		Total Length		125,219	100,226		

Table 6-3
Kleinfelder Model Results: Estimated Groundwater Flow Beneath Sacramento River East Levee in Natomas Basin With and Without Slurry Cutoff Walls[1]

Reach	Stations		Seepage Based on Simulated Station	Length of Reach (ft)	Seepage Without Cutoff Walls (afy)	Seepage With Cutoff Walls (afy)	Impact of Cutoff Walls	
	Start	End					(afy)	(%)
1	00+00	48+00	27+00	4,800	19	19	0	0
2	48+00	100+00	70+00	5,200	14	2	12	85
3	100+00	110+00	70+00	1,000	3	0.4	2.6	85
4a	110+00	120+00	70+00	1,000	3	3	0	0
4a	120+00	190+00	353+00	7,000	95	95	0	0
4b	190+00	228+00	217+00	3,800	490	490	0	0
5a	228+00	263+00	70+00	3,500	10	10	0	0
5b	263+00	280+00	27+00	1,700	6	6	0	0
6	280+00	330+00	217+00	5,000	650	100	550	85
7a	330+00	345+00	353+00	1,500	20	3	17	85
7b	345+00	362+00	353+00	1,700	23	3	20	85
8	362+00	402+00	353+00	4,000	55	8	47	85
9	402+00	430+00	353+00	2,800	38	38	0	0
9	430+00	468+10	353+00	3,800	50	8	42	85
10	468+10	495+00	217+00	2,690	350	210	140	40
11	495+00	635+00	217+00	14,000	1810	1810	0	0
12	635+00	640+00	217+00	500	65	65	0	0
12	640+00	667+00	70+00	2,700	7	7	0	0
13	667+00	700+00	353+00	3,300	45	30	15	40
14	700+00	732+00	70+00	3,200	8	8	0	0
15	732+00	780+00	217+00	4,800	620	375	245	40
16	780+00	832+00	217+00	5,200	675	675	0	0
17	832+00	842+00	217+00	1,000	130	80	50	40
18	842+00	857+00	217+00	1,500	195	120	75	40
19a	857+00	875+00	217+00	1,800	235	140	95	40
19b	875+00	925+00	70+00	5,000	15	8	7	40
20a	925+00	925+50	27+00	50	0.2	0.2	0	0
20b	925+50	960+00	27+00	3,550	13	13	0	0
Total				**96,090**	**5,650**	**4,330**	**1,320**	**23**

1. Based on Table 5 in Kleinfelder (2009). Shading indicates reaches with proposed cutoff walls.

Table 6-4
Darcy's Law Estimate of Groundwater Recharge from Sacramento River to Natomas Basin With and Without Slurry Cutoff Walls
(Based on Existing Conditions)

Reach	Stations	Proposed Mitigation Includes Cutoff Wall	Length of Reach (ft)	Length of Cutoff Wall (ft)	Cutoff Wall Depth (ft)	Cutoff Wall Bottom Elev. (ft msl)	Average Ground-Water Elev. (ft)	Saturated Fine/Medium Sand Thickness: Total (ft)	Saturated Fine/Medium Sand Thickness: To Base of Wall (ft)	Saturated Coarse Sand & Gravel Thickness: Total (ft)	Saturated Coarse Sand & Gravel Thickness: To Base of Wall (ft)	Permeable Area (length x thickness) Fine/Medium Sand Area: Total (sq. ft)	Permeable Area Fine/Medium Sand Area: To Base of Wall (sq. ft)	Permeable Area Coarse Sand & Gravel Area: Total (sq. ft)	Permeable Area Coarse Sand & Gravel Area: To Base of Wall (sq. ft)	Hydraulic Conductivity[2] Fine/ Medium Sand (ft/day)	Hydraulic Conductivity[2] Coarse Sand & Gravel (ft/day)	Hydraulic Gradient[3] (ft/ft)	Estimated Flow Without Cutoff Walls: Fine/ Medium Sand (afy)	Estimated Flow Without Cutoff Walls: Coarse Sand & Gravel (afy)	Estimated Flow Without Cutoff Walls: Total Flow (afy)	Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Estimated Flow With Cutoff Walls: Flow Through Cutoff Walls[4] (afy)	Estimated Flow With Cutoff Walls: Flow Beneath/ Around Cutoff Walls (afy)	Estimated Flow With Cutoff Walls: Total Flow (afy)	Impact of Cutoff Walls (afy)	Impact of Cutoff Walls (%)
1	0+00 to 2+00	No	200	-	-	-	19.8	35	-	0	-	7,000	N/A	0	N/A	28	140	0.0032	5	0	5	0	0	5	5	0	0
	2+00 to 26+00	Yes	2,400	2,400	27	7	19.8	35	0	0	0	84,000	0	0	0	28	140	0.0032	63	0	63	0	0	63	63	0	0
	26+00 to 46+00	Yes	2,000	2,000	22	12	19.8	26	0	0	0	52,000	0	0	0	28	140	0.0032	39	0	39	0	0	39	39	0	0
	46+00 to 48+00	Yes	200	200	61	-27	19.8	64	11	0	0	12,800	2200	0	0	28	140	0.0032	10	0	10	2	0	8	8	1	12
2	48+00 to 98+00	Yes	5,000	5,000	61	-27	19.8	67	22	0	0	335,000	110,000	0	0	28	140	0.0032	252	0	252	83	25	169	194	58	23
	98+00 to 100+00	Yes	200	200	48	-15	19.8	30	17	0	0	6,000	3,400	0	0	28	140	0.0032	5	0	5	3	1	2	3	2	40
3	100+00 to 105+00	Yes	500	500	48	-15	19.8	21	19	0	0	10,500	9,500	0	0	28	140	0.0032	8	0	8	7	2	1	3	5	63
	105+00 to 109+00	Yes	400	400	23	10	19.8	13	0	0	0	5,200	0	0	0	28	140	0.0032	4	0	4	0	0	4	4	0	0
	109+00 to 110+00	Yes	100	100	23	10	19.8	11	0	0	0	1,100	0	0	0	28	140	0.0032	1	0	1	0	0	1	1	0	0
4a	110+00 to 142+00	Yes	3,200	3,200	23	10	19.3	43	0	14	0	137,600	0	44,800	0	28	140	0.0032	103	168	271	0	0	271	271	0	0
	142+00 to 187+00	Yes	4,500	4,500	37	-5	19.3	60	5	30	0	270,000	22,500	135,000	0	28	140	0.0032	203	507	709	17	5	693	698	12	2
	187+00 to 190+00	Yes	300	300	37	-5	19.3	27	0	11	0	8,100	0	3,300	0	28	140	0.0032	6	12	18	0	0	18	18	0	0
4b	190+00 to 201+50	Yes	1,150	1,150	57	-25	18.8	50	25	5	2	57,500	28,750	5,750	2,300	28	140	0.0032	43	22	65	30	9	35	44	21	33
	201+50 to 214+00	Yes	1,250	1,250	14	18	18.8	55	25	15	0	68,750	31,250	18,750	0	28	140	0.0032	52	70	122	23	7	99	106	16	13
	214+00 to 224+00	Yes	1,000	1,000	14	18	18.8	65	0	25	0	65,000	0	25,000	0	28	140	0.0032	49	94	143	0	0	143	143	0	0
	224+00 to 228+00	Yes	400	400	14	18	18.8	40	0	0	0	16,000	0	0	0	28	140	0.0032	12	0	12	0	0	12	12	0	0
5a	228+00 to 231+00	Yes	300	300	75	-40	17.3	34	8	0	0	10,200	2,400	0	0	28	140	0.0032	8	0	8	2	1	6	6	1	16
	231+00 to 250+00	Yes	1,900	1,900	75	-40	17.3	22	22	0	0	41,800	41,800	0	0	28	140	0.0032	31	0	31	31	9	0	9	22	70
	250+00 to 263+00	Yes	1,300	1,300	65	-30	17.3	27	10	0	0	35,100	13,000	0	0	28	140	0.0032	26	0	26	10	3	17	20	7	26
5b	263+00 to 280+00	Yes	1,700	1,700	40	-5	17.3	27	0	0	0	45,900	0	0	0	28	140	0.0032	34	0	34	0	0	34	34	0	0
6a	280+00 to 303+00	Yes	2,300	2,300	115	-80	17.3	65	65	35	15	149,500	149,500	80,500	34,500	28	140	0.0032	112	302	414	242	73	173	245	169	41
6b	303+00 to 320+00	Yes	1,700	1,700	115	-80	17.8	55	55	20	20	93,500	93,500	34,000	34,000	28	140	0.0032	70	128	198	198	59	0	59	138	70
	320+00 to 330+00	Yes	1,000	1,000	120	-85	17.8	55	55	20	20	55,000	55,000	20,000	20,000	28	140	0.0032	41	75	116	116	35	0	35	81	70
7	330+00 to 345+00	Yes	1,500	1,500	120	-85	17.8	70	70	19	19	105,000	105,000	28,500	28,500	28	140	0.0032	79	107	186	186	56	0	56	130	70
	345+00 to 362+00	Yes	1,700	1,700	85	-50	17.8	46	0	0	0	78,200	0	0	0	28	140	0.0032	59	0	59	0	0	59	59	0	0
8	362+00 to 373+00	Yes	1,100	1,100	85	-50	17.8	32	32	0	0	35,200	35,200	0	0	28	140	0.0032	26	0	26	26	8	0	8	18	70
	373+00 to 402+00	Yes	2,900	2,900	95	-60	17.8	33	33	0	0	95,700	95,700	0	0	28	140	0.0032	72	0	72	72	22	0	22	50	70
9a	402+00 to 407+00	Yes	500	500	85	-50	17.8	40	40	0	0	20,000	20,000	0	0	28	140	0.0032	15	0	15	15	5	0	5	11	70
9b	407+00 to 425+00	Yes	1,800	1,800	95	-60	17.3	30	30	0	0	54,000	54,000	0	0	28	140	0.0032	41	0	41	41	12	0	12	28	70
	425+00 to 438+00	Yes	1,300	1,300	90	-55	17.3	38	38	0	0	49,400	49,400	0	0	28	140	0.0032	37	0	37	37	11	0	11	26	70
	438+00 to 456+00	Yes	1,800	1,800	85	-50	17.3	25	25	0	0	45,000	45,000	0	0	28	140	0.0032	34	0	34	34	10	0	10	24	70

Table 6-4 (continued)
Darcy's Law Estimate of Groundwater Recharge from Sacramento River to Natomas Basin With and Without Slurry Cutoff Walls
(Based on Existing Conditions)

Reach	Stations	Proposed Mitigation Includes Cutoff Wall	Length of Reach (ft)	Length of Cutoff Wall (ft)	Cutoff Wall Depth (ft)	Cutoff Wall Bottom Elev. (ft msl)	Average Ground-Water Elev. (ft)	Saturated Fine/Medium Sand Thickness		Saturated Coarse Sand & Gravel Thickness		Permeable Area (length x thickness): Fine/Medium Sand Area		Permeable Area (length x thickness): Coarse Sand & Gravel Area		Hydraulic Conductivity[2]		Hydraulic Gradient[3] (ft/ft)	Estimated Flow Without Cutoff Walls			Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Estimated Flow With Cutoff Walls			Impact of Cutoff Walls	
								Total (ft)	To Base of Wall (ft)	Total (ft)	To Base of Wall (ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Fine/ Medium Sand (ft/day)	Coarse Sand & Gravel (ft/day)		Fine/ Medium Sand (afy)	Coarse Sand & Gravel (afy)	Total Flow (afy)		Flow Through Cutoff Walls[4] (afy)	Flow Beneath/ Around Cutoff Walls (afy)	Total Flow (afy)	(afy)	(%)
9b	456+00 to 464+00	Yes	800	800	95	-60	17.3	34	34	0	0	27,200	27,200	0	0	28	140	0.0032	20	0	20	20	6	0	6	14	70
	464+00 to 468+00	Yes	400	400	95	-60	17.3	43	43	0	0	17,200	17,200	0	0	28	140	0.0032	13	0	13	13	4	0	4	9	70
10	468+00 to 495+00	No	2,700	-	-	-	17.3	28	-	22	-	75,600	N/A	59,400	N/A	28	140	0.0032	57	223	280	0	0	280	280	0	0
11a	495+00 to 535+00	No	4,000	-	-	-	17.3	32	-	53	-	128,000	N/A	212,000	N/A	28	140	0.0032	96	796	892	0	0	892	892	0	0
11b	535+00 to 635+00	No	10,000	-	-	-	17.3	32	-	53	-	320,000	N/A	530,000	N/A	28	140	0.0032	240	1,990	2,230	0	0	2,230	2,230	0	0
12a	635+00 to 650+00	No	1,500	-	-	-	12.8	65	-	0	-	97,500	N/A	0	N/A	28	140	0.0032	73	0	73	0	0	73	73	0	0
	650+00 to 655+00	Yes	500	500	70	-35	12.8	58	19	0	0	29,000	9,500	0	0	28	140	0.0032	22	0	22	7	2	15	17	5	23
12b	655+00 to 667+00	Yes	1,200	1,200	70	-35	12.8	58	19	0	0	69,600	22,800	0	0	28	140	0.0032	52	0	52	17	5	35	40	12	23
13	667+00 to 671+00	Yes	400	400	70	-35	13.3	58	19	0	0	23,200	7,600	0	0	28	140	0.0032	17	0	17	6	2	12	13	4	23
	671+00 to 678+00	Yes	700	700	70	-35	13.3	58	19	0	0	40,600	13,300	0	0	28	140	0.0032	30	0	30	10	3	20	23	7	23
	678+00 to 681+50	Yes	350	350	70	-35	13.3	58	19	0	0	20,300	6,650	0	0	28	140	0.0032	15	0	15	5	1	10	12	3	23
	681+50 to 698+00	No	1,650	-	-	-	13.3	57	-	0	-	94,050	N/A	0	N/A	28	140	0.0032	71	0	71	0	0	71	71	0	0
	698+00 to 700+00	Yes	200	200	75	-40	13.3	57	27	0	0	11,400	5,400	0	0	28	140	0.0032	9	0	9	4	1	5	6	3	33
14	700+00 to 701+00	Yes	100	100	75	-40	14.8	57	0	0	0	5,700	0	0	0	28	140	0.0032	4	0	4	0	0	4	4	0	0
	701+00 to 732+00	Yes	3,100	3,100	75	-40	14.8	50	0	7	0	155,000	0	21,700	0	28	140	0.0032	116	81	198	0	0	198	198	0	0
15	732+00 to 735+00	Yes	300	300	75	-40	15.8	57	27	0	0	17,100	8,100	0	0	28	140	0.0032	13	0	13	6	2	7	9	4	33
	735+00 to 769+50	No	3,450	-	-	-	15.8	60	-	15	-	207,000	N/A	51,750	N/A	28	140	0.0032	155	194	350	0	0	350	350	0	0
	769+50 to 780+00	No	1,050	-	-	-	15.8	60	-	15	-	63,000	N/A	15,750	N/A	28	140	0.0032	47	59	106	0	0	106	106	0	0
16	780+00 to 832+00	No	5,200	-	-	-	14.8	58	-	12	-	301,600	N/A	62,400	N/A	28	140	0.0032	226	234	461	0	0	461	461	0	0
17	832+00 to 842+00	No	1,000	-	-	-	13.8	73	-	2	-	73,000	N/A	2,000	N/A	28	140	0.0032	55	8	62	0	0	62	62	0	0
18a	842+00 to 848+00	No	600	-	-	-	12.8	75	-	0	-	45,000	N/A	0	N/A	28	140	0.0032	34	0	34	0	0	34	34	0	0
18b	848+00 to 857+00	No	900	-	-	-	12.3	75	-	0	-	67,500	N/A	0	N/A	28	140	0.0032	51	0	51	0	0	51	51	0	0
19a	857+00 to 875+00	No	1,800	-	-	-	10.3	80	-	0	-	144,000	N/A	0	N/A	28	140	0.0032	108	0	108	0	0	108	108	0	0
19b	875+00 to 925+00	No	5,000	-	-	-	8.3	60	-	0	-	300,000	N/A	0	N/A	28	140	0.0032	225	0	225	0	0	225	225	0	0
20a	925+00 to 925+50	No	50	-	-	-	6.3	20	-	2	-	1,000	N/A	100	N/A	28	140	0.0032	1	0	1	0	0	1	1	0	0
20b	925+50 to 960+00	No	3,450	-	-	-	4.3	24	-	2	-	82,800	N/A	6,900	N/A	28	140	0.0032	62	26	88	0	0	88	88	0	0
Average							**16**	**46**	**20**	**7**	**2**																
Total			**96,000**	**53,450**								**4,466,400**	**1,084,850**	**1,357,600**	**119,300**				**3,353**	**5,096**	**8,450**	**1,262**	**379**	**7,187**	**7,566**	**884**	**10**

1. Hydraulic conductivity based on estimates in Table 2-1.
2. Hydraulic gradient based on annual average value in Table 3-2.
3. Assumes a 70% reduction in flow through the cutoff wall based on the Kleinfelder transient model results (Kleinfelder, 2009).

Table 6-5
Darcy's Law Estimate of Groundwater Recharge from Sacramento River to Natomas Basin With and Without Slurry Cutoff Walls
(Including Increase in Hydraulic Gradient Due to Additional Pumping in 2030)

Reach	Stations	Proposed Mitigation Includes Cutoff Wall	Length of Reach (ft)	Length of Cutoff Wall (ft)	Cutoff Wall Depth (ft)	Cutoff Wall Bottom Elev. (ft msl)	Average Ground-Water Elev. (ft)	Saturated Fine/Medium Sand Thickness		Saturated Coarse Sand & Gravel Thickness		Permeable Area (length x thickness): Fine/Medium Sand Area		Permeable Area (length x thickness): Coarse Sand & Gravel Area		Hydraulic Conductivity[2]		Increase in Hydraulic Gradient[3] (ft/ft)	Hydraulic Gradient Including Sutter Pointe Pumping (ft/ft)	Estimated Flow Without Cutoff Walls			Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Estimated Flow With Cutoff Walls			Impact of Cutoff Walls	
								Total (ft)	To Base of Wall (ft)	Total (ft)	To Base of Wall (ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Fine/ Medium Sand (ft/day)	Coarse Sand & Gravel (ft/day)			Fine/ Medium Sand (afy)	Coarse Sand & Gravel (afy)	Total Flow (afy)		Flow Through Cutoff Walls[4] (afy)	Flow Beneath/ Around Cutoff Walls (afy)	Total Flow (afy)	(afy)	(%)
1	0+00 to 2+00	No	200	-	-	-	19.8	35	-	0	-	7,000	N/A	0	N/A	28	140	0.0010	0.0042	7	0	7	0	0	7	7	0	0
1	2+00 to 26+00	Yes	2,400	2,400	27	7	19.8	35	0	0	0	84,000	0	0	0	28	140	0.0010	0.0042	82	0	82	0	0	82	82	0	0
1	26+00 to 46+00	Yes	2,000	2,000	22	12	19.8	26	0	0	0	52,000	0	0	0	28	140	0.0010	0.0042	51	0	51	0	0	51	51	0	0
1	46+00 to 48+00	Yes	200	200	61	-27	19.8	64	11	0	0	12,800	2200	0	0	28	140	0.0010	0.0042	13	0	13	2	1	10	11	2	12
2	48+00 to 98+00	Yes	5,000	5,000	61	-27	19.8	67	22	0	0	335,000	110,000	0	0	28	140	0.0018	0.0050	391	0	391	128	39	263	301	90	23
2	98+00 to 100+00	Yes	200	200	48	-15	19.8	30	17	0	0	6,000	3,400	0	0	28	140	0.0018	0.0050	7	0	7	4	1	3	4	3	40
3	100+00 to 105+00	Yes	500	500	48	-15	19.8	21	19	0	0	10,500	9,500	0	0	28	140	0.0018	0.0050	12	0	12	11	3	1	4	8	63
3	105+00 to 109+00	Yes	400	400	23	10	19.8	13	0	0	0	5,200	0	0	0	28	140	0.0018	0.0050	6	0	6	0	0	6	6	0	0
3	109+00 to 110+00	Yes	100	100	23	10	19.8	11	0	0	0	1,100	0	0	0	28	140	0.0018	0.0050	1	0	1	0	0	1	1	0	0
4a	110+00 to 142+00	Yes	3,200	3,200	23	10	19.3	43	0	14	0	137,600	0	44,800	0	28	140	0.0011	0.0043	140	228	367	0	0	367	367	0	0
4a	142+00 to 187+00	Yes	4,500	4,500	37	-5	19.3	60	5	30	0	270,000	22,500	135,000	0	28	140	0.0011	0.0043	274	686	960	23	7	937	944	16	2
4a	187+00 to 190+00	Yes	300	300	37	-5	19.3	27	0	11	0	8,100	0	3,300	0	28	140	0.0011	0.0043	8	17	25	0	0	25	25	0	0
4b	190+00 to 201+50	Yes	1,150	1,150	57	-25	18.8	50	25	5	2	57,500	28,750	5,750	2,300	28	140	0.0011	0.0043	58	29	88	41	12	47	59	29	33
4b	201+50 to 214+00	Yes	1,250	1,250	14	18	18.8	55	25	15	0	68,750	31,250	18,750	0	28	140	0.0011	0.0043	70	95	165	32	10	133	143	22	13
4b	214+00 to 224+00	Yes	1,000	1,000	14	18	18.8	65	0	25	0	65,000	0	25,000	0	28	140	0.0011	0.0043	66	127	193	0	0	193	193	0	0
4b	224+00 to 228+00	Yes	400	400	14	18	18.8	40	0	0	0	16,000	0	0	0	28	140	0.0011	0.0043	16	0	16	0	0	16	16	0	0
5a	228+00 to 231+00	Yes	300	300	75	-40	17.3	34	8	0	0	10,200	2,400	0	0	28	140	0.0005	0.0037	9	0	9	2	1	7	7	1	16
5a	231+00 to 250+00	Yes	1,900	1,900	75	-40	17.3	22	22	0	0	41,800	41,800	0	0	28	140	0.0005	0.0037	36	0	36	36	11	0	11	25	70
5a	250+00 to 263+00	Yes	1,300	1,300	65	-30	17.3	27	10	0	0	35,100	13,000	0	0	28	140	0.0005	0.0037	30	0	30	11	3	19	22	8	26
5b	263+00 to 280+00	Yes	1,700	1,700	40	-5	17.3	27	0	0	0	45,900	0	0	0	28	140	0.0005	0.0037	40	0	40	0	0	40	40	0	0
6a	280+00 to 303+00	Yes	2,300	2,300	115	-80	17.3	65	65	35	15	149,500	149,500	80,500	34,500	28	140	0.0003	0.0035	121	327	448	261	78	187	265	183	41
6b	303+00 to 320+00	Yes	1,700	1,700	115	-80	17.8	55	55	20	20	93,500	93,500	34,000	34,000	28	140	0.0003	0.0035	76	138	214	214	64	0	64	150	70
6b	320+00 to 330+00	Yes	1,000	1,000	120	-85	17.8	55	55	20	20	55,000	55,000	20,000	20,000	28	140	0.0003	0.0035	45	81	126	126	38	0	38	88	70
7	330+00 to 345+00	Yes	1,500	1,500	120	-85	17.8	70	70	19	19	105,000	105,000	28,500	28,500	28	140	0.0002	0.0034	84	115	199	199	60	0	60	139	70
7	345+00 to 362+00	Yes	1,700	1,700	85	-50	17.8	46	0	0	0	78,200	0	0	0	28	140	0.0002	0.0034	63	0	63	0	0	63	63	0	0
8	362+00 to 373+00	Yes	1,100	1,100	85	-50	17.8	32	32	0	0	35,200	35,200	0	0	28	140	0.0002	0.0034	28	0	28	28	8	0	8	20	70
8	373+00 to 402+00	Yes	2,900	2,900	95	-60	17.8	33	33	0	0	95,700	95,700	0	0	28	140	0.0002	0.0034	75	0	75	75	23	0	23	53	70
9a	402+00 to 407+00	Yes	500	500	85	-50	17.8	40	40	0	0	20,000	20,000	0	0	28	140	0.0001	0.0033	16	0	16	16	5	0	5	11	70
9b	407+00 to 425+00	Yes	1,800	1,800	95	-60	17.3	30	30	0	0	54,000	54,000	0	0	28	140	0.0001	0.0033	42	0	42	42	13	0	13	30	70
9b	425+00 to 438+00	Yes	1,300	1,300	90	-55	17.3	38	38	0	0	49,400	49,400	0	0	28	140	0.0001	0.0033	39	0	39	39	12	0	12	27	70
9b	438+00 to 456+00	Yes	1,800	1,800	85	-50	17.3	25	25	0	0	45,000	45,000	0	0	28	140	0.0001	0.0033	35	0	35	35	11	0	11	25	70

Table 6-5 (continued)
Darcy's Law Estimate of Groundwater Recharge from Sacramento River to Natomas Basin With and Without Slurry Cutoff Walls
(Including Increase in Hydraulic Gradient Due to Additional Pumping in 2030)

Reach	Stations	Proposed Mitigation Includes Cutoff Wall	Length of Reach (ft)	Length of Cutoff Wall (ft)	Cutoff Wall Depth (ft)	Cutoff Wall Bottom Elev. (ft msl)	Average Ground-Water Elev. (ft)	Saturated Fine/Medium Sand Thickness		Saturated Coarse Sand & Gravel Thickness		Permeable Area (length x thickness)				Hydraulic Conductivity[2]		Increase in Hydraulic Gradient[3] (ft/ft)	Hydraulic Gradient Including Sutter Pointe Pumping (ft/ft)	Estimated Flow Without Cutoff Walls			Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Estimated Flow With Cutoff Walls			Impact of Cutoff Walls	
												Fine/Medium Sand Area		Coarse Sand & Gravel Area														
								Total (ft)	To Base of Wall (ft)	Total (ft)	To Base of Wall (ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Total (sq. ft)	To Base of Wall (sq. ft)	Fine/ Medium Sand (ft/day)	Coarse Sand & Gravel (ft/day)			Fine/ Medium Sand (afy)	Coarse Sand & Gravel (afy)	Total Flow (afy)		Flow Through Cutoff Walls[4] (afy)	Flow Beneath/ Around Cutoff Walls (afy)	Total Flow (afy)	(afy)	(%)
9b	456+00 to 464+00	Yes	800	800	95	-60	17.3	34	34	0	0	27,200	27,200	0	0	28	140	0.0001	0.0033	21	0	21	21	6	0	6	15	70
	464+00 to 468+00	Yes	400	400	95	-60	17.3	43	43	0	0	17,200	17,200	0	0	28	140	0.0001	0.0033	13	0	13	13	4	0	4	9	70
10	468+00 to 495+00	No	2,700	-	-	-	17.3	28	-	22	-	75,600	N/A	59,400	N/A	28	140	0.0001	0.0033	59	232	291	0	0	291	291	0	0
11a	495+00 to 535+00	No	4,000	-	-	-	17.3	32	-	53	-	128,000	N/A	212,000	N/A	28	140	0.0001	0.0033	99	824	923	0	0	923	923	0	0
11b	535+00 to 635+00	No	10,000	-	-	-	17.3	32	-	53	-	320,000	N/A	530,000	N/A	28	140	0.0001	0.0033	249	2,060	2,308	0	0	2,308	2,308	0	0
12a	635+00 to 650+00	No	1,500	-	-	-	12.8	65	-	0	-	97,500	N/A	0	N/A	28	140	0.0001	0.0033	76	0	76	0	0	76	76	0	0
	650+00 to 655+00	Yes	500	500	70	-35	12.8	58	19	0	0	29,000	9,500	0	0	28	140	0.0001	0.0033	23	0	23	7	2	15	17	5	23
12b	655+00 to 667+00	Yes	1,200	1,200	70	-35	12.8	58	19	0	0	69,600	22,800	0	0	28	140	0.0001	0.0033	54	0	54	18	5	36	42	12	23
13	667+00 to 671+00	Yes	400	400	70	-35	13.3	58	19	0	0	23,200	7,600	0	0	28	140	0.0001	0.0033	18	0	18	6	2	12	14	4	23
	671+00 to 678+00	Yes	700	700	70	-35	13.3	58	19	0	0	40,600	13,300	0	0	28	140	0.0001	0.0033	31	0	31	10	3	21	24	7	23
	678+00 to 681+50	Yes	350	350	70	-35	13.3	58	19	0	0	20,300	6,650	0	0	28	140	0.0001	0.0033	16	0	16	5	2	11	12	4	23
	681+50 to 698+00	No	1,650	-	-	-	13.3	57	-	0	-	94,050	N/A	0	N/A	28	140	0.0001	0.0033	73	0	73	0	0	73	73	0	0
	698+00 to 700+00	Yes	200	200	75	-40	13.3	57	27	0	0	11,400	5,400	0	0	28	140	0.0001	0.0033	9	0	9	4	1	5	6	3	33
14	700+00 to 701+00	Yes	100	100	75	-40	14.8	57	0	0	0	5,700	0	0	0	28	140	0.0000	0.0032	4	0	4	0	0	4	4	0	0
	701+00 to 732+00	Yes	3,100	3,100	75	-40	14.8	50	0	7	0	155,000	0	21,700	0	28	140	0.0000	0.0032	116	81	198	0	0	198	198	0	0
15	732+00 to 735+00	Yes	300	300	75	-40	15.8	57	27	0	0	17,100	8,100	0	0	28	140	0.0000	0.0032	13	0	13	6	2	7	9	4	33
	735+00 to 769+50	No	3,450	-	-	-	15.8	60	-	15	-	207,000	N/A	51,750	N/A	28	140	0.0000	0.0032	155	194	350	0	0	350	350	0	0
	769+50 to 780+00	No	1,050	-	-	-	15.8	60	-	15	-	63,000	N/A	15,750	N/A	28	140	0.0000	0.0032	47	59	106	0	0	106	106	0	0
16	780+00 to 832+00	No	5,200	-	-	-	14.8	58	-	12	-	301,600	N/A	62,400	N/A	28	140	0.0000	0.0032	226	234	461	0	0	461	461	0	0
17	832+00 to 842+00	No	1,000	-	-	-	13.8	73	-	2	-	73,000	N/A	2,000	N/A	28	140	0.0000	0.0032	55	8	62	0	0	62	62	0	0
18a	842+00 to 848+00	No	600	-	-	-	12.8	75	-	0	-	45,000	N/A	0	N/A	28	140	0.0000	0.0032	34	0	34	0	0	34	34	0	0
18b	848+00 to 857+00	No	900	-	-	-	12.3	75	-	0	-	67,500	N/A	0	N/A	28	140	0.0000	0.0032	51	0	51	0	0	51	51	0	0
19a	857+00 to 875+00	No	1,800	-	-	-	10.3	80	-	0	-	144,000	N/A	0	N/A	28	140	0.0000	0.0032	108	0	108	0	0	108	108	0	0
19b	875+00 to 925+00	No	5,000	-	-	-	8.3	60	-	0	-	300,000	N/A	0	N/A	28	140	0.0000	0.0032	225	0	225	0	0	225	225	0	0
20a	925+00 to 925+50	No	50	-	-	-	6.3	20	-	2	-	1,000	N/A	100	N/A	28	140	0.0000	0.0032	1	0	1	0	0	1	1	0	0
20b	925+50 to 960+00	No	3,450	-	-	-	4.3	24	-	2	-	82,800	N/A	6,900	N/A	28	140	0.0000	0.0032	62	26	88	0	0	88	88	0	0
Average							**16**	**46**	**20**	**7**	**2**																	
Total			**96,000**	**53,450**								**4,466,400**	**1,084,850**	**1,357,600**	**119,300**					**3,781**	**5,560**	**9,341**	**1,417**	**425**	**7,924**	**8,349**	**992**	**11**

1. Hydraulic conductivity based on estimates in Table 2-1.
2. Hydraulic gradient based on annual average value in Table 3-2.
3. Assumes a 70% reduction in flow through the cutoff wall based on the Kleinfelder transient model results (Kleinfelder, 2009).

Table 6-6
Effects of Proposed Slurry Cutoff Walls on Groundwater Flow

Levee	Time Period	Total Length of Levee (ft)	Saturated Thickness for Ground-Water Flow (ft)	Cross-Sectional Area for Flow (ft^2)	Total Flow Without Cutoff Walls[1] (afy)	Flow per Cross-Sectional Area (afy/ft^2)	Length of Proposed Cutoff Walls (ft)	Average Depth of Cutoff Walls (ft)	Cross-Sectional Area of Cutoff Walls (ft^2)	Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Flow Through, Beneath, or Around Cutoff Walls (afy)	Flow Reduction Due to Cutoff Walls[8] (afy)	Flow Reduction Due to Cutoff Walls[8] (%)
Sacramento River East Levee	Existing	96,000	200	19,200,000	8,450 [2]	4.40E-04	53,500	65	3,474,300	1,262	7,566	884	10
	2030				9,341 [3]	4.40E-04				1,417	8,349	992	11
NCC South Levee	2004	28,700	400	11,480,000	459 [4]	4.00E-05	28,700	70	2,009,000	80	403	56	12
	2030				3,918 [5]	3.41E-04				686	3,438	480	12
PGCC West Levee	2004	17,400	400	6,957,600	-4,451 [6]	-6.40E-04	14,000	38	532,500	-341	-4,212	-238	5
	2030				-246 [7]	-3.53E-05				-19	-233	-13	5
NEMDC West Levee (North)	2004	35,700	400	14,276,000	-9,132 [6]	-6.40E-04	22,800	37	845,200	-541	-8,753	-378	4
	2030				-504 [7]	-3.53E-05				-30	-483	-21	4
NEMDC West Levee (South)	2004	31,900	400	12,750,000	-8,156 [6]	-6.40E-04	23,100	45	1,040,000	-665	-7,690	-466	6
	2030				-450 [7]	-3.53E-05				-37	-425	-26	6
American River North Levee	2004	11,600	200	2,312,000	1,086 [6]	4.70E-04	11,600	55	640,400	301	875	211	19
	2030				-500 [7]	-2.16E-04				-139	-403	-97	19
Total (Existing or 2004)					**-11,743**					**97**	**-4,106**	**68**	
Total (2030)					**11,559**					**1,879**	**10,244**	**1,315**	
Total (All)		**221,300**					**153,700**		**8,541,400**				

1. Positive values indicate groundwater inflow; negative values indicate goundwater outflow.
2. Source of total flow estimate = Table 6-4.
3. Source of total flow estimate = Table 6-5.
4. Source of total flow estimate = groundwater inflow from 2004 IGSM simulation (241 afy) plus canal seepage estimated by Kleinferlder (218 afy).
5. Source of total flow estimate = groundwater inflow from 2030 IGSM simulation (3,700 afy) plus canal seepage estimated by Kleinferlder (218 afy).
6. Source of total flow estimate = IGSM 2004 simulation.
7. Source of total flow estimate = IGSM 2030 simulation.
8. Increased groundwater inflow (or decreased outflow) shown as positive value; increased outflow (or decreased inflow) is shown as negative. 70% flow reduction assumed for slurry cutoff walls based on Kleinfelder (2009).

FILE: \\server_pe2900\Public\SAFCA\GIS\Fig 6-1 SlurryCutoffLocation map.mxd Date: 5/4/2009

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Figure 6-1
Proposed Slurry Cutoff Walls
Surrounding Natomas Basin

7.0 Groundwater Impacts of SAFCA Construction Activities

The effects of SAFCA's proposed construction activities on groundwater conditions in the Natomas Basin were evaluated using the water budget approach discussed above. Water budget impacts resulting from land use changes and canal construction were addressed in Chapter 5, and water budget impacts due to proposed slurry cutoff walls were addressed in Chapter 6. All of the predicted impacts of SAFCA's activities are summarized in **Table 7-1** for existing/2004 conditions and in **Table 7-2** for future/2030 conditions. This chapter also addresses cumulative impacts for 2004 and 2030 conditions based on the groundwater budgets calculated by the IGSM models.

7.1 Levee Improvements

Groundwater impacts from proposed levee improvements are primarily limited to the effects of land use changes and slurry cutoff walls. No direct groundwater impacts are expected from increasing the height or width of levees, modifying levee slopes, or building seepage berms because all of this construction would be above the water table.

Proposed land use changes will result in the loss of about 20 acres of rice, 175 acres of field crops, and five acres of orchard along the Sacramento River East Levee. Other land use changes include the loss of five acres of rice along the NCC South Levee and 50 acres of rice along the PGCC West Levee. As shown in **Tables 7-1** and **7-2**, these changes are estimated to reduce deep percolation from applied water by a total of 105 afy.

Estimated reductions in groundwater flow beneath the levees due to the proposed slurry cutoff walls are shown in **Table 6-6** based both on simulations of "existing" (or 2004) and future (2030) conditions. Estimated inflow reductions for existing conditions shown in **Table 7-1** include 105 afy of deep percolation, 1,095 afy of recharge from the Sacramento and American Rivers, and 56 afy of inflow to the Natomas Basin beneath the NCC. The total estimated inflow reduction is 1,256 afy. The reduction in subsurface outflow from the Natomas Basin beneath the PGCC and NEMDC is estimated to be 1,083 afy. The estimated effect of all proposed slurry cutoff walls based on the simulation of existing conditions will be to reduce groundwater storage in the Natomas Basin by about 173 afy.

Estimated inflow reductions for 2030 conditions shown in **Table 7-2** include 105 afy of deep percolation, 895 afy of recharge from the Sacramento and American Rivers, and 480 afy of inflow to the Natomas Basin beneath the NCC. The total estimated inflow reduction is 1,480 afy. The reduction in subsurface outflow from the Natomas Basin beneath the PGCC and NEMDC is estimated to be 60 afy. The estimated effect of all proposed slurry cutoff walls based on the simulation of existing conditions would be to reduce groundwater storage in the Natomas Basin by about 1,420 afy.

7.2 Canal Improvements

The construction of the new GSS/Drainage Canal and relocation and improvements to the West Drainage Canal, the Elkhorn Canal, and the Riverside Canal will affect deep percolation from applied water (due to land use changes) and seepage from the canals. For all four canals, deep percolation is estimated to decrease by 41 afy and canal seepage is estimated to increase by 327 afy (**Tables 7-1** and **7-2**). The net effect of proposed canal construction would be to increase groundwater storage in the Natomas Basin by about 285 afy.

7.3 Borrow Sites

Excavation and reclamation of the Brookfield and Fisherman's Lake borrow sites is expected to have an indirect effect on groundwater conditions due to proposed land use and water supply changes. No such changes are planned for the Airport North Bufferlands borrow site.

At the Brookfield borrow site, approximately 325 acres are currently planted to rice, and SAFCA plans to restore about 286 acres to rice cultivation after construction activities are complete. As shown in **Tables 7-1** and **7-2**, an estimated 30 afy of deep percolation will be lost at this site due to the reduction in irrigated acreage. The Brookfield site is currently irrigated entirely with groundwater, but SAFCA plans to provide the infrastructure so that about 80 percent of the borrow site can be irrigated with surface water after reclamation. This transition would reduce groundwater pumping by about 1,625 afy. Groundwater levels will increase due to the reduced pumping, resulting in an increase in subsurface outflow beneath the PGCC of about 76 afy.

At the Fisherman's Lake borrow site, about 400 acres of land would be used for borrow material, including 49 acres currently planted to rice, 266 acres of field crops, and 85 acres of managed marsh. After reclamation, there would be about 175 acres of managed marsh and 225 acres of non-irrigated grassland or woodland. The predicted net loss in deep percolation is 36 afy at this site, as shown in **Tables 7-1** and **7-2**.

The reduction in groundwater pumping at the Brookfield site more than offsets the loss of deep percolation at all borrow sites. The net effect of excavation and reclamation of all borrow sites would be to increase groundwater storage by about 1,483 afy.

7.4 Summary of SAFCA Groundwater Impacts

The totals at the bottom of **Tables 7-1** and **7-2** show the combined effect of SAFCA's proposed construction activities based on exising/2004 and future/2030 conditions, respectively. For both simulations, deep percolation is estimated to decrease by 213 afy, seepage from canals is estimated to increase by 327 afy, and groundwater pumping is estimated to decrease by 1,625 afy. Other changes for existing/2004 conditions include decreases in net recharge from streams (1,095 afy), subsurface inflow (56 afy), and subsurface outflow (1,007 afy). Summing these terms results in an increase in groundwater storage in the Natomas Basin of 1,595 afy for existing/2004 conditions, which means that groundwater levels would be expected to increase slightly due to all construction activities. The reduction in subsurface outflow would have a slightly negative effect on groundwater levels and storage east of the Natomas Basin.

The totals at the bottom of **Table 7-2** show the combined effect of SAFCA's proposed construction activities based on future conditions in 2030. Estimated changes in deep percolation, seepage from canals, and groundwater pumping are the same as for existing/2004 conditions. The estimated reduction in net recharge from streams (895 afy) is smaller than for the 2004 simulation, and the reduction in subsurface inflow (480 afy) is larger. Groundwater storage in the Natomas Basin is predict to increase due to the proposed construction, but by a smaller amount (348 afy). Subsurface outflow to the east is predicted to increase slightly in 2030 (by 16 afy). These small changes would have a slightly positive effect on groundwater levels and storage in and near the Natomas Basin.

7.5 Cumulative Effects

The cumulative impacts of SAFCA's construction activities on existing groundwater conditions based on the 2004 and 2030 IGSM simulation are shown in **Tables 7-3** and **7-4**. On these tables, the estimated SAFCA impacts discussed above are added to the groundwater budget for the Natomas Basin discussed in Chapter 4. The 2004 groundwater budget showed a total groundwater inflow to the Natomas Basin of 52,304 afy without the effects of SAFCA's activities and 51,267 afy including the proposed construction (**Table 7-3**). There is a similar reduction in groundwater outflow from 57,275 afy without SAFCA's construction activities to 54,643 afy including the construction. The simulated reduction in groundwater storage for 2004 is 4,971 afy without SAFCA, which represents an average water level decline of about one foot. The decrease in groundwater storage would be smaller (3,376 afy) due to SAFCA's construction activities. Overall, SAFCA's proposed construction would have a small positive impact on groundwater supplies in the Natomas Basin based on existing conditions. Outside of the Natomas Basin, the predicted reduction in groundwater outflow to the east (1,007 afy) would have a small negative impact on groundwater levels and storage within the cones of depression east of the Natomas Basin, but groundwater outflow is still estimated to be large (20,731 afy).

The estimate of the cumulative impacts of SAFCA's construction activities based on the simulation of future (2030) groundwater conditions is summarized in **Table 7-4**. The 2030 groundwater budget shows that the total groundwater inflow to the Natomas Basin without the effects of SAFCA's activities (35,187 afy) would decrease to 33,926 afy including SAFCA proposed construction. This is offset by a reduction in groundwater outflow from 33,615 afy without SAFCA's construction activities to 32,006 afy including SAFCA's activities. The simulation shows an increase in groundwater storage in 2030 of 1,572 afy without SAFCA. The results indicate that, on average, SAFCA's construction activities will have a positive effect on groundwater levels in the Natomas Basin, resulting in an additional increase in storage of 348 afy (to 1,920 afy). Subsurface outflow to the east is predicted to be much smaller in 2030 (only 1,200 afy without SAFCA's construction activities), but would increase by 16 afy due to SAFCA's proposed construction. Overall, SAFCA's activities would have a slightly positive effect on groundwater levels and storage within and east of the Natomas Basin in 2030.

Table 7-1
Groundwater Budget for Proposed SAFCA Construction Activities Based on Existing Conditions

SAFCA Construction Activity	Inflow (afy)[1]					Outflow (afy)[1]			Change in Storage (afy)
	Deep Percolation	Net Recharge from Streams	Seepage from Canals	Subsurface Inflow	Total Inflow	Subsurface Outflow	Groundwater Pumping	Total Outflow	
Levee Improvements[2]									
Sacramento River East Levee	-63	-884	0	0	**-947**	0	0	**0**	-
NCC South Levee	-4	0	0	-56	**-60**	0	0	**0**	-
PGCC West Levee	-39	0	0	0	**-39**	-238	0	**-238**	-
NEMDC West Levee (North)	0	0	0	0	**0**	-378	0	**-378**	-
NEMDC West Levee (South)	0	0	0	0	**0**	-466	0	**-466**	-
American River North Levee	0	-211	0	0	**-211**	0	0	**0**	-
Subtotal	**-105**	**-1,095**	**0**	**-56**	**-1,256**	**-1,083**	**0**	**-1,083**	**-173**
Canal Improvements									
New GGS/Drainage Canal	-11	0	162	0	**151**	0	0	**0**	-
West Drainage Canal	0	0	128	0	**127**	0	0	**0**	-
Elkhorn Canal relocation	-11	0	27	0	**16**	0	0	**0**	-
Riverside Canal relocation	-19	0	10	0	**-9**	0	0	**0**	-
Subtotal	**-41**	**0**	**327**	**0**	**285**	**0**	**0**	**0**	**285**
Borrow Sites									
Airport North	0	0	0	0	**0**	0	0	**0**	-
Brookfield	-30	0	0	0	**-30**	76	-1,625	**-1,549**	-
Fisherman's Lake	-36	0	0	0	**-36**	0	0	**0**	-
Subtotal	**-67**	**0**	**0**	**0**	**-67**	**76**	**-1,625**	**-1,549**	**1,483**
Total	**-213**	**-1,095**	**327**	**-56**	**-1,037**	**-1,007**	**-1,625**	**-2,632**	**1,595**

1. Increased groundwater inflow (or decreased outflow) shown as a positive value; increased outflow (or decreased inflow) is shown as negative.
2. Effect of slurry cutoff walls represent existing/2004 results from Table 6-6.

Table 7-2

Groundwater Budget for Proposed SAFCA Construction Activities Based on Future (2030) Conditions

SAFCA Construction Activity	Inflow (afy)[1]					Outflow (afy)[1]			Change in Storage (afy)
	Deep Percolation	Net Recharge from Streams	Seepage from Canals	Subsurface Inflow	Total Inflow	Subsurface Outflow	Groundwater Pumping	Total Outflow	
Levee Improvements[2]									
Sacramento River East Levee	-63	-992	0	0	**-1,055**	0	0	**0**	-
NCC South Levee	-4	0	0	-480	**-484**	0	0	**0**	-
PGCC West Levee	-39	0	0	0	**-39**	-13	0	**-13**	-
NEMDC West Levee (North)	0	0	0	0	**0**	-21	0	**-21**	-
NEMDC West Levee (South)	0	0	0	0	**0**	-26	0	**-26**	-
American River North Levee	0	97	0	0	**97**	0	0	**0**	-
Subtotal	**-105**	**-895**	**0**	**-480**	**-1,480**	**-60**	**0**	**-60**	**-1,420**
Canal Improvements									
New GGS/Drainage Canal	-11	0	162	0	**151**	0	0	**0**	-
West Drainage Canal	0	0	128	0	**127**	0	0	**0**	-
Elkhorn Canal relocation	-11	0	27	0	**16**	0	0	**0**	-
Riverside Canal relocation	-19	0	10	0	**-9**	0	0	**0**	-
Subtotal	**-41**	**0**	**327**	**0**	**285**	**0**	**0**	**0**	**285**
Borrow Sites									
Airport North	0	0	0	0	**0**	0	0	**0**	-
Brookfield	-30	0	0	0	**-30**	76	-1,625	**-1,549**	-
Fisherman's Lake	-36	0	0	0	**-36**	0	0	**0**	-
Subtotal	**-67**	**0**	**0**	**0**	**-67**	**76**	**-1,625**	**-1,549**	**1,483**
Total	**-213**	**-895**	**327**	**-480**	**-1,261**	**16**	**-1,625**	**-1,609**	**348**

1. Increased groundwater inflow (or decreased outflow) shown as a positive value; increased outflow (or decreased inflow) is shown as negative.
2. Effect of slurry cutoff walls represent 2030 results from Table 6-6.

Table 7-3
Groundwater Budget for Natomas Basin Showing Effect of SAFCA Activities on Existing Groundwater Conditions (Based on 2004 Simulation)

	Water Budget Component	2004 Simulation[1] (afy)	Impact of SAFCA Activities (afy)	2004 Simulation Plus SAFCA Activities (afy)
Inflow	Deep Percolation (Including Canal Seepage)	31,429	114	31,543
	Recharge from Sacramento River	6,469	-884	5,585
	Recharge from American River	1,086	-211	875
	Boundary Inflow from West	10,365	0	10,365
	Subsurface Inflow from North	241	-56	185
	Subsurface Inflow from South	2,714	0	2,714
	Total Inflow	**52,304**	**-1,037**	**51,267**
Outflow	Groundwater Pumping	35,537	-1,625	33,912
	Subsurface Outflow to East	21,738	-1,007	20,731
	Total Outflow	**57,275**	**-2,632**	**54,643**
Inflow minus Outflow	**Change in Storage**	**-4,971**	**1,595**	**-3,376**

1. Based on final year (2004) of calibration simulation (LSCE, 2008b).

Table 7-4
Groundwater Budget for Natomas Basin Showing Effect of SAFCA Activities on Future Groundwater Conditions (Based on 2030 Simulation)

	Water Budget Component	2030 Simulation[1] (afy)	Impact of SAFCA Activities (afy)	2030 Simulation Plus SAFCA Activities (afy)
Inflow	Deep Percolation (Including Canal Seepage)	27,187	114	27,301
	Recharge from Sacramento River[2]	1,100	-992	108
	Recharge from American River	-500	97	-403
	Boundary Inflow from West	3,700	0	3,700
	Subsurface Inflow from North	3,700	-480	3,220
	Subsurface Inflow from South	0	0	0
	Total Inflow	**35,187**	**-1,261**	**33,926**
Outflow	Groundwater Pumping	31,615	-1,625	29,990
	Subsurface Outflow to East	1,200	16	1,216
	Subsurface Outflow to South	800	0	800
	Total Outflow	**33,615**	**-1,609**	**32,006**
Inflow minus Outflow	**Change in Storage**	**1,572**	**348**	**1,920**

1. Based on 1982-2004 average for Sutter Pointe Project Scenario 2B (LSCE, 2008b).

8.0 Effects on Groundwater Quality and Private Wells

8.1 Potential Groundwater Quality Impacts

The primary potential groundwater quality impact of SAFCA's proposed construction activities is a slight reduction in groundwater recharge to the Natomas Basin, including stream recharge and deep percolation from rice fields and other irrigated farmland. This recharge is generally of high quality, especially the stream recharge, which typically has very low salinity and few contaminants. Seepage from canals is another source of good quality recharge, and this will increase due to SAFCA's proposed canal construction. Water recharged via deep percolation has somewhat higher salinity than river water due to the use of recycled tailwater and the effects of ET.

As estimated above, the combined effect of SAFCA's proposed construction activities on existing groundwater conditions would be to reduce low-salinity recharge from rivers and canals by 768 afy and reduce groundwater outflow beneath the PGCC and NEMDC by 1,007 afy. The combined effect of these inflow and outflow reductions would be expected to slightly increase salt accumulation in the Natomas Basin and have a small effect on groundwater quality east of the Natomas Basin. However, these reductions represent less than two percent and five percent of the total estimated groundwater inflow and outflow to and from the Natomas Basin, and the water quality impacts are not expected to be measurable.

For future groundwater conditions in 2030, the combined effect of SAFCA's proposed construction activities would be to reduce low-salinity groundwater recharge from rivers and canals by 568 afy and groundwater outflow to the east by 16 afy. Again, the overall effect of these changes on future groundwater quality would be small.

In the vicinity of the Brookfield borrow site, groundwater quality would improve due to the transition from groundwater to surface water for about 80 percent of the rice acreage. Groundwater quality would improve in this area because deep percolation from fields irrigated with surface water will have lower salinity than from fields irrigated with groundwater.

The slurry cutoff walls will be constructed primarily of soil mixed with bentonite, but Portland cement may be used as an additive in some cases. Bentonite is a naturally occurring form of clay, and Portland cement is made from limestone and clay. Neither bentonite nor cured Portland cement are water soluble, and grouts composed of both materials are widely used in the water well industry. Both bentonite and cement are used to construct seals in wells drilled for various purposes, including drinking water supply. No groundwater contamination would be expected due to construction of the proposed slurry cutoff walls and other improvements proposed for the levees surrounding the Natomas Basin.

Although SAFCA's proposed construction activities would cause slight groundwater quality impacts in some areas and improvements in other areas, the effects would be too small to be measurable. The overall effect of SAFCA's proposed construction on future groundwater quality in the Natomas Basin can be considered negligible.

8.2 Potential Impacts to Private Wells

8.2.1 Private Well Locations and Construction

For the *Sacramento River Basinwide Water Management Plan*, DWR reviewed drillers' logs in the Natomas Basin and reported that average well depths were 149 feet for domestic wells, 313 feet for irrigation wells, 378 feet for industrial wells, and 308 feet for municipal wells (DWR, 2003c). The majority of the wells in the Natomas Basin are either domestic or agricultural wells, which typically extract groundwater from the upper aquifer system as defined above.

Figure 8-1 shows wells with known or estimated locations in and near the Natomas Basin. "Private wells" shown along the Sacramento River East Levee and the NCC South Levee are primarily domestic wells mapped by M&H (Stephen Sullivan, pers. comm., January 23, 2008) but include some irrigation wells. Well numbers provided for these wells correspond to numbers assigned by M&H. Similar mapping of private wells along the PGCC and NEMDC West Levees is still in progress, and well locations along the eastern edge of the Natomas Basin shown on **Figure 8-1** are estimated based on parcel boundaries. Only a portion of the estimated well locations in the Valley View Acres (VVA) community, located along the NEMDC north of Del Paso Road and east of Sorento Road, are shown on the map due to the high density of domestic wells in this area.

In addition to domestic wells, **Figure 8-1** also shows wells with water level data mapped by LSCE based on locations provided by DWR and other sources. Symbols used for these wells indicate the depth zone (upper, lower, multiple, and unknown). Most of these are agricultural wells, M&I wells, or monitoring wells. If available, the wells are numbered based on the last four digits of the State Well Number.

Approximately 138 private wells along the Sacramento River East Levee have been mapped by M&H (2008), and these are grouped by depth and type in **Table 8-1**. There are 103 domestic wells, 15 irrigation wells, and 20 wells used for other or unknown purposes in this area. Monitoring and municipal wells are not included on this table. All of the domestic wells are less than 300 feet deep, and 84 percent are between 100 and 200 feet deep. All but one of the irrigation wells are also less than 300 feet deep, with six wells between 100 and 200 feet deep and eight wells between 200 and 300 feet deep. The average depth of the private wells along the Sacramento River East Levee is 158 feet. As reported by LSCE (2008a), approximately two-thirds of these wells are located on the river side of the levee and one-third on the land side. The average depth of these wells is 151 feet on the river side of the levee and 163 feet on the land side. The land side wells are slightly deeper on average because they include more irrigation wells.

As shown in **Table 8-1**, nine wells along the NCC South Levee were mapped by M&H (2008). These include one domestic well and eight irrigation wells. The domestic well is between 100 and 200 feet deep. One of the irrigation wells is between 100 and 200 feet deep, three are between 200 and 300 feet deep, two are between 300 and 400 feet deep, and two are of unknown depth. The average depth of wells with depth information is 260 feet.

There are about 150 residences in the VVA community, situated on about 300 acres of land west of the NEMDC. The VVA community is supplied by groundwater, and each residence is assumed to have a domestic well. Compilation of construction information for these wells is still in progress, but M&H has provided drillers' logs for 27 VVA wells to date. These wells range in depth from 65 to 290 feet, with an average of 122 feet. Most of the drillers' logs do not show the perforated interval, but it is expected to be below the depth of the cutoff wall proposed for this portion of the NEMDC West Levee (53 feet) for almost all wells.

8.2.2 Potential Impacts

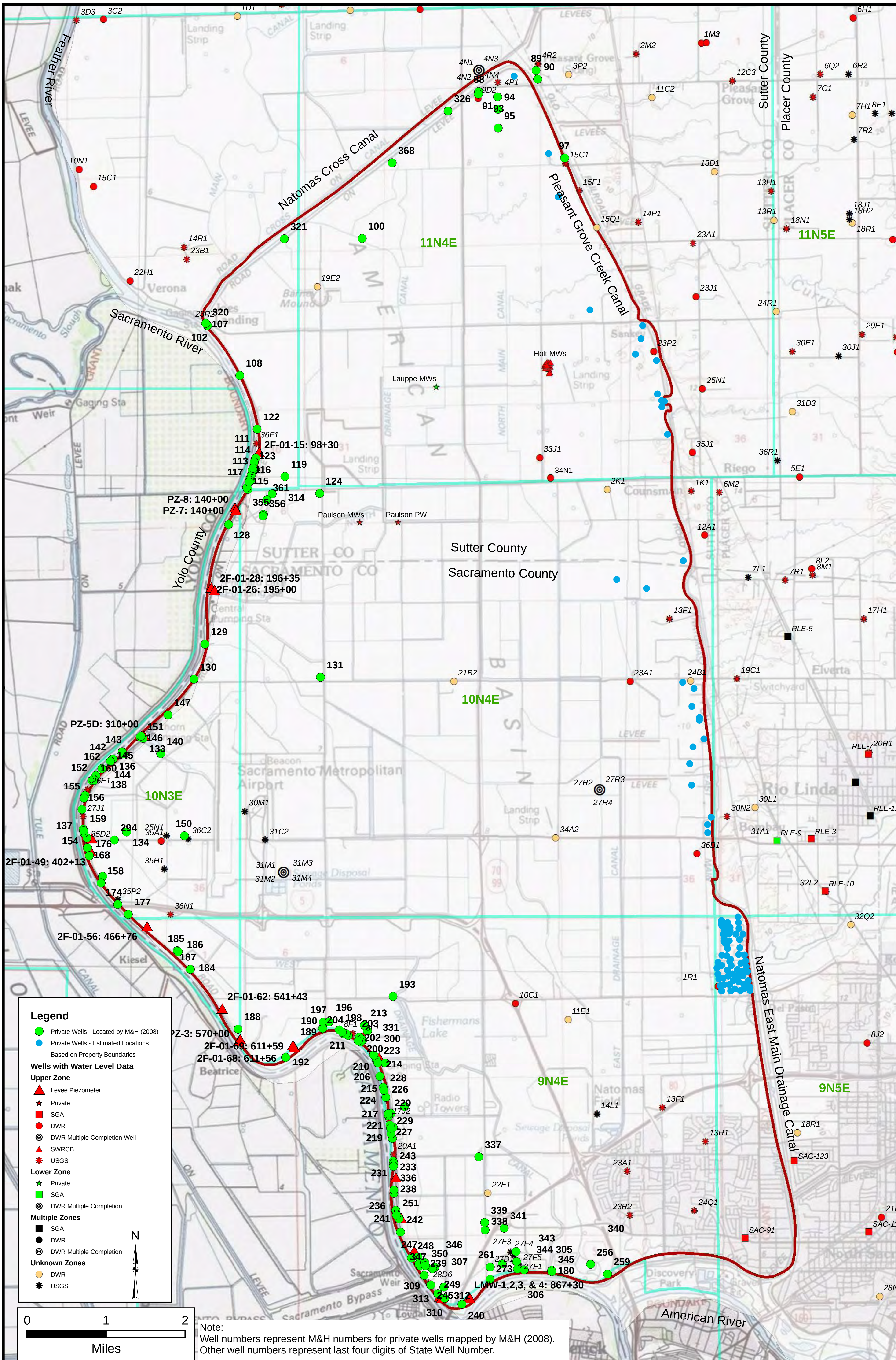
Kleinfelder (2009) estimated the water level changes due to the slurry cutoff walls along the Sacramento River East Levee using the steady-state and transient versions of the seepage model discussed above. The transient version of the model is considered to be more accurate, and the changes in head due to the proposed slurry cutoff wall along one reach of the Sacramento River East Levee predicted by the transient model are shown on **Figure 8-2**. On the river side of the levee, the predicted effects of the cutoff walls are negligible at low stage, and there would be a slight increase in head (less than one foot) at high stage. On the land side of the levee, the Kleinfelder simulation shows that heads would be from one to 6.5 feet lower (average of 2.2 feet) due to the cutoff wall during the winter months when the direction of groundwater flow is away from the River. During the rest of the year, the direction of groundwater flow is toward the River because gaining conditions are simulated with the model. Under these conditions, land side groundwater levels are predicted to be up to 1.5 feet higher (average of 0.9 foot) with the cutoff wall in place. These small effects are considered to be negligible even for the shallowest domestic wells (less than 100 feet deep). No measurable decreases in well yields or increases in pumping costs are expected due to slurry cutoff walls along the Sacramento River East Levee.

Similar modeling has not been conducted for wells along the PGCC or NEMDC, but cutoff walls would be expected to have similarly small effects near the eastern edge of the Natomas Basin. Since the general direction of groundwater flow in this area is to the east, static groundwater levels will increase slightly west of the levee and decrease slightly east of the levee. Shallow wells on either side of the levee could experience slightly lower pumping water levels because the cutoff wall will act as a low permeability boundary that will reduce the aerial extent and increase the depth of the cone of depression. This effect will be small because the production zone for most wells is below the bottom of the proposed cutoff walls. No measurable decreases in well yields or increases in pumping costs are expected due to the slurry cutoff walls. Overall, no measurable effects on groundwater levels or quality are expected for wells in or near the Natomas Basin due to SAFCA's proposed construction activities.

Table 8-1

Depths of Private Wells Along Sacramento River East Levee and Natomas Cross Canal South Levee

Levee	Well Type	Well Depth						Total
		0-100 ft	100-200 ft	200-300 ft	300-400 ft	> 400 ft	Unknown	
Sacramento River East Levee	Domestic	10	87	6	0	0	0	103
	Irrigation	0	6	8	0	1	0	15
	Other/Unknown	6	6	6	0	0	2	20
	Subtotal	**16**	**99**	**20**	**0**	**1**	**2**	**138**
Natomas Cross Canal South Levee	Domestic	0	1	0	0	0	0	1
	Irrigation	0	1	3	2	0	2	8
	Subtotal	**0**	**2**	**3**	**2**	**0**	**2**	**9**
Total		**16**	**101**	**23**	**2**	**1**	**4**	**147**



FILE: \\server_pe2900\Public\SAFCA\GIS\Well Location map.mxd Date: 5/4/2009

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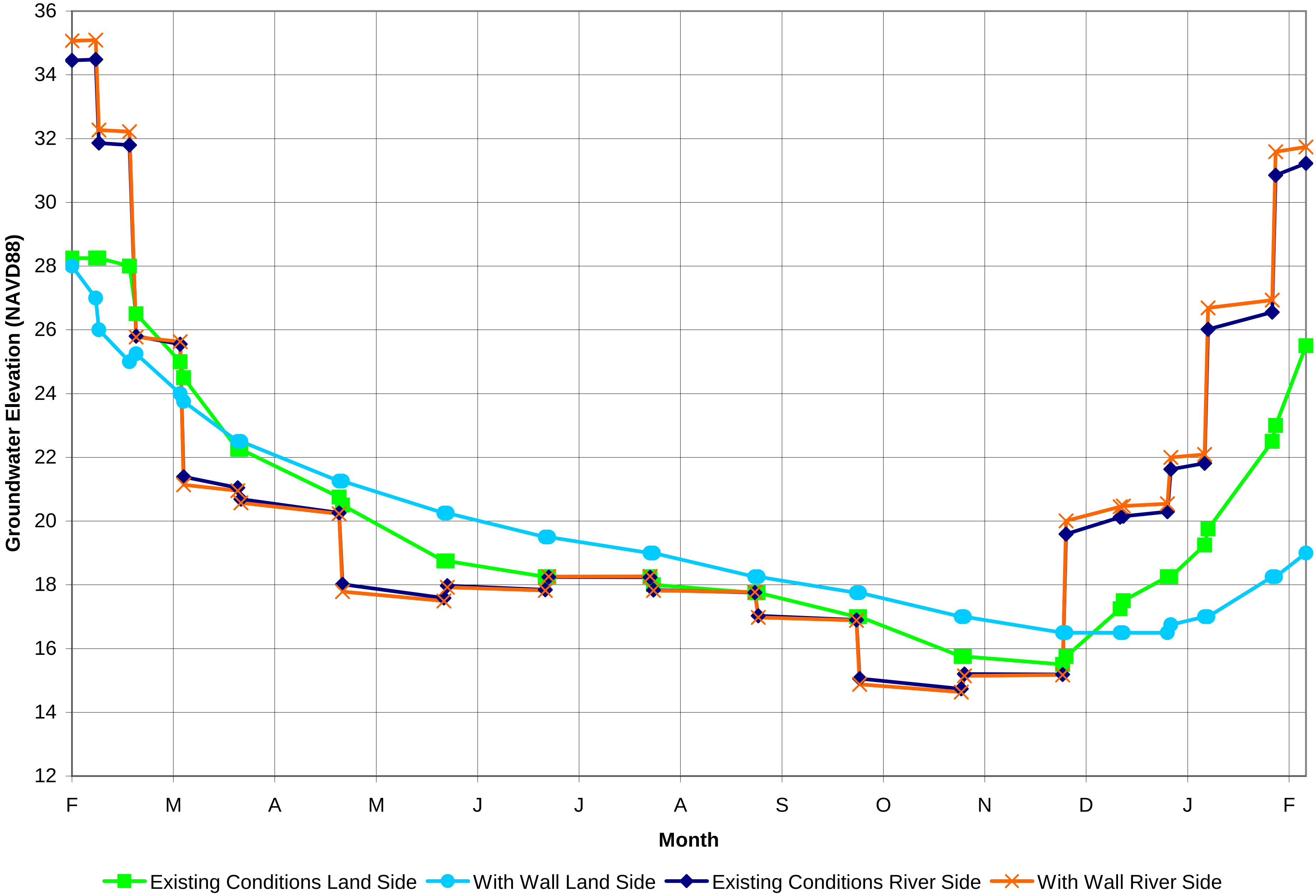
Figure 8-1
Wells In and Near the Natomas Basin



Y:\SAFCA\Cutoff Wall Impacts (2009)\plate 25_05-01-09.xls\Est GW Table Ele

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Figure 8-2
Simulated Groundwater Elevations from Kleinfelder Transient Model With and Without Slurry Cutoff Walls

9.0 Summary of Potential Impacts

Most of SAFCA's proposed levee improvements will have no effect on groundwater in the Natomas Basin, but the proposed slurry cutoff walls are intended to reduce seepage beneath the levees and will affect groundwater conditions. Some of SAFCA's construction activities will involve land use changes that will reduce groundwater recharge. This reduction will be at least partially offset by seepage from new and relocated canals, which will increase groundwater recharge. Finally, water supply changes at the Brookfield property borrow site will result in a large reduction in groundwater pumping.

The effects of SAFCA's proposed construction activities on groundwater conditions in the Natomas Basin were evaluated using the water budget approach and other methods discussed above. Potential impacts resulting from land use changes and canal construction were addressed in Chapter 5, potential impacts due to proposed slurry cutoff walls were addressed in Chapter 6, and the potential cumulative impacts were addressed in Chapter 7. The analysis of potential impacts to groundwater quality and private wells was discussed in Chapter 8. Each of these potential impacts is summarized below.

9.1 Potential Water Budget Impacts

9.1.1 Levee Improvements

Groundwater impacts from proposed levee improvements are primarily limited to the effects of land use changes and slurry cutoff walls. No direct groundwater impacts are expected from increasing the height or width of levees, modifying levee slopes, building seepage berms, or other construction above the water table.

Proposed land use changes for all five levees will result in the loss of about 75 acres of existing rice, 175 acres of field crops, and five acres of orchard. These changes are estimated to reduce deep percolation from applied water by a total of 105 afy.

Groundwater flow reductions due to the slurry cutoff walls were estimated based on simulations of "existing" (or 2004) and future (2030) conditions. The combined effect of all proposed slurry cutoff walls along the levees surrounding the Natomas Basin for existing/2004 conditions is estimated to reduce groundwater inflow by 1,256 afy and groundwater outflow by 1,083 afy, resulting in a reduction in groundwater storage in the Natomas Basin of about 173 afy (**Table 7-1**). For 2030 conditions, groundwater inflow is predicted to be reduced by 1,480 afy and groundwater outflow by 60 afy, resulting in a reduction in groundwater storage of about 1,420 afy (**Table 7-2**).

9.1.2 Canal Improvements

The construction of the new GSS/Drainage Canal and relocation and improvements to the West Drainage Canal, the Elkhorn Canal, and the Riverside Canal will affect deep percolation from applied water (due to land use changes) and seepage from the canals. For all four canals, deep percolation is estimated to decrease by 41 afy and canal seepage is estimated to increase by 327 afy. The net effect of proposed canal construction would be to increase groundwater storage in the Natomas Basin by about 285 afy (**Tables 7-1** and **7-2**).

9.1.3 Borrow Sites

Excavation of two of the three primary borrow sites is expected to have an indirect effect on groundwater conditions due to proposed land use and water supply changes. At the Brookfield borrow site, approximately 325 acres are currently planted to rice, and SAFCA plans to restore about 286 acres to rice cultivation after construction activities are complete. At the Fisherman's Lake borrow site, about 400 acres of land would be used for borrow material, including 49 acres currently planted to rice, 266 acres of field crops, and 85 acres of managed marsh. After reclamation, there would be about 175 acres of managed marsh and 225 acres of non-irrigated grassland or woodland. No land use changes are planned at the Airport North Bufferlands borrow site due to airport safety considerations. The predicted net loss in deep percolation for all borrow sites is 67 afy.

The Brookfield borrow site is currently irrigated entirely with groundwater, but SAFCA plans to provide the infrastructure so that about 80 percent of the borrow site can be irrigated with surface water after reclamation. This transition would reduce groundwater pumping in the Natomas Basin by about 1,625 afy. The reduction in groundwater pumping at the Brookfield site more than offsets the loss of deep percolation at all borrow sites. The reduced pumping would also result in slightly increased groundwater outflow from the northern portion of the Natomas Basin. The net effect of excavation and reclamation of all borrow sites will be to increase groundwater storage by about 1,483 afy (**Tables 7-1** and **7-2**).

9.1.4 Summary of Potential Water Budget Impacts

The combined effects of SAFCA's proposed construction activities for both existing and future conditions include estimated decreases in deep percolation (213 afy) and groundwater pumping (1,625 afy) and an increase in seepage from canals (327 afy). The effect on other water budget components varies between the existing/2004 and future/2030 simulations. For the existing/2004 period, there are predicted decreases in net recharge from streams (1,095 afy), subsurface inflow (56 afy), and subsurface outflow (1,083 afy), and groundwater storage is estimated to increase by 1,596 afy. This means that groundwater levels in the Natomas Basin would be expected to increase slightly due to SAFCA's construction activities. The estimated reduction in subsurface outflow (1,007 afy) would result in a small decrease in groundwater levels and storage east of the Natomas Basin.

For the 2030 period, decreases in groundwater inflow include net recharge from streams (895 afy) and subsurface inflow (480 afy). There would be a smaller increase groundwater storage (348afy) and a small increase in subsurface outflow (16 afy) as compared to the existing/2004 simulation. These changes would have a slight positive effect on groundwater levels in or near the Natomas Basin.

The cumulative impacts of SAFCA's proposed construction activities on existing and future groundwater conditions were based primarily on the 2004 and 2030 IGSM simulations discussed in Chapter 4. The 2004 simulation results show a reduction in groundwater storage of 4,971 afy in the Natomas Basin without SAFCA's construction; this equates to an average head decline of about one foot. The decrease in groundwater storage would be smaller (3,376 afy) due to SAFCA's construction activities. Subsurface outflow from the Natomas Basin to the east would decrease from 21,738 to 20,731 afy due to SAFCA's activities. Overall, SAFCA's activities would have a small positive impact on groundwater supplies in the Natomas Basin and a small negative impact on groundwater conditions east of the Natomas Basin.

The 2030 IGSM simulation provides an estimate of the cumulative impacts of SAFCA's construction activities on future groundwater conditions. The results of the 2030 simulation show a positive change in groundwater storage in the Natomas Basin of 1,572 afy, which would increase slightly to 1,920 afy due to SAFCA's activities. There would be a very small increase in groundwater outflow (from 1,200 to 1,216 afy). Overall, the cumulative impact of SAFCA's proposed construction activities on future groundwater levels in and near the Natomas Basin is predicted to be slightly positive.

9.2 Potential Water Quality Impacts

This investigation also included a summary of potential impacts to groundwater quality due to SAFCA's construction activities. The primary potential groundwater quality impact will be a slight reduction in groundwater recharge to the Natomas Basin, including stream recharge and deep percolation from rice fields and other irrigated farmland. This recharge is generally of high quality, especially the stream recharge, which has very low salinity. Seepage from canals is another source of good quality recharge, and increased seepage due to SAFCA's proposed canal construction will offset some of the reductions in groundwater recharge due to slurry cutoff walls. In the vicinity of the Brookfield borrow site, groundwater quality would improve due to the transition from groundwater to surface water for about 80 percent of the rice acreage. No groundwater contamination would be expected due to construction of the proposed slurry cutoff walls and other improvements proposed for the levees surrounding the Natomas Basin.

SAFCA's proposed construction activities would cause slight groundwater quality degradation in some areas and improvements in other areas. The overall effect would likely be a slight increase in salt accumulation in the aquifers underlying the Natomas Basin. However, this impact would be too small to be measurable.

9.3 Potential Impacts to Private Wells

The majority of the domestic wells along the Sacramento River East Levee are between 100 and 200 feet deep, and irrigation wells in this area are slightly deeper. The average depth of the domestic and irrigation wells along the Sacramento River East Levee is 158 feet. Evaluation of well construction along the PGCC and NEMDC is still in progress, but there are about 150 residences in the VVA community with mostly shallow domestic wells. The drillers' logs for wells in this area that have been cataloged to date show an average well depth of 122 feet. Most of the drillers' logs do not show the perforated interval, but it is expected to be below the depth of the cutoff wall proposed for this portion of the NEMDC West Levee (53 feet) for almost all wells.

Kleinfelder estimated the water level changes due to the slurry cutoff walls along the Sacramento River East Levee using the SEEP/W groundwater model. On the river side of the levee, the predicted effect of the cutoff wall is negligible at low stage, and there would be a slight increase in head (less than one foot) at high stage. On the land side of the levee, the model results show that, on average, heads would be about 2.2 feet lower during the winter months and 0.9 foot higher during the rest of the year with the cutoff wall in place. In both cases, any impacts would be small enough to be considered negligible even for the shallowest domestic wells (less than 100 feet deep). No measurable decrease in groundwater levels or well yields or increase in pumping costs is expected due to the slurry cutoff walls.

Although similar modeling has not been conducted for wells along the PGCC or NEMDC, cutoff walls would be expected to have similarly small effects in this area. Static groundwater levels will increase slightly west of the levee and decrease slightly east of the levee. Shallow wells on either side of the levee could experience slightly lower pumping water levels because the cutoff wall will act as a low permeability boundary. This effect will be small because the production zone for most wells is below the depth of the proposed cutoff walls. No measurable decreases in well yields or increases in pumping costs are expected due to slurry cutoff walls. Overall, no measurable effects on groundwater levels or quality are expected for wells in or near the Natomas Basin due to SAFCA's proposed construction activities.

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C3 Evaluation of Cutoff Walls

December 19, 2007
Revised April 21, 2009
File No.: 72834

Mr. Timothy Washburn
SAFCA
1007 7th Street, 7th Floor
Sacramento, CA 95814

Subject: **Evaluation of Cutoff Walls Impact on Groundwater Recharge**
Sacramento River East Levee
Natomas Levee Improvement Project
Sacramento and Sutter Counties, California

Dear Mr. Washburn:

This Memorandum is a revised version of a draft memorandum submitted to you on December 19, 2007. The analyses and data presented in December 2007 memo have been converted to the North American Vertical Datum (NAVD 88). The updated memorandum does not reflect any changes to the proposed remedial design and/or site subsurface characterization model that may have occurred since December 2007.

One of the design alternatives considered for remediation of the Sacramento River East Levee from Reach 1 to Reach 20 includes construction of cutoff walls through an adjacent levee. These soil-bentonite (SB) walls are proposed to mitigate underseepage concerns and reduce exit seepage gradients to the acceptable levels, according to the established project criteria.

A concern has been raised that the SB walls could potentially impede seepage from the river through the levee foundation and adversely impact groundwater recharge landward of the levee. To address these concerns, we have performed simplified seepage analyses to estimate seepage flow from the river into the aquifer under both existing conditions and with cutoff walls in place.

Based on the design recommendations provided by Kleinfelder, the SB wall material should have permeability of about $5x10^{-7}$ cm/sec or lower and will extend at least 5 feet into a fine grained layer(s) underneath the permeable near surface foundation layer. To account for the variability of the slurry and the potential for construction defects, for this study the SB wall was modeled with and average overall permeability of $1x10^{-6}$ cm/sec.

In addition, we have evaluated potential seepage loss from the proposed Giant Garter Snake ditch. This new 2 mile long unlined canal will be located approximately 500 to 1,000 feet landward of the levee toe and will follow the existing levee alignment between Stations 200+00 and 305+00. In general, the canal will be filled with water during summer month and will be dry during the winter months. During periods of time when the canal is filled with water, seepage through its bottom and side slopes may temporarily affect the groundwater table in the area.

General Assumptions

- Idealized stratigraphic models at Stations 27+00, 70+00, 217+00, and 353+00 were selected to represent the range of subsurface conditions along the Sacramento River East Levee. Analyses at Station 217+00 are based on the stratigraphy model developed by URS, as presented in the URS "Draft Subsurface Investigation Report for Sacramento River East Levee, Natomas General Reevaluation Report" prepared for US Army Corps of Engineers, Sacramento District, dated 18 July 2007. Analyses at Stations 27+00, 70+00, and 353+00 are based on the models developed by Kleinfelder as presented in the Draft Basis of Design Report (Kleinfelder, 2007).
- Total length and location of the SB wall were estimated based on the information provided in the Final Draft Basis of Design Report dated December 18, 2007 and in the Alternatives Analysis Report for Seepage Mitigation Revision 1 dated September 24, 2007. Two representative cross-sections (Stations 70+00 and 353+00) have been selected to represent the proposed wall locations and depths.
- Seepage analyses were completed using steady state and transient analysis procedures with the finite element program SEEP/W version 6.17, provided with the GeoStudio 2004 package. These analyses do not account for 3-D effects, such as flow around the cutoff wall.
- Typical seasonal river level fluctuations were estimated based on the information provided by the Department of Water Resources (DWR), Division of Flood Management (http://cdec.water.ca.gov/queryStation.html) for the Sacramento River gage at Verona. River stage data recorded at Verona from 11/26/1995 to 11/26/2007 are presented on Plates 1 through 5 and summarized in a tabular form on Plate 6.
- Elevation of the groundwater table landward of the levee was estimated based on piezometer data obtained from "Final Observation Wells Report II: for Reaches North and South of Powerline Road", prepared by URS.
- All elevations in this memorandum are referenced in North American Vertical Datum (NAVD 88). Elevations referenced in previous reports and other sources of information are based on the National Geodetic Vertical Datum (NGVD 29). To correct from NGVD29 datum to NAVD88 datum elevations should be adjusted by 2.28 feet (NAVD88 = NGVD29 + 2.28 feet).
- River gage data reported by DWR was in the United States Engineering Datum (USED). In the Sacramento and San Joaquin River Basins, the adjustment from USED to NGVD29 varies from gaging station to gaging station within a range of 2.48 feet to 3.2 feet. According to the DWR website, the commonly used adjustment, when not otherwise known, is 3.0 feet. Elevations reported in USED

are approximately 3 feet higher than elevations reported in NGVD29 and 0.72 feet lower than elevations reported in NAVD88.

- Seepage parameters selected for this study are consistent with those presented in the Basis of Design Report. Permeability values used in each analysis case are shown on plates presenting the results.
- Only recharge due to seepage from the river was considered. The model does not account for flow into or out of the system due to precipitation, pumping or regional groundwater flow that maybe occurring from a direction parallel to the levee axis.

Analysis Approach

We have performed simplified seepage analyses to estimate seepage flow from the river into the aquifer under both existing conditions and with cutoff walls in place we have further evaluated the impact of the proposed canal construction and operation based on the methodology outlined below. The following sections of this memo discuss analysis assumptions and details and present the results.

1. Review available historical data and develop representative average river level and ground water table hydrographs.
2. Perform series of steady state seepage analyses at four representative cross-sections to estimate seepage through levee foundation under the existing conditions as a function of river elevation. Boundary conditions used in steady state seepage modeling simulations are defined below. Fixed-head boundary conditions set to the water surface elevations were applied along the boundary nodes of the upstream slope, river bottom, and the upstream (riverside) vertical edge of the model. Nodes along the bottom of the model were modeled as no flow boundary (zero total flux boundary condition). Infinite elements with fixed-head boundary conditions were used along the right vertical edge of the model. The total head along the vertical edge was set to an estimated groundwater table elevation landward of the levee. The landside slope of the levee and the ground surface were modeled as potential seepage exit surfaces.
3. Using results from Steps 1 and 2 for each representative cross-section estimate seepage flow under the existing conditions over a typical year report seepage quantities in acre-feet per year per 1,000 feet of levee.
4. Using results from Step 3 and subsurface condition profiles at the landside toe of the levee, estimate seepage flow under the existing conditions over the entire length of the levee. Report seepage quantities in acre-feet per year.
5. Perform series steady state seepage analyses at two representative cross-sections (Stations 70+00 and 353+00) to estimate seepage through the levee foundation with a cutoff wall in place as a function of river elevation.
6. Using results from Steps 1 and 5, for Stations 70+00 and 353+00 estimate seepage flow with a cutoff wall in place over a typical year. Report seepage quantities in acre-feet per year per 1,000 feet of levee.
7. Using results from Steps 4 and 6, calculate reduction in seepage quantities at Stations 70+00 and 353+00 due to the cutoff wall.

8. Using river and groundwater table hydrographs from Step 1, perform transient seepage analyses at Station 70+00 with and without the cutoff wall. The purpose of this analysis is two-fold: 1) better understand the impact of the cutoff wall on the recharge of the aquifer throughout the year; 2) verify percent reduction estimated based on the steady state analysis.
9. Using results from Steps 4 and 7 and subsurface condition profiles at the landside toe of the levee, estimate impact of the cutoff wall construction over the entire length of the levee. Report seepage quantities in acre-feet per year.
10. Perform transient analysis at Station 70+00 with the cutoff wall and canal to estimate seepage from the canal during a typical year.

Analysis Results

Step1

Historical data recorded by the Sacramento River gage station at Verona from 11/26/1995 to 11/26/2007 are plotted on Plates 1 through 5. We have estimated typical number of days per year that river level remains at a given elevation as presented on Plate 6. The water surface rarely exceeds Elevation 35. The highest water surface included in our analyses was El. 34.25. Based on historical data, the water surface remains at this level approximately 1% of the year. We have also developed a representative (approximately average) annual river hydrograph (river level as a function of time) as shown graphically on Plate 7 and in tabular format on Plate 8. Transient seepage analyses utilized this hydrograph as a time-dependent boundary condition on the river side of the model.

Data from piezometer 2F-01-15N located north of Powerline Road indicates that the ground water elevation varies throughout the year from about 5 to 15 feet below ground level (see Attachment A). Based on the piezometer data, we have developed a representative groundwater table hydrograph as shown on Plate 7. Transient seepage analyses utilized this hydrograph as a time-dependent boundary condition on the landside of the model. For our steady state analyses we have set the groundwater table at 7 feet below ground surface, or Elevation 17.25.. Our assumption of Elevation 17.25 is also supported by the groundwater contour maps from County of Sacramento, Department of Water Resources for the spring and fall. The groundwater contours immediately landward of the levee near Reach 4B indicate groundwater elevations greater than 10 feet but generally less than 20.

Steps 2 and 3

Estimated seepage quantities through the levee foundation as a function of river elevation under the existing conditions (no cutoff wall) at Stations 27+00, 70+00, 217+00, and 353+00 are summarized in Table 1 and presented on Plate 9. A range of river levels above the ground water table was considered in the analyses. As discussed in Step 1, the highest river level considered was El. 34.25. Seepage analyses results for WSE at Elevation 34.25 are presented graphically on Plates 10 through 13. As shown in Table1 and graphically on Plate 9, the seepage quantities increase two orders of magnitude as the river level rises from Elevation 17.25 to 34.25. These results also indicate Station 217+00 provides the greatest contribution to the aquifer recharge landward of the levee. For a given river stage, estimated seepage quantities at Station 217+00 are approximately 100 times greater than the estimated quantities at the other three stations. Seepage quantities at Stations 27+00, 70+00, and 353+00 are approximately the same order of magnitude. The higher seepage quantities at Station 217+00 are primarily due to the presence of thick highly permeably sand and gravel layers in the foundation.

The second result worth noting is the aquifer only recharges when the river level is above the groundwater elevation. When the river elevation is below the groundwater table (Elevation 17.25), the direction of the seepage flow in the model is reversed, indicating flow out of the aquifer.

Table 1
Estimated Seepage Quantities Versus River Stage
Existing Conditions

Model Elevation	27+00 Flow Existing Conditions	70+00 Flow Existing Conditions	217+00 Flow Existing Conditions	353+00 Flow Existing conditions
17.25	-4.98E-11	8.61E-03	1.51E+00	-3.69E-12
18.25	8.53E-02	4.31E-02	6.06E+00	3.88E-01
19.25	1.71E-01	7.75E-02	1.21E+01	7.78E-01
20.25	2.56E-01	1.12E-01	1.82E+01	1.17E+00
21.25	3.41E-01	1.46E-01	2.42E+01	1.56E+00
22.25	4.26E-01	1.81E-01	3.03E+01	1.95E+00
23.25	5.13E-01	2.15E-01	3.63E+01	2.35E+00
24.25	5.99E-01	2.50E-01	4.24E+01	2.74E+00
25.25	6.84E-01	2.85E-01	4.85E+01	3.14E+00
26.25	7.70E-01	3.19E-01	5.45E+01	3.53E+00
27.25	9.24E-01	3.54E-01	6.07E+01	3.92E+00
28.25	1.08E+00	3.89E-01	6.68E+01	4.87E+00
29.25	1.43E+00	5.17E-01	7.33E+01	6.09E+00
30.25	1.93E+00	8.47E-01	7.97E+01	7.47E+00
31.25	2.60E+00	1.40E+00	8.62E+01	9.05E+00
32.25	3.26E+00	2.10E+00	9.28E+01	1.08E+01
33.25	4.08E+00	2.99E+00	9.95E+01	1.28E+01
34.25	5.07E+00	4.21E+00	1.06E+02	1.51E+01
Total Flux Acre ft/yr/1000ft	3.9	2.6	129.4	13.2

Notes: 1. All fluxes in ft^3/day/ft unless noted otherwise.
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

Step 4

The total length of the Sacramento River East Levee between Station 0+00 (Reach 1) and Station 960+00 (Reach 20) is approximately 18.1 miles. The general profile for the subsurface conditions along the levee crown/landside toe is provided in Attachment B. In general, the subsurface conditions profile is comprised of five units. These strata listed in order of increasing depth include: existing levee, surficial clay/fine grain soil blanket, silty and clayey sand layer, clean sand layer, gravel layer, and a lower clay/lower permeability soil region. As shown in Table 2, conditions at Station 27+00 are representative of approximately 1.8 miles or 11 percent of the entire length of the Sacramento River East Levee. Conditions at Station 70+00 are representative of approximately 4 miles or 23 percent of the entire length of the Sacramento River East Levee. Conditions at Station 217+00 are representative of approximately 7.6 miles or 42 percent of the entire length of the Sacramento River East Levee. Conditions at Station 353+00 are representative of approximately 4.7 miles or 24 percent of the entire length of the Sacramento River East Levee. Accordingly, the total estimated flow from the Sacramento River through the levee foundation between Station 0+00 and Station 960+00 is approximately 5,650 acre-feet per year.

Table 2
Estimated Seepage Quantities, Entire East Levee
Existing Conditions

Reach	Stations	Representative Station	Length of Stretch (ft)	Seepage without Cutoff Wall (ac-ft/yr)
1	00+00 to 48+00	27+00	4,800	19
2	48+00 to 100+00	70+00	5,200	14
3	100+00 to 110+00	70+00	1,000	3
4a	110+00 to 120+00	70+00	1,000	3
4a	120+00 to 190+00	353+00	7,000	95
4b	190+00 to 228+00	217+00	3,800	490
5a	228+00 to 263+00	70+00	3,500	10
5b	263+00 to 280+00	27+00	1,700	6
6	280+00 to 330+00	217+00	5,000	650
7	330+00 to 345+00	353+00	1,500	20
7	345+00 to 362+00	353+00	1,700	23
8	362+00 to 402+00	353+00	4,000	55
9a	402+00 to 430+00	353+00	2,800	38
9b	430+00 to 468+10	353+00	3,810	50
10	468+10 to 495+00	217+00	2,690	350
11	495+00 to 635+00	217+00	14,000	1810
12	635+00 to 640+00	217+00	500	65
12	640+00 to 667+00	70+00	2,700	7
13	667+00 to 700+00	353+00	3,300	45
14	700+00 to 732+00	70+00	3,200	8
15	732+00 to 780+00	217+00	4,800	620
16	780+00 to 832+00	217+00	5,200	675
17	832+00 to 842+00	217+00	1,000	130
18	842+00 to 857+00	217+00	1,500	195
19a	857+00 to 875+00	217+00	1,800	235
19b	875+00 to 925+00	70+00	5,000	15
20a	925+00 to 925+50	27+00	50	.2
20b	925+50 to 960+00	27+00	3,450	13
Total Seepage ac-ft/year				**5,650**

Steps 5 and 6

Cutoff soil-bentonite (SB) walls are currently proposed at thirteen locations along the east levee, as summarized in Table 3. The total length of the proposed SB walls is approximately 8 miles. The proposed depth of the wall varies from location to location based on the subsurface conditions and the required underseepage mitigation. Idealized cross-sections at Stations 70+00 and 353+00 were selected to represent the range of conditions at the proposed cutoff wall locations. At Station 70+00 where the surficial clay blanket is relatively thin and the underlying permeable layer is relatively shallow, the wall would completely penetrate the sand layer and key into the clay layer beneath. On the other hand at Station 353+00, only a partially penetrating cutoff wall is required. Proposed depth of the wall relative to the estimated bottom of the permeable layer at each location is presented in Table 3.

Table 3
Proposed Cutoff Wall Locations

Reach	Stations	Length of Stretch	Proposed depth of wall, Elevation	Depth of Sand layer, Elevation	Representative station for wall impact evaluation
2	48+00 to 100+00	5,200	-25	-25	70+00
3	100+00 to110+00	1,000	-25	-10	70+00
6	280+00 to 330+00	5,000	-70	-65	70+00
7	330+00 to 362+00	3,200	-60	-50	70+00
8	362+00 to 402+00	4,000	-60	-50	70+00
9	430+00 to 468+00	3,800	-70	-45	70+00
10	468+10 to 495+00	2,690	-25	-70	353+00
13	667+00 to 700+00	3,300	-20	-100	353+00
15	732+00 to 780+00	4,800	-10	-100	353+00
17	832+00 to 842+00	1,000	-25	-100	353+00
18	842+00 to 857+00	1,500	-25	-100	353+00
19a	857+00 to 875+00	1,800	-25	-100	353+00
19b	875+00 to 925+00	5,000	-25	-40	353+00

We have performed a series of steady state seepage analyses to estimate seepage quantities through the levee foundation with an SB wall in place. The analyses results for Stations 70+00 and 353+00 with the river WSE at Elevation 34.25 are presented on Plates 14 and 15. Total flow through a flux section located immediately landward of the SB wall was calculated with and without the cutoff wall in place. The two results were compared to estimate the groundwater recharge effects of the cutoff wall. Seepage quantities as a function of river stage are summarized in Table 4.

Table 4
Estimated Seepage Quantities versus River Stage
With and Without Cutoff Wall

River Elevation (ft)	70+00 Flow Existing Conditions	70+00 Flow With Cutoff Wall	353+00 Flow Existing Conditions	353+00 Flow With Cutoff Wall
17.25	8.61E-03	4.56E-03	-3.69E-12	-5.97E-13
18.25	4.31E-02	2.29E-02	3.89E-01	3.90E-01
19.25	7.75E-02	4.14E-02	7.78E-01	7.80E-01
20.25	1.12E-01	6.00E-02	1.17E+00	1.17E+00
21.25	1.46E-01	7.87E-02	1.56E+00	1.56E+00
22.25	1.81E-01	9.75E-02	1.96E+00	1.96E+00
23.25	2.15E-01	1.16E-01	2.35E+00	2.35E+00

Table 4 (Cont.)

River Elevation (ft)	70+00 Flow Existing Conditions	70+00 Flow With Cutoff Wall	353+00 Flow Existing Conditions	353+00 Flow With Cutoff Wall
24.25	2.50E-01	1.36E-01	2.74E+00	2.74E+00
25.25	2.85E-01	1.55E-01	3.14E+00	3.13E+00
26.25	3.19E-01	1.74E-01	3.53E+00	3.52E+00
27.25	3.54E-01	1.93E-01	3.92E+00	3.92E+00
28.25	3.89E-01	2.13E-01	4.87E+00	4.31E+00
29.25	5.17E-01	2.33E-01	6.09E+00	4.70E+00
30.25	8.47E-01	2.54E-01	7.47E+00	5.12E+00
31.25	1.40E+00	2.75E-01	9.05E+00	5.59E+00
32.25	2.10E+00	2.95E-01	1.08E+01	6.06E+00
33.25	2.99E+00	3.16E-01	1.28E+01	6.54E+00
34.25	4.21E+00	3.37E-01	1.51E+01	7.02E+00
Total Flux Acre ft/yr/1000ft	2.6	0.4	13.4	8.4

Notes: 1. All fluxes in ft^3/day/ft unless noted otherwise.
2. Elevations in the seepage models were adjusted to a nearest mesh node.

Step 7

Based on the results of steady state seepage analyses presented in Table 4, the cutoff wall could potentially reduce seepage through the foundation by 40 to 85 percent depending on the subsurface conditions and the proposed depth of the wall. At the locations where the wall fully penetrates the permeable sand layer (Station 70+00) seepage quantities could be reduced by approximately 85 percent. At the locations, where the cutoff is shallow and only partially penetrates the sand layer (Station 353+00), the reduction would be approximately 40 percent.

Step 8

To verify and validate steady state seepage analyses described above, we have performed transient seepage analyses for Station 70+00. The purpose of these analyses was to better understand effects of seasonal groundwater table fluctuations on the estimated seepage quantities with and without the cutoff wall and more accurately model typical river conditions throughout the year. Time-dependent boundary conditions assigned to the riverside and the landside of the model as shown on Plate 16 and summarized in a tabular form on Plate 8 were used in these analyses. Seepage quantity computations were performed at 34 time steps, starting in February and ending a year later.

Transient seepage analyses results are presented on Plates 17 through 20. Existing seepage flow regime during typical winter and summer conditions is illustrated on Plates

17 and 18 respectively. Seepage conditions with the cutoff wall in place are shown on Plates 19 and 20. The plates show calculated seepage velocity vectors which illustrate the direction and the amount of flow - the larger the arrow, the higher the velocity and the larger the flow. A consistent scale was used on all four plates for easier visual comparison. The results indicate seepage occurs primarily through the permeable foundation sand layer and the existing sand levee. The flow is significantly higher during the elevated river stages (winter). Further, conditions may exist during the year when the river water surface is lower than the groundwater table. During these periods of time, the direction of the flow is reversed indicating seepage flow toward the river as illustrated on Plate 18.

Seepage quantities through the levee foundation with and without the cutoff wall as a function of time are presented on Plate 21. Positive seepage quantities indicate flow from the river landward of the levee while the negative sign indicates flow in the opposite direction. As shown on Plate 21, construction of the cutoff wall impedes flow in both direction and as a result may prevent flow into the river during the summer months.

Based on the transient seepage analyses, flow through the levee foundation at Station 70+00 without the wall is estimated at 5.6 acre-ft/year per 1,000 feet of the levee. Seepage through the levee foundation with the wall in place is approximately 1.7 acre-ft/year per 1,000 feet. Compared to the steady state analyses results for the same station, the transient seepage analyses indicate higher seepage quantities. For example, as shown in Table 4, steady-state seepage quantities estimated for Station 70+00 are 2.6 acre-ft/year per 1,000 feet for the existing conditions and approximately 0.4 acre-ft/year per 1,000 feet of the levee with the cutoff wall in place. The estimated reduction in flow due to the wall is comparable for both types of analyses. Based on the transient analysis, the seepage quantities would be reduced by about 70% compared to 85% estimated from the steady-state seepage analyses. Accordingly, we conclude the steady state seepage analyses conservatively approximate the effect of the cutoff walls.

Step 9

The overall effect of the cutoff wall construction can be estimated based on the information presented in Table 5.

Table 5
Estimated Seepage Quantities through Levee Foundation
Reaches 1 through 20

Reach	Stations	Representative Station	Stretch Length (ft)	Seepage without Cutoff Wall (ac-ft/yr)	Percent reduction based on cross section	Seepage with Cutoff Wall (ac-ft/yr)	Is Cutoff Wall Proposed at this Location?
1	00+00 to 48+00	27+00	4,800	19	0	19	N
2	48+00 to 100+00	70+00	5,200	14	85	2	Y
3	100+00 to 110+00	70+00	1,000	3	85	.4	Y
4a	110+00 to 120+00	70+00	1,000	3	0	3	N

Table 5 (Cont.)

Reach	Stations	Representative Station	Stretch Length (ft)	Seepage without Cutoff Wall (ac-ft/yr)	Percent reduction based on cross section	Seepage with Cutoff Wall (ac-ft/yr)	Is Cutoff Wall Proposed at this Location?
4a	120+00 to 190+00	353+00	7,000	95	0	95	N
4b	190+00 to 228+00	217+00	3,800	490	0	490	N
5a	228+00 to 263+00	70+00	3,500	10	0	10	N
5b	263+00 to 280+00	27+00	1,700	6	0	6	N
6	280+00 to 330+00	217+00	5,000	650	85	100	Y
7a	330+00 to 345+00	353+00	1,500	20	85	3	Y
7b	345+00 to 362+00	353+00	1,700	23	85	3	Y
8	362+00 to 402+00	353+00	4,000	55	85	8	Y
9	402+00 to 430+00	353+00	2,800	38		38	N
9	430+00 to 468+10	353+00	3,800	50	85	8	Y
10	468+10 to 495+00	217+00	2,690	350	40	210	Y
11	495+00 to 635+00	217+00	14,000	1810	0	1810	N
12	635+00 to 640+00	217+00	500	65	0	65	N
12	640+00 to 667+00	70+00	2,700	7	0	7	N
13	667+00 to 700+00	353+00	3,300	45	40	30	Y
14	700+00 to 732+00	70+00	3,200	8	0	8	N
15	732+00 to 780+00	217+00	4,800	620	40	375	Y
16	780+00 to 832+00	217+00	5,200	675	0	675	N
17	832+00 to 842+00	217+00	1,000	130	40	80	Y
18	842+00 to 857+00	217+00	1,500	195	40	120	Y
19a	857+00 to 875+00	217+00	1,800	235	40	140	Y
19b	875+00 to 925+00	70+00	5,000	15	40	8	Y
20a	925+00 to 925+50	27+00	50	.2	0	.2	N
20b	925+50 to 960+00	27+00	3,550	13	0	13	N
Total Seepage				**5,650**		**4,330**	

The results presented in Table 5 indicate the construction of cutoff walls could potentially reduce the groundwater aquifer recharge landward of the levee by approximately 20-25%. Seepage through the levee foundation without the wall is estimated at 5,650 acre-feet per year. Seepage with the SB cutoff wall in place is approximately 4,330 acre-feet per year. The resulting impact to the groundwater recharge is approximately 1,300 acre-feet per year. In our opinion, these results are likely conservative and represent the upper-bound estimate. The actual impact is likely lower, due to 3-D effects that cannot be assessed with the existing modeling.

Step 10

A new 2 mile long canal will be constructed along the east levee between Stations 200+00 and 305+00. This canal, shown in plan in Attachment C, will be located approximately 500 to 1,000 feet landward of the levee toe and will follow the existing levee alignment. In general, the canal will be filled with water during summer months and will be dry during the winter months (See Plate 7).

We have evaluated the impact of the canal operation on the groundwater conditions in the area. Transient analyses were performed to estimate seepage quantities from and into the canal at various times throughout the year. The analyses were performed for Station 70+00 with a cutoff wall in place. The canal cross-section was incorporated into the transient analysis model described in Step 8 above as a 8 feet deep and 10 feet wide ditch with 3H:1V side slopes positioned 1,000 ft landward of the levee. The canal was assumed to be filled with up to 5 feet of water from May through November and was allowed to seep in the winter, modeled as a free seepage discharge face. The canal operation was modeled as another time-dependent boundary condition applied, as shown on Plate 22. The canal will be excavated through the surficial clay blanket which consists primarily of CL with some CH and ML soils with percent fines between 50 and 70 percent. The permeability of this layer is estimated at 10^{-5} cm/sec. This permeability was assigned to the surface layer to represent base-case conditions. The clay blanket thickness varies across the site and excavation of the canal may result in a complete removal of the surficial clay at some locations. To account for variability in subsurface conditions and the possibility of a complete removal of the clay blanket, we have conducted a sensitivity analysis with permeability of the surface layer increased by one order of magnitude (10^{-4} cm/sec). The results of this analysis provide an upper bound estimate of seepage losses from the canal.

Seepage quantities were calculated using a flux line placed along the perimeter of canal cross-section. Positive and negative quantities indicate flow from and into the ditch, respectively. The estimated seepage quantities as a function of time are shown on Plate 23. Based on the results of the transient analyses, seepage loss is estimated at 1.4 acre-t/year per 1,000 feet of the canal for base-case conditions. Only positive flow (flow from the canal) was considered in these computations. Seepage loss over the entire length of the canal is estimated at 15 acre-ft per year. The upper bound estimate is approximately 90 acre-ft per year.

We have also evaluated the combined impact of the cutoff wall construction and the canal operation on the groundwater table in the vicinity of the levee. This evaluation was performed based on the results of transient seepage analysis described in Steps 8 and 10. Seepage quantities as a function of time are shown graphically on Plate 24. Positive and negative quantities indicate flow from and into the river, respectively. Seepage quantities were calculated using a flux line placed immediately landside of the cutoff wall. In addition, groundwater table elevation was estimated as a function of time at the location halfway between the existing levee and the proposed canal. The results, provided on Plate 25, indicate minimal impact of the canal during winter months. However, during summer months groundwater table elevation in the immediate vicinity of the proposed wall locations could increase by as much as 3 feet. This increase is likely due to the combined effect of the cutoff wall preventing backflow into the river and the additional inflow from the canal.

Conclusions

The key findings and conclusions presented in this memorandum are as follows:

- Under the existing conditions seepage from the Sacramento River through the levee foundation along Sacramento River East Levee between Stations 00+00 and 960+00 is estimated to be about 5,650 acre-ft/year.
- At the proposed wall locations seepage flow could be reduced locally by up 85 percent, depending on stratigraphy and proposed wall depth.
- The overall impact of the proposed cutoff walls is estimated at approximately 1,300 acre-ft/year (20 percent reduction of the total recharge rate)
- The cutoff wall could impede seepage flow towards the river in the summer months when the river level is low.
- Construction of an irrigation canal may increase aquifer recharge by approximately 15 to 90 acre-ft per year.
- Construction of the cutoff wall and the canal may locally increase the groundwater levels up to 3 feet in the summer months.

Due to the limitations of the model, the analyses can only provide an order-of-magnitude estimate of the seepage quantities. Additional analyses with a three-dimensional model such as MODFLOW are recommended to properly characterize groundwater flow regime in the area account for 3-Dimensional effects and quantify the impact of the proposed SB cutoff wall on the aquifer recharge.

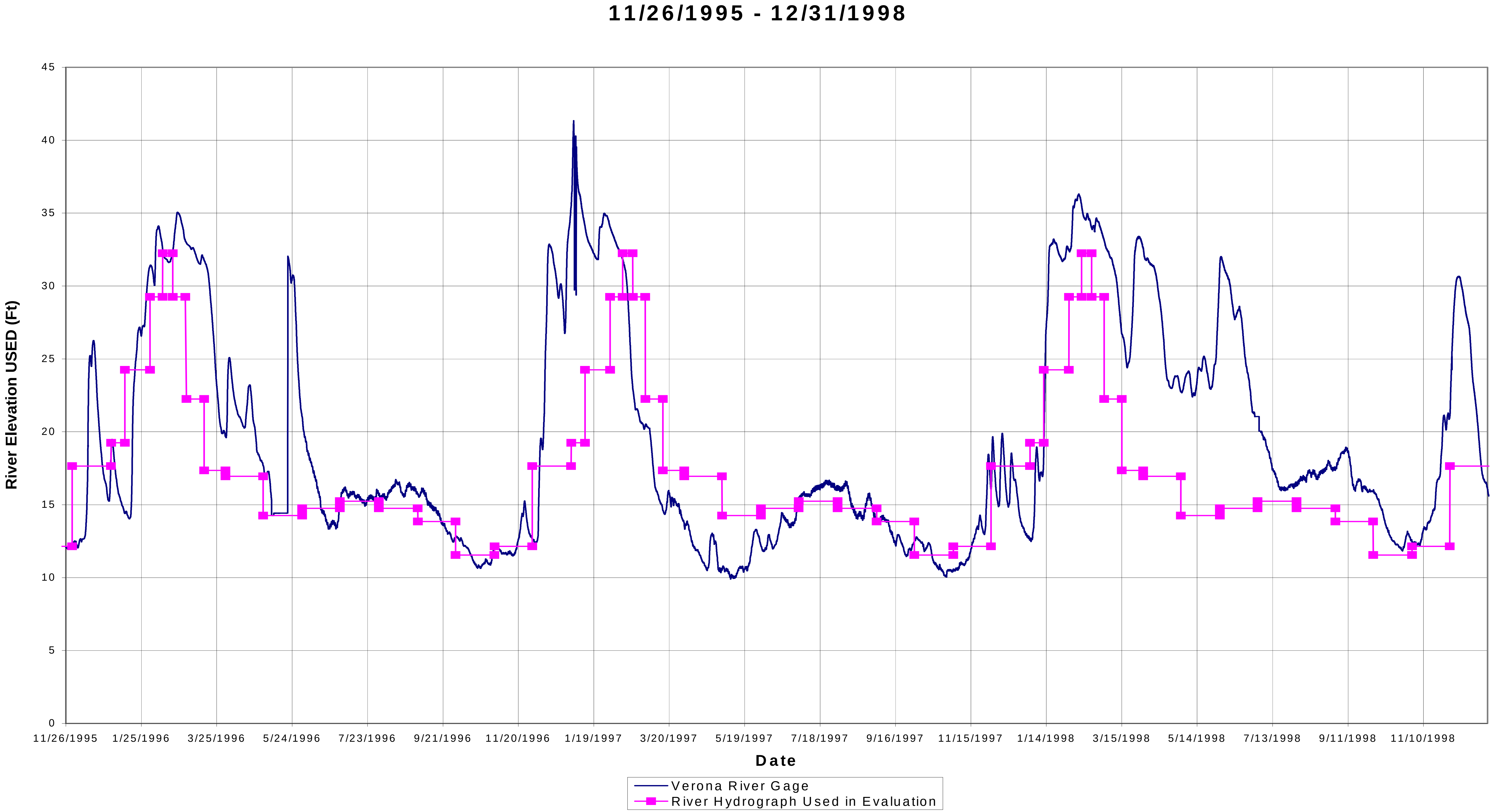
If you have questions regarding this design or require additional information, please contact either Elena Sossenkina at (303) 237-6601 or the undersigned.

Sincerely,

KLEINFELDER WEST, INC.

Keith A. Ferguson, PE
Principal Engineer

PLATES



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Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

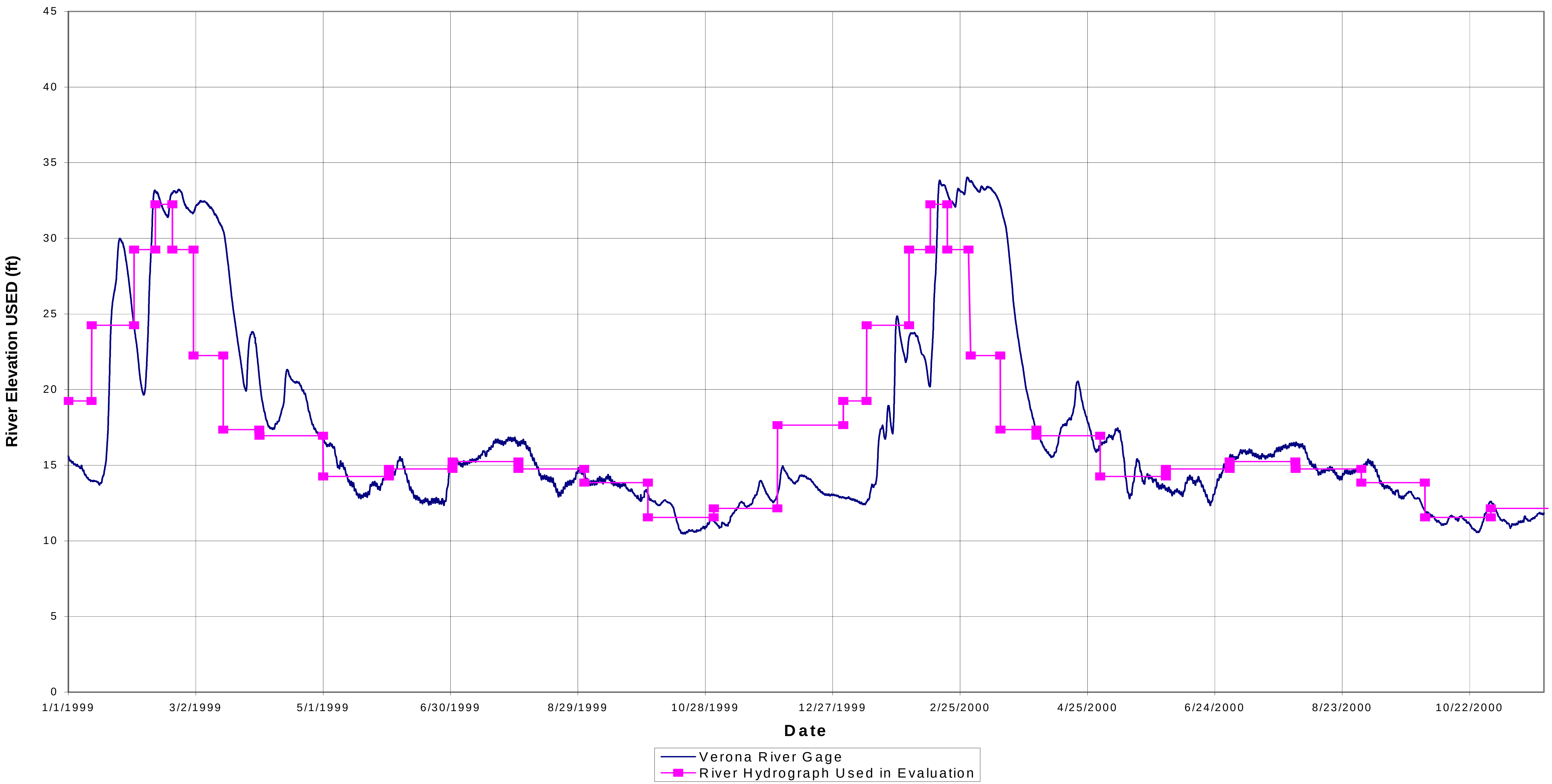
PLATE 1

Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 1995-2000 Hydrograph Data 03-23-09.xls

Ref: http://cdec.water.ca.gov/queryStation.html

01/01/1999 - 11/26/2000



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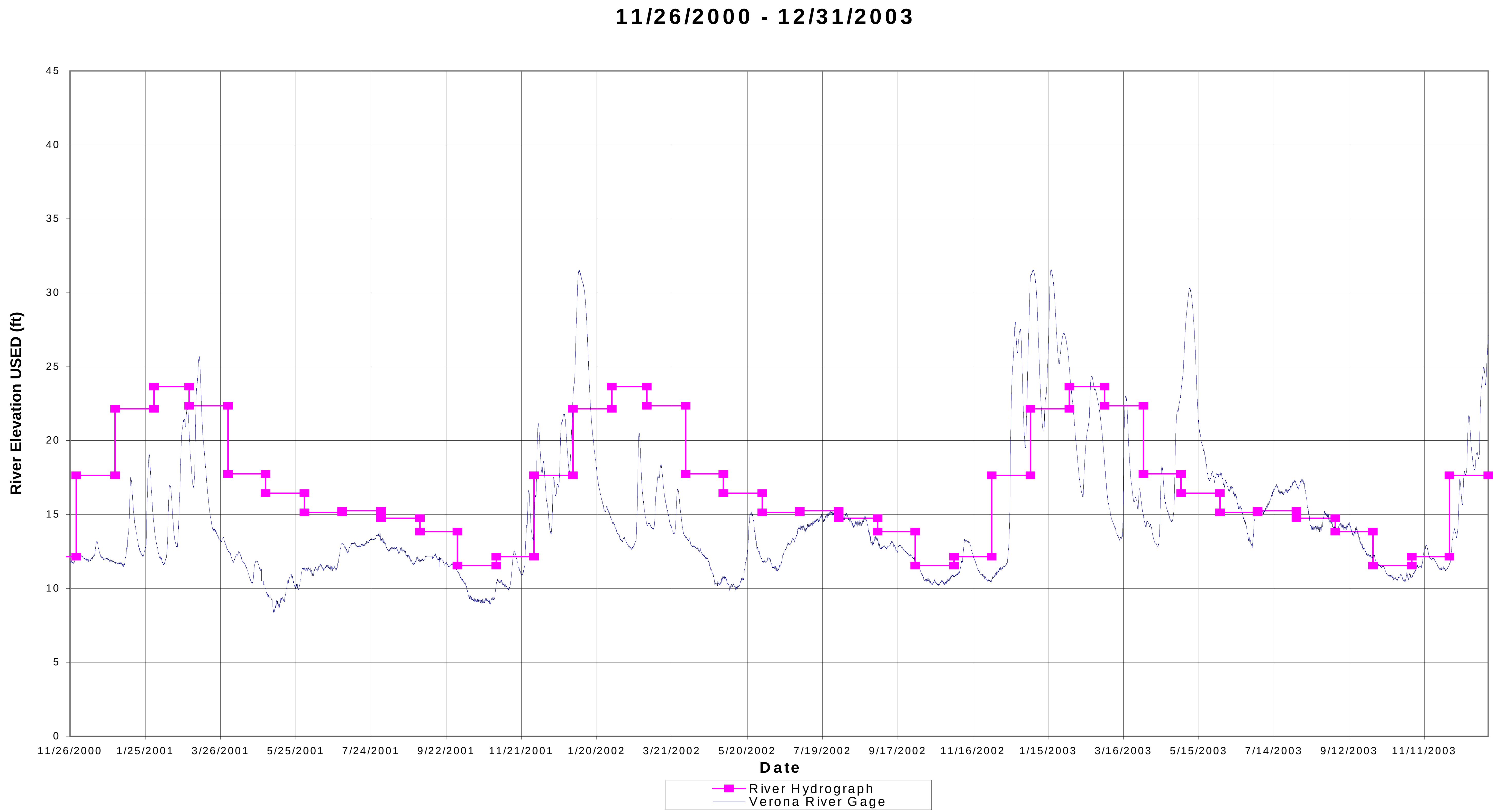
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 1995-2000 Hydrograph Data 03-23-09.xls

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 2

Ref: http://cdec.water.ca.gov/queryStation.html



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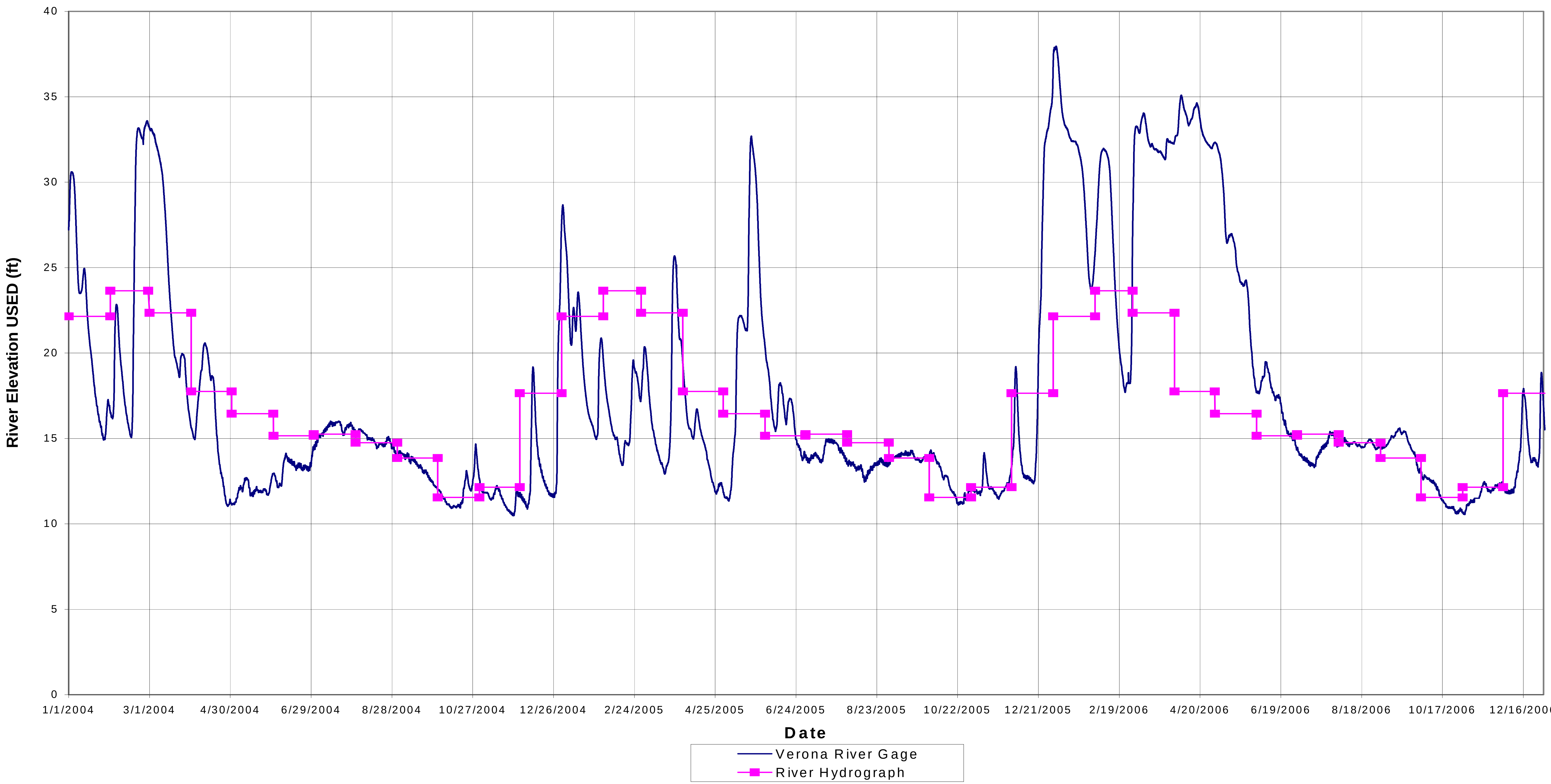
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 00-07 Hydrograph Data 03-2309.xls	Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 3

Ref: http://cdec.water.ca.gov/queryStation.html

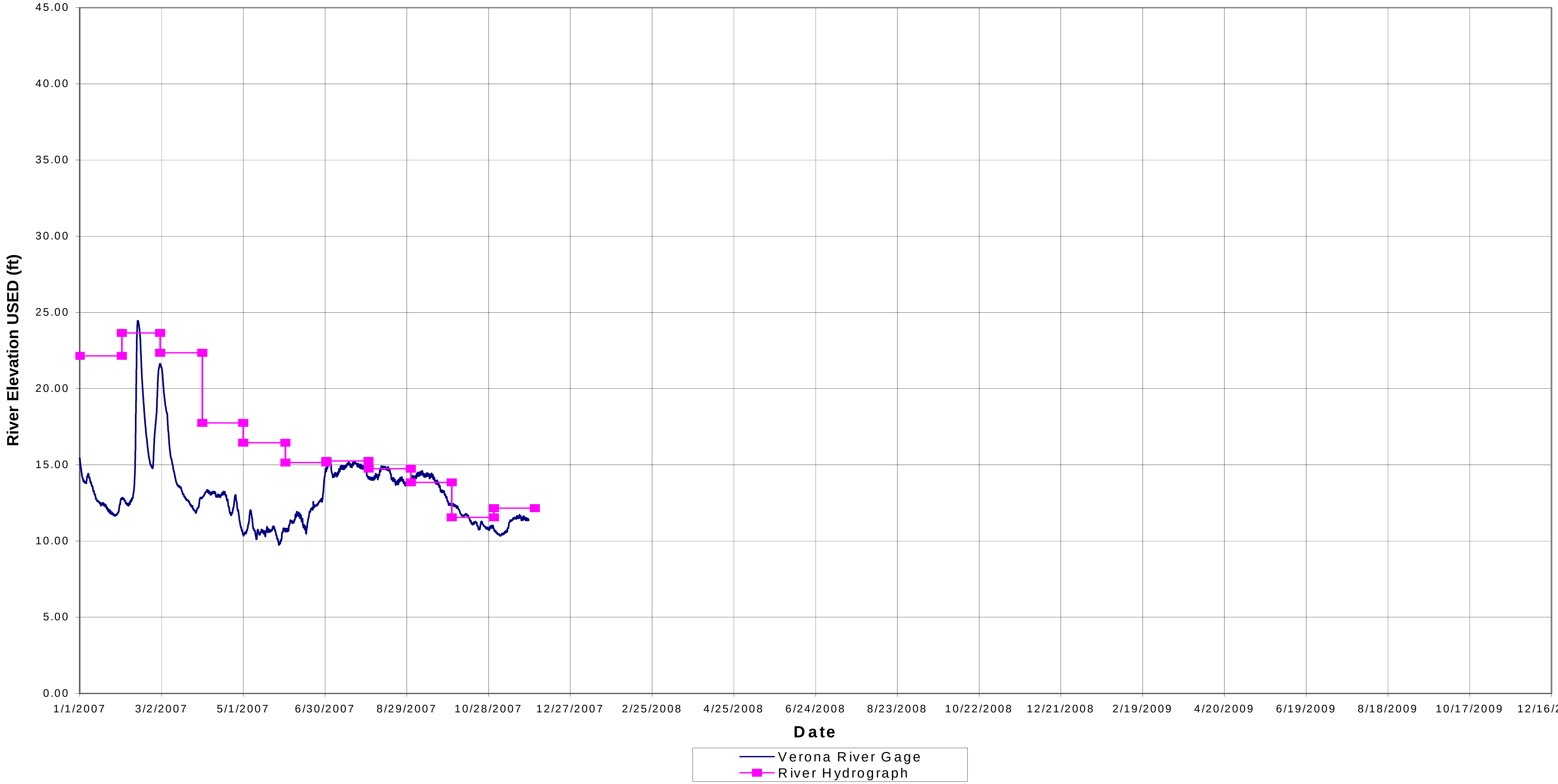
01/01/2004 - 12/31/2006



KLEINFELDER Bright People. Right Solutions.	Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 4
Graphics by: ESS Project No. 72834	Date: 04/21/09 File:00-07 Hydrograph Data 03-2309.xls	

Ref: http://cdec.water.ca.gov/queryStation.html

01/01/2007 - 11/26/2007



KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 5
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 00-07 Hydrograph Data 03-2309.xls		

Ref: http://cdec.water.ca.gov/queryStation.html

Sacramento River Elevation in Ft

Elevation	% of days per year river at given El.	Days per year river at El.	Elevation	% of days per year river at given El.	Days per year river at El.
8	0.0	0	25	1.2	4
9	0.5	2	26	0.8	3
10	1.2	4	27	1.0	4
11	8.2	30	28	0.8	3
12	12.4	45	29	0.7	3
13	12.3	45	30	0.8	3
14	12.5	45	31	1.2	4
15	11	40	32	2.6	10
16	7.8	29	33	2.9	10
17	5.4	20	34	1.4	5
18	3.5	13	35	0.8	3
19	2.3	8	36	0.2	1
20	1.8	7	37	0.1	0.4
21	1.9	7	38	0.1	0.4
22	1.5	6	39	0.0	0
23	1.4	5	40	0.0	0
24	1.7	6	41	0.0	0

Notes:

1. Historical river elevations in Plates 1-5 are reported in the USED datum. Elevations reported above are using NAVD88 datum. Satistics are based on data from the Verona River Gage obtained from http://cdec.water.ca.gov/queryStation.html from the period 11/26/1995-11/26/2007.
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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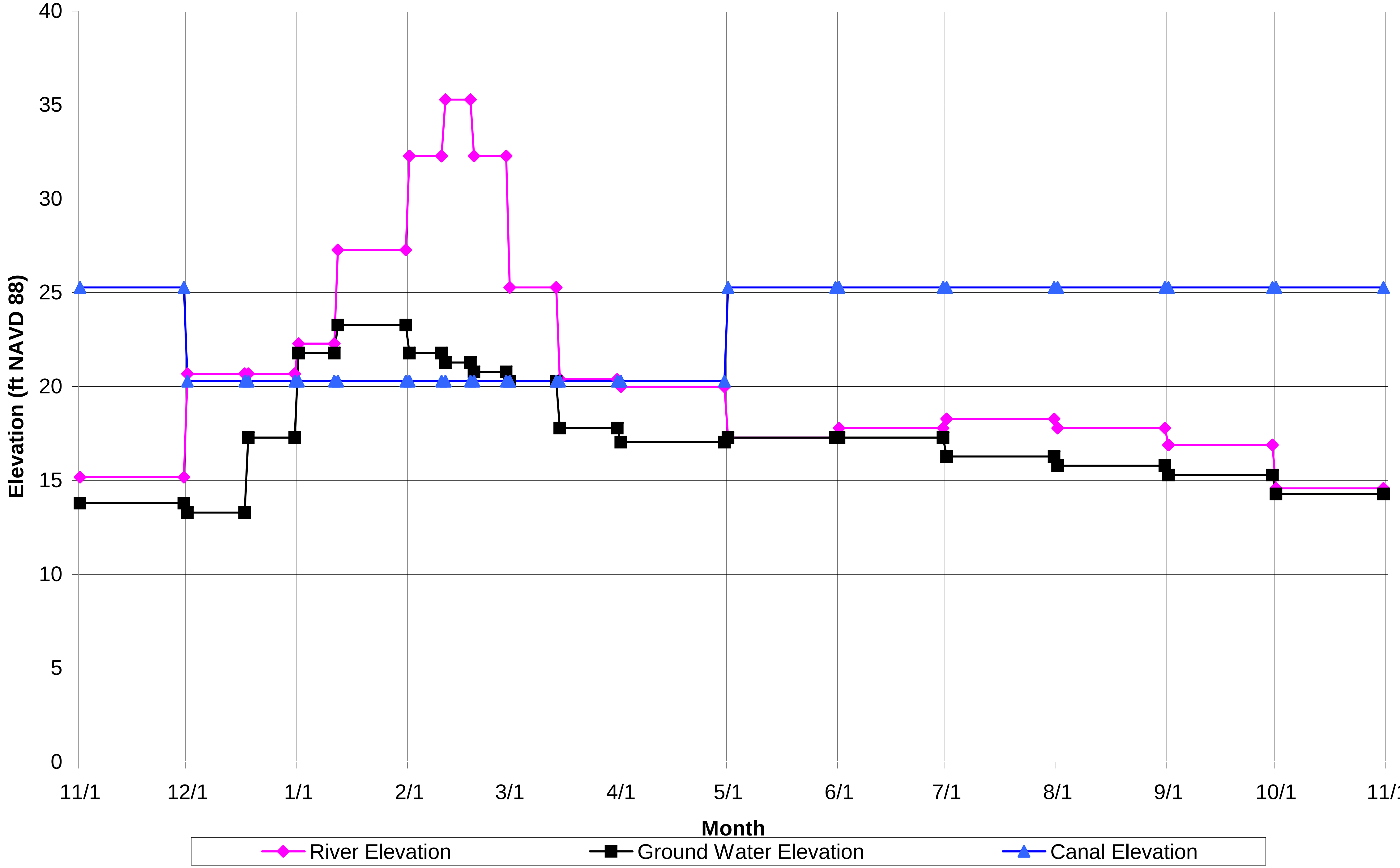
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: SacRiverCutoffWall Eval_04-07-09.ppt

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 6

Groundwater, River, and Canal Hydrographs



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: TransientTimeStep Elevs_03-20-09

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 7

Transient Time Step Table

Time Step	Date	River Elevation	Ground Water Elevation	Canal Elevation
1	2/11	35.25	21.25	20.25
2	2/18	35.25	21.25	20.25
3	2/19	32.25	20.75	20.25
4	2/28	32.25	20.75	20.25
5	3/1	25.25	20.25	20.25
6	3/14	25.25	20.25	20.25
7	3/15	20.35	17.75	20.25
8	3/31	20.35	17.75	20.25
9	4/1	19.95	17.00	20.25
10	4/30	19.95	17.00	20.25
11	5/1	17.25	17.25	25.25
12	5/31	17.25	17.25	25.25
13	6/1	17.75	17.25	25.25
14	6/30	17.75	17.25	25.25
15	7/1	18.25	16.25	25.25
16	7/31	18.25	16.25	25.25
17	8/1	17.75	15.75	25.25

Time Step	Date	River Elevation	Ground Water Elevation	Canal Elevation
18	8/31	17.75	15.75	25.25
19	9/1	16.85	15.25	25.25
20	9/30	16.85	15.25	25.25
21	10/1	14.55	14.25	25.25
22	10/31	14.55	14.25	25.25
23	11/1	15.15	13.75	25.25
24	11/30	15.15	13.75	25.25
25	12/1	20.65	13.25	20.25
26	12/17	20.65	13.25	20.25
27	12/18	20.65	17.25	20.25
28	12/31	20.65	17.25	20.25
29	1/1	22.25	21.75	20.25
30	1/11	22.25	21.75	20.25
31	1/12	27.25	23.25	20.25
32	1/31	27.25	23.25	20.25
33	2/1	32.25	21.75	20.25
34	2/10	32.25	21.75	20.25

Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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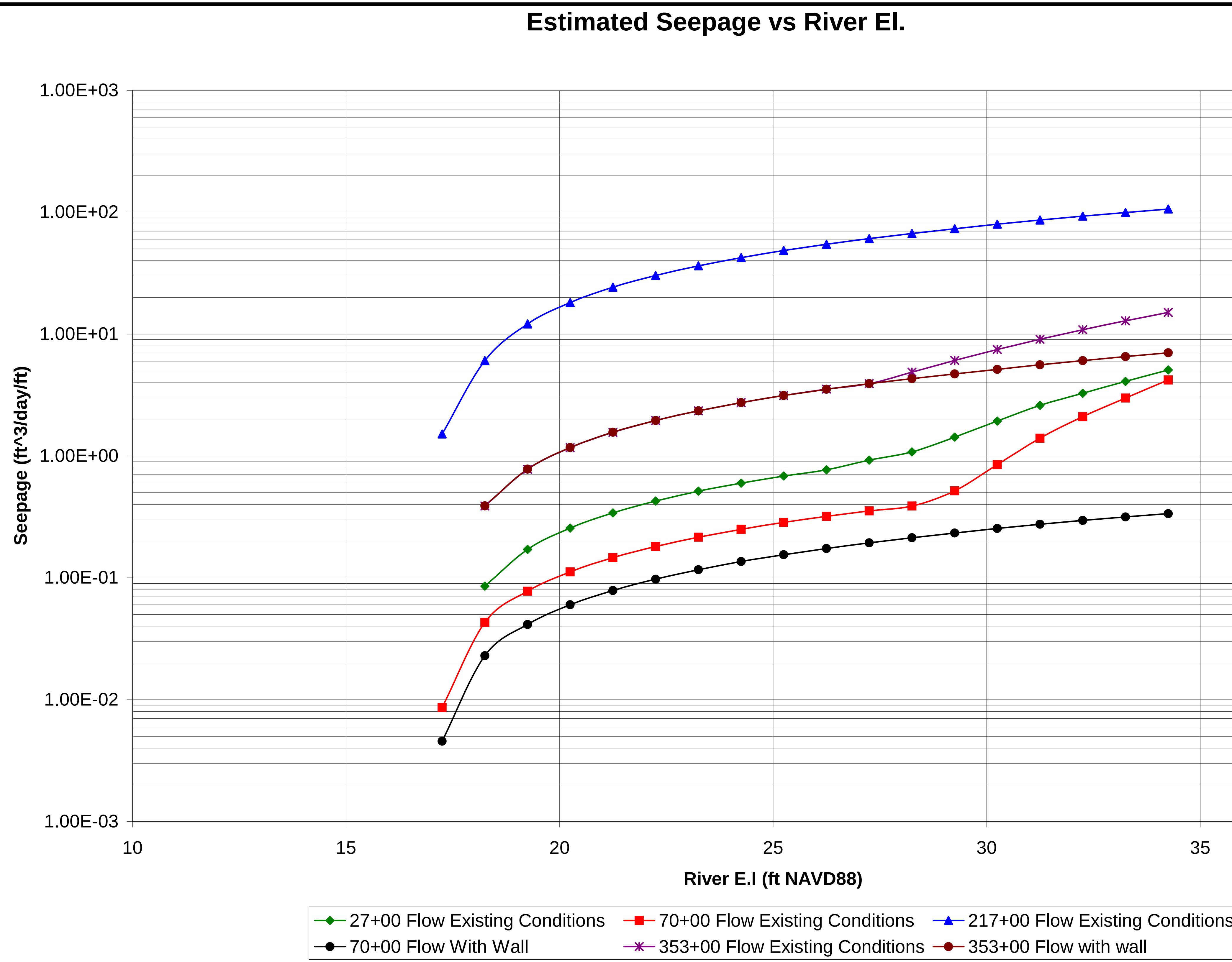
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: TransientTimeStep Elevs_03-23-09.xls

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 8



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 00-07 Hydrograph Data 03-23-09.xls

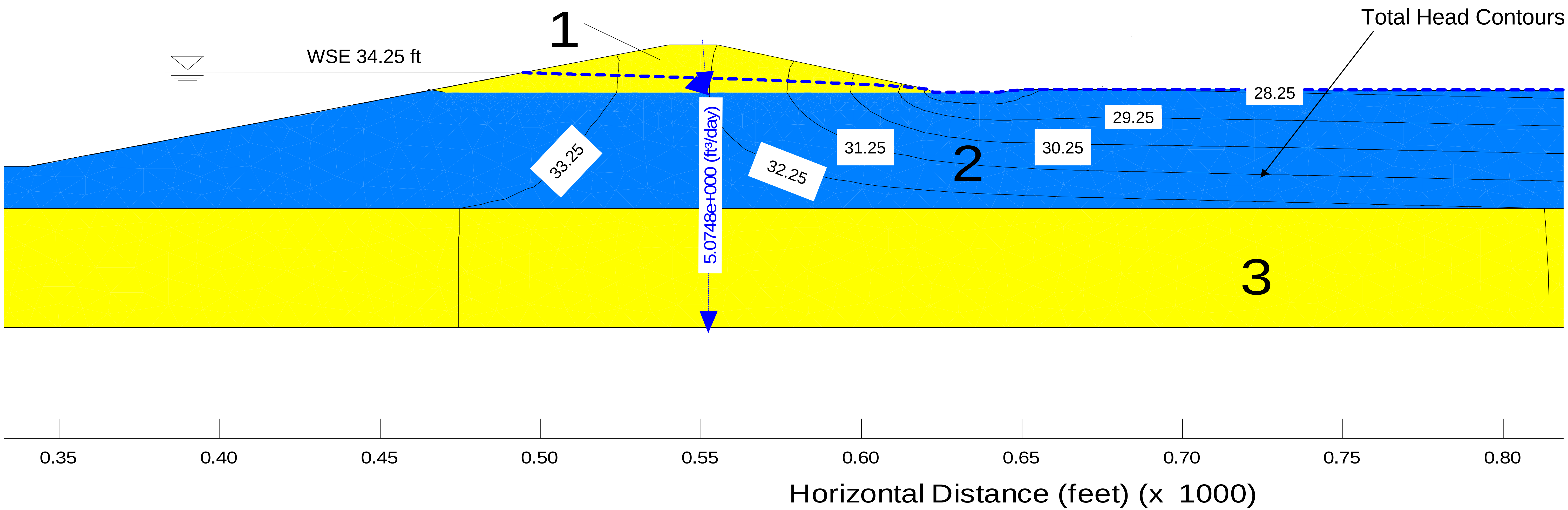
Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 9

STA 27+00, steady-state analysis, existing conditions
Total Flow: 3.9 acre ft/yr/1000 ft

Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 7 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 5 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 7 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 27+00_Plate10

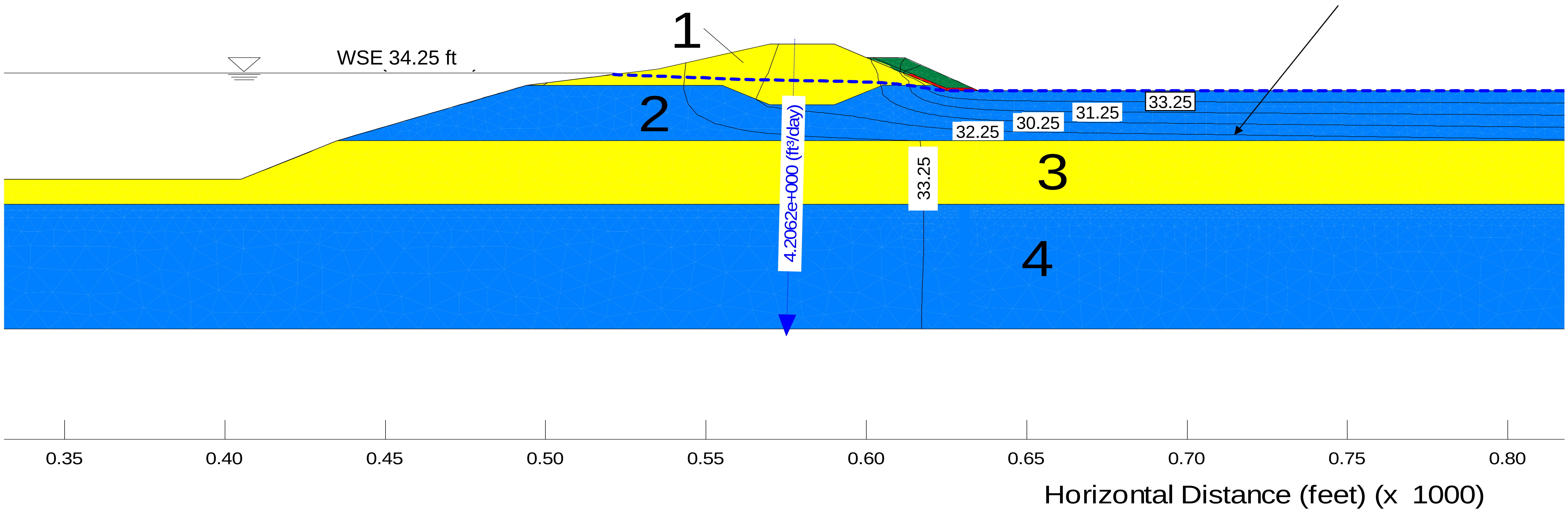
Evaluation of Cutoff Wall Impact
on Groundwater Recharge
Sacramento River East Levee

PLATE
10

STA 70+00, steady-state analysis, existing conditions
Total Flow: 2.6 acre ft/yr/1000 ft

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

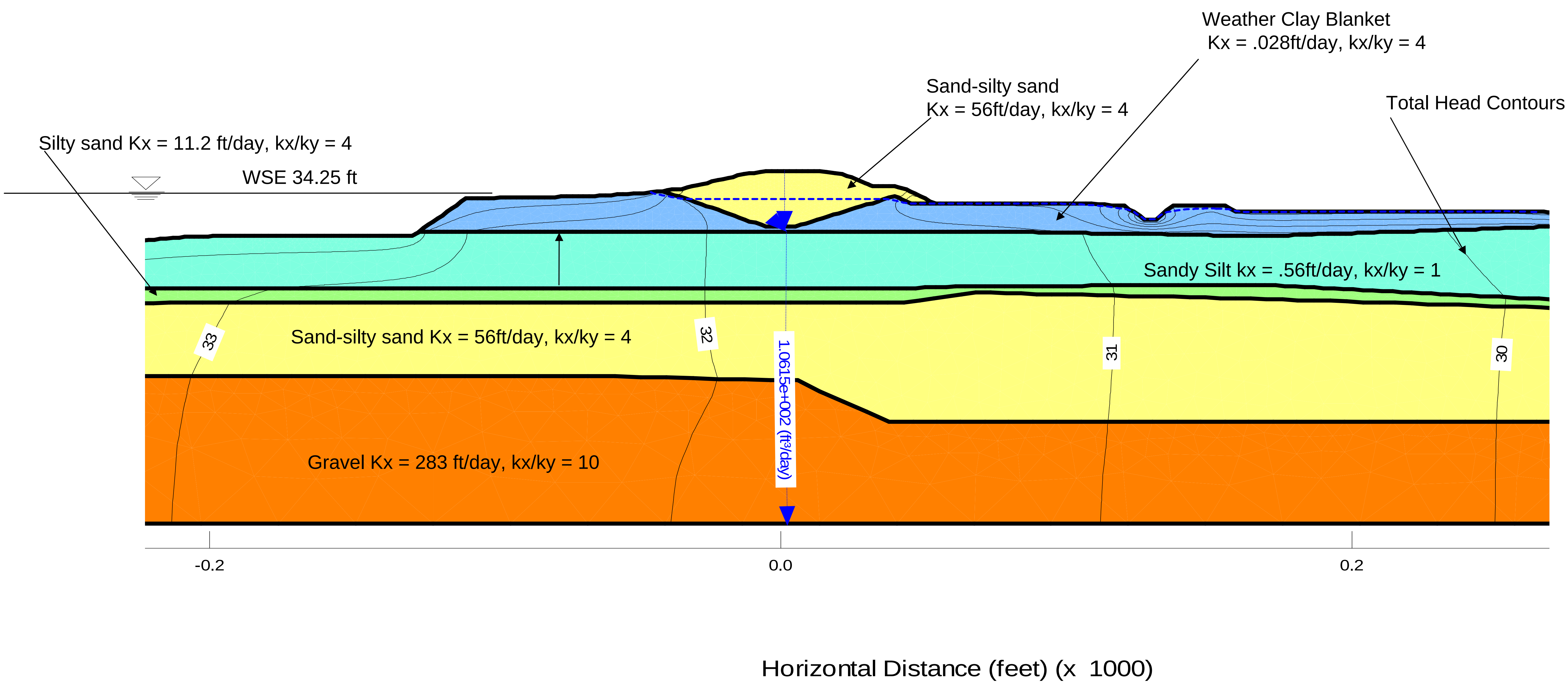
Material #1 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 11
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 70+00_Plate11		

STA 217+00, steady-state analysis, existing conditions
Total Flow: 129 acre ft/yr/1000 ft
Ref: URS model 217+00 from Sac Levees report 2007



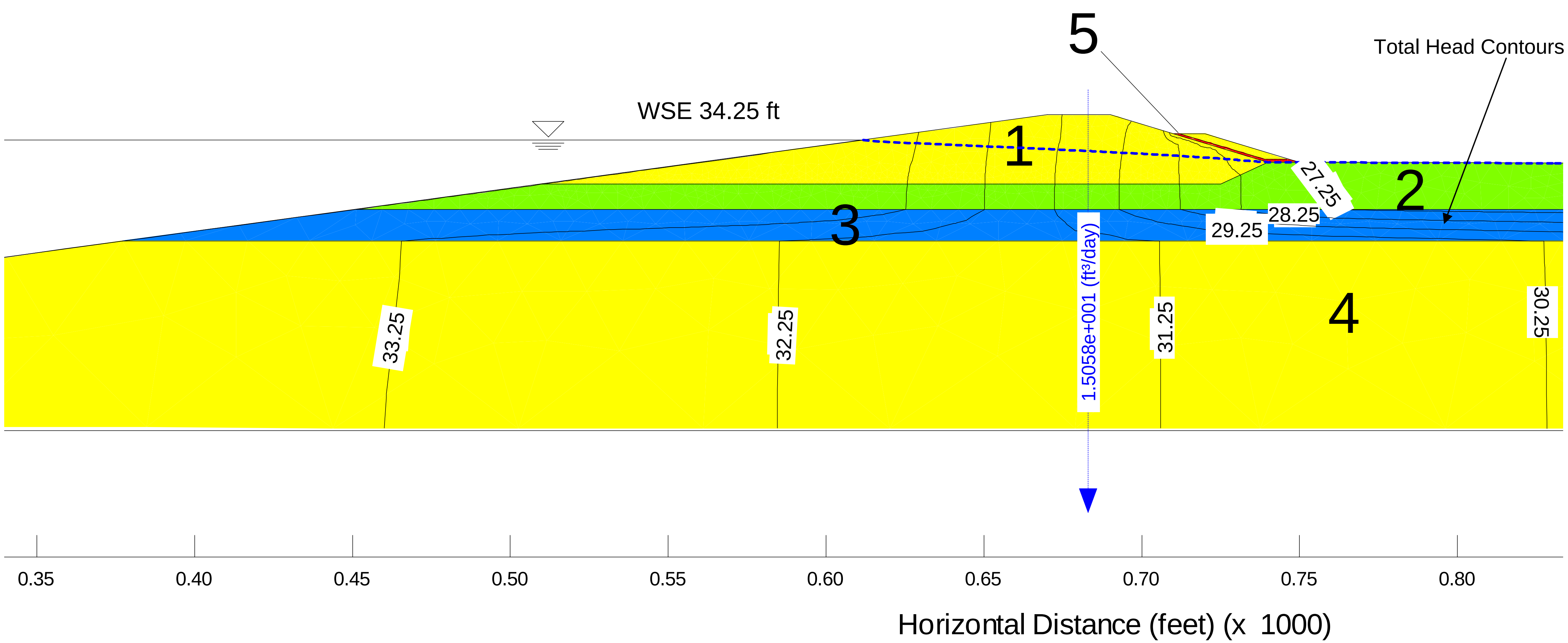
Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 12
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 217+00_Plate12		

STA 353+00, steady-state analysis, existing conditions
Total Flow: 13.4 acre ft/yr/1000 ft

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 9 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 7 Silt Ks=0.56 ft/day (2x10E-4 cm/s) Ky/Kx Ratio: 1
Material #3 Hyd K Fn: 5 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #4 Hyd K Fn: 9 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #5 Hyd K Fn: 8 Drainage Rock Ks=2800 ft/day (10 cm/s) Ky/Kx Ratio: 1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 353+00_Plate13

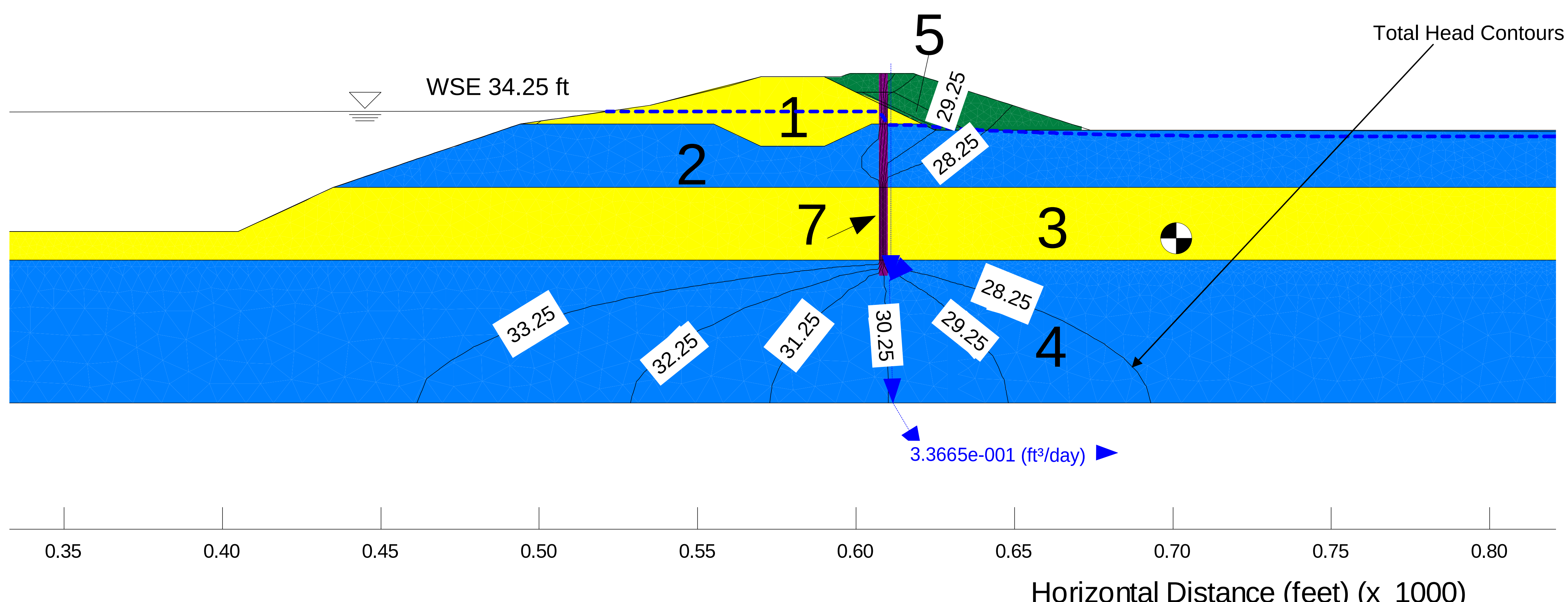
Evaluation of Cutoff Wall Impact
on Groundwater Recharge
Sacramento River East Levee

PLATE
13

STA 70+00, steady-state analysis, adjacent levee, with wall
Total Flow: 0.4 acre ft/yr/1000 ft

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 10 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 7 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 10 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: 7 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #5 Hyd K Fn: 8 Silt Ks= 0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #7 Hyd K Fn: 11 Cutoff wall Ks = 0.0028ft/day (1.0x10-6 cm/sec) Ky/Kx Ratio: 1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

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Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 70+00_Plate14

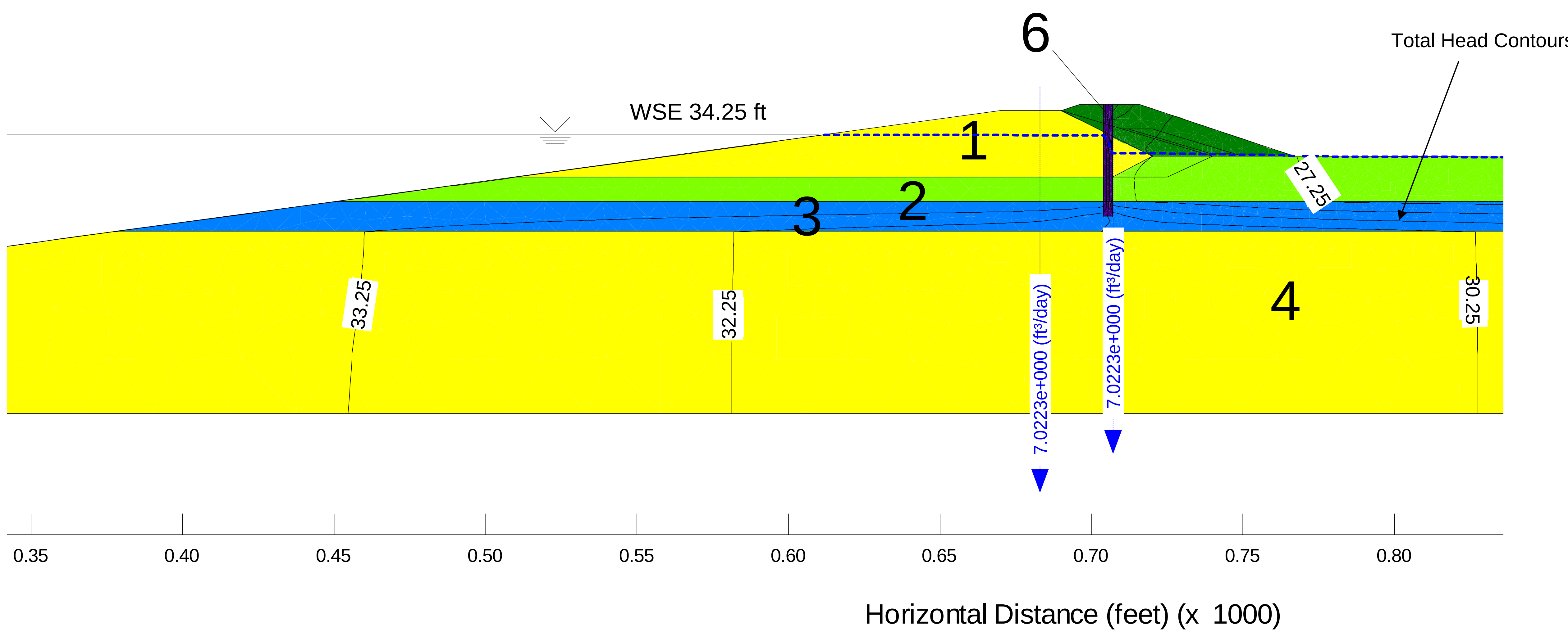
Evaluation of Cutoff Wall Impact
on Groundwater Recharge
Sacramento River East Levee

PLATE
14

STA 353+00, steady-state analysis, adjacent levee, with wall
Total Flow: 8.4 acre ft/yr/1000 ft

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

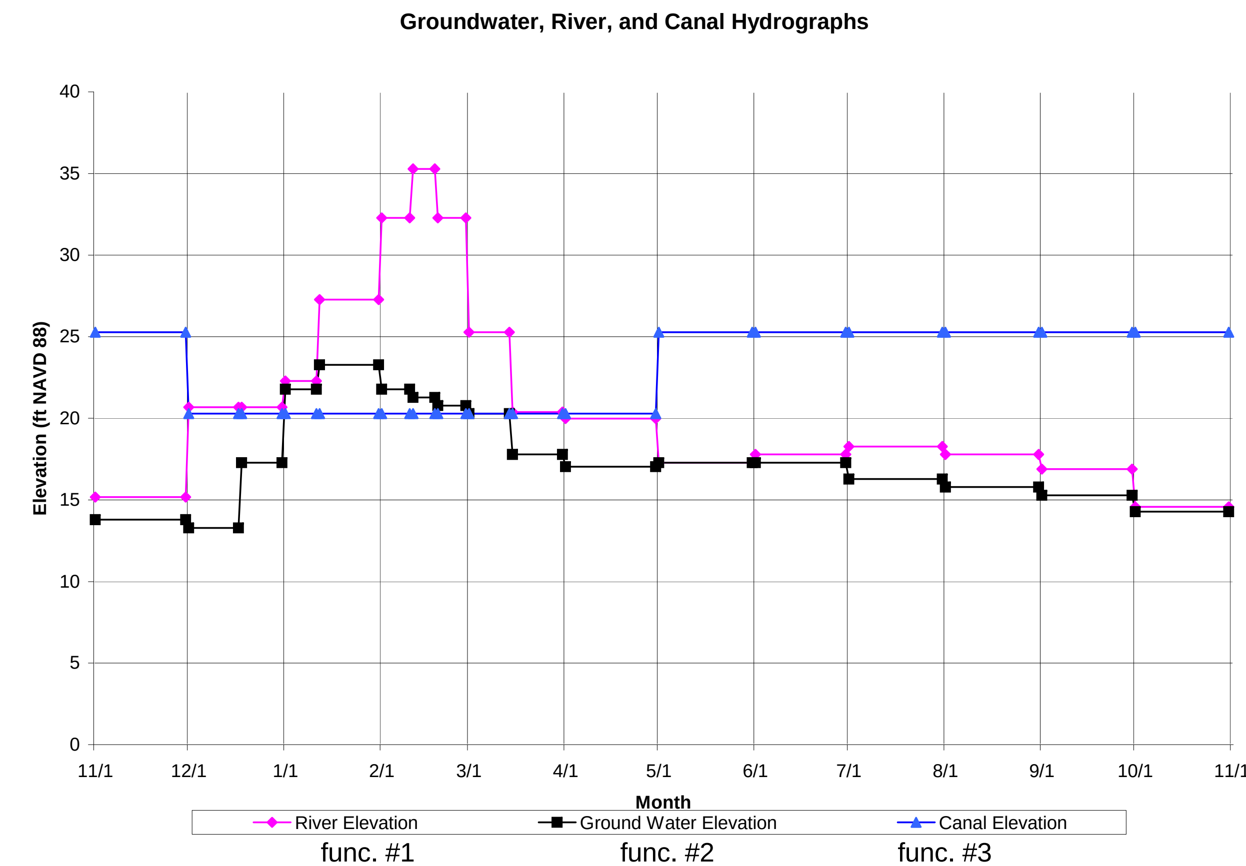
Material #1 Hyd K Fn: 9 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 7 Silt Ks=0.56 ft/day (2x10E-4 cm/s) Ky/Kx Ratio: 1
Material #3 Hyd K Fn: 5 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #4 Hyd K Fn: 9 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #6 Hyd K Fn: 10 Cutoff wall Ks = 0.0028 ft/day (1.0x10-6 cm/sec) Ky/Kx Ratio: 1

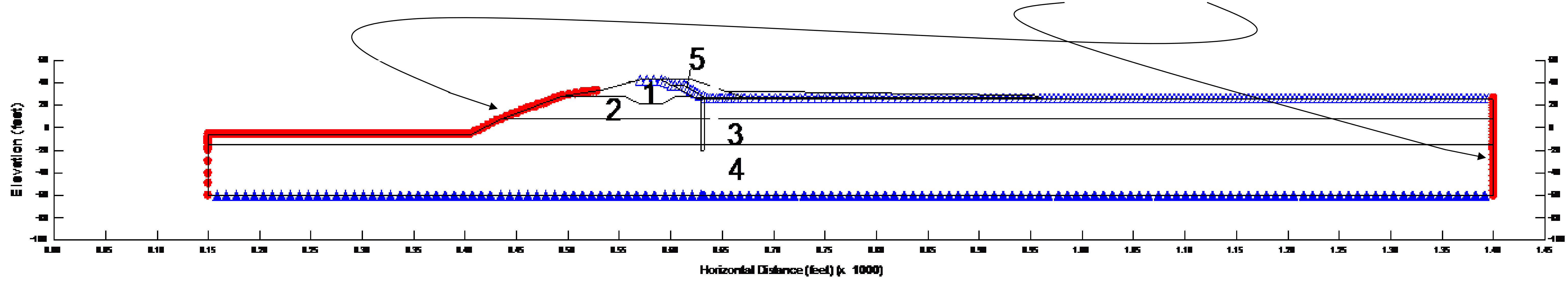


Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 15
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 353+00_Plate15		

STA 70+00, boundary conditions
Transient analysis, existing conditions





Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: 70+00_Plate16_BC

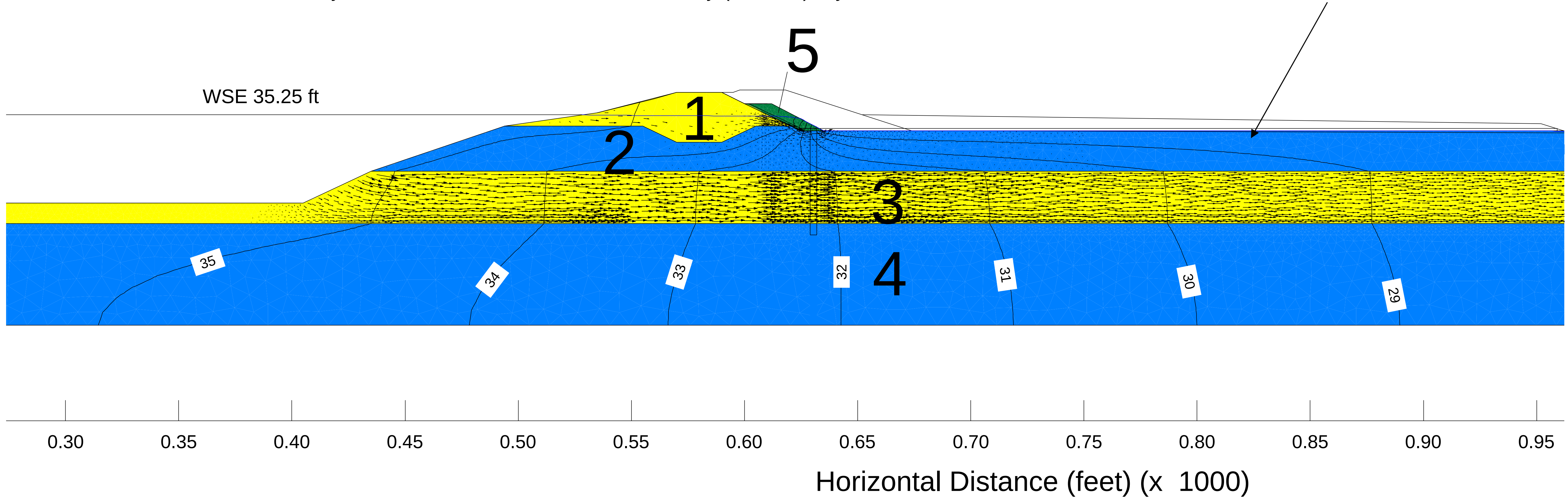
Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 16

STA 70+00, transient analysis, existing conditions
Time Step: 2 (Winter)

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #5 Hyd K Fn: 19 Silt Ks= 0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #6 Hyd K Fn: 17 Drain Rock, Ks = 2800 ft/day (10 cm/s) Ky/Kx Ratio: 1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

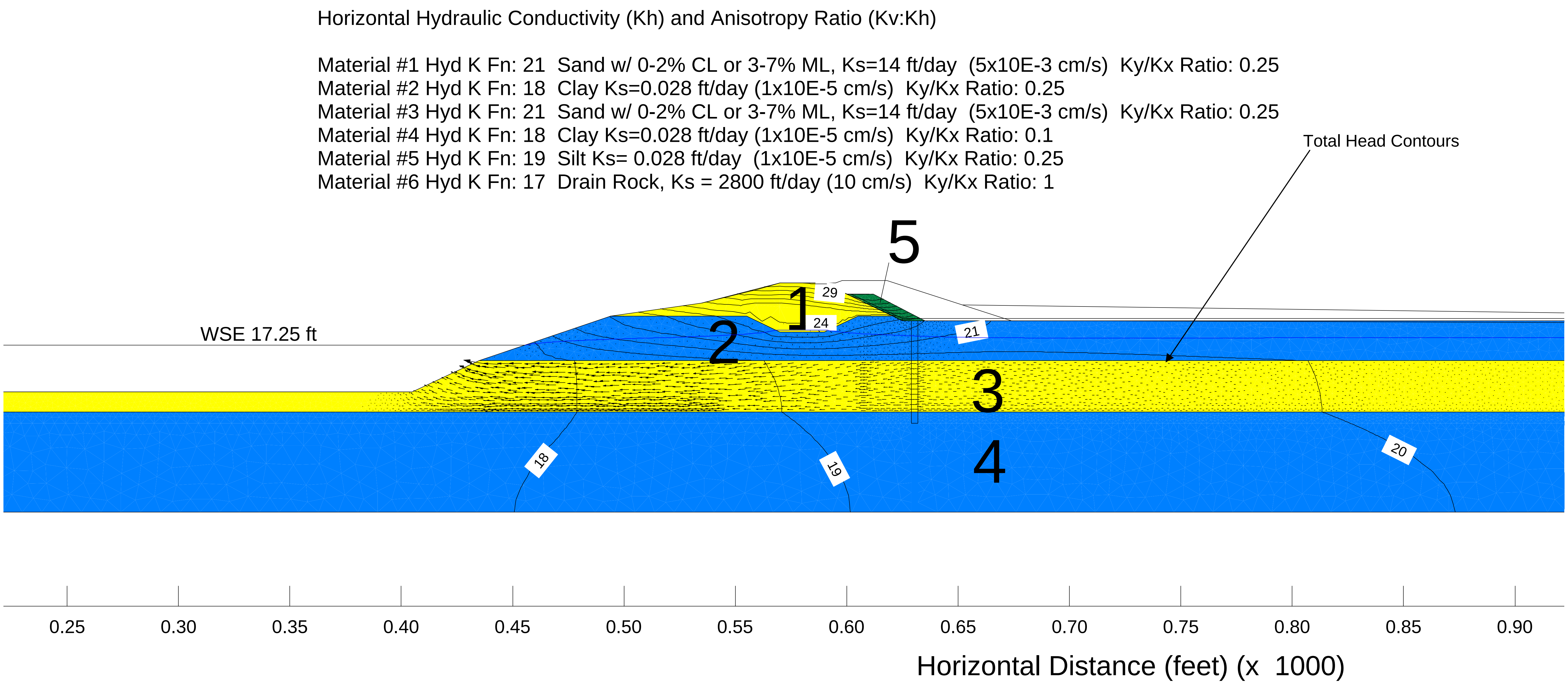
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: Tyler's adjusted run_ NAVD88

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

PLATE 17

STA 70+00, transient analysis, existing conditions
Time Step: 11 (Summer)



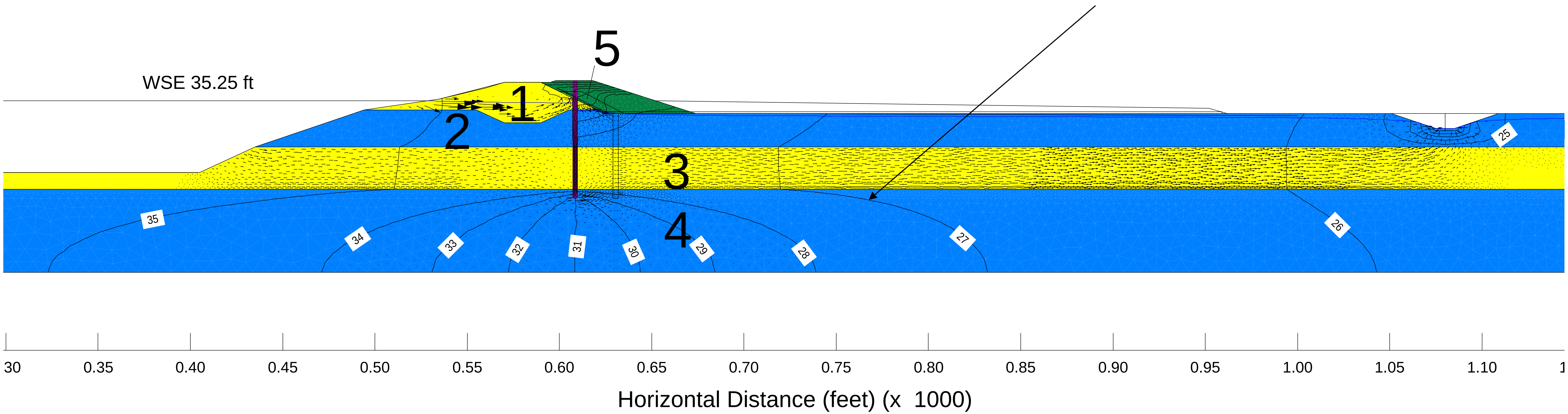
Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 18
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: Tyler's adjusted run_ NAVD88		

STA 70+00, transient analysis with cutoff wall
Time Step: 2 (Winter)

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #5 Hyd K Fn: 19 Silt Ks= 0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #6 Hyd K Fn: 17 Drain Rock, Ks = 2800 ft/day (10 cm/s) Ky/Kx Ratio: 1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: Tyler's Original NAVD88
Transient with canal

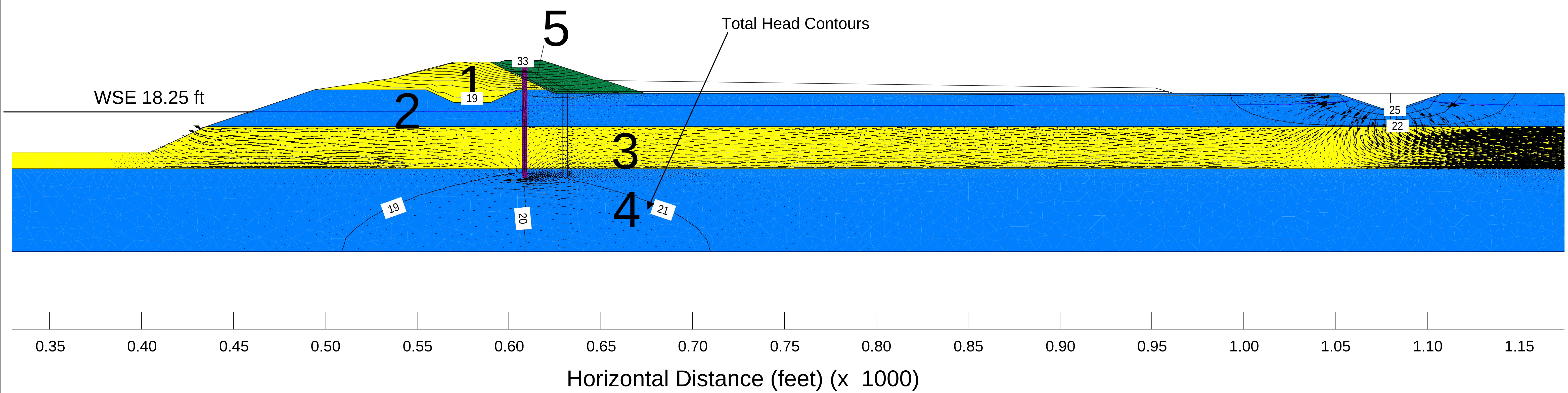
Evaluation of Cutoff Wall Impact
on Groundwater Recharge
Sacramento River East Levee

PLATE
19

STA 70+00, transient analysis with cutoff wall
Time Step: 16 (Summer)

Horizontal Hydraulic Conductivity (Kh) and Anisotropy Ratio (Kv:Kh)

Material #1 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #2 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #3 Hyd K Fn: 21 Sand w/ 0-2% CL or 3-7% ML, Ks=14 ft/day (5x10E-3 cm/s) Ky/Kx Ratio: 0.25
Material #4 Hyd K Fn: 18 Clay Ks=0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.1
Material #5 Hyd K Fn: 19 Silt Ks= 0.028 ft/day (1x10E-5 cm/s) Ky/Kx Ratio: 0.25
Material #6 Hyd K Fn: 17 Drain Rock, Ks = 2800 ft/day (10 cm/s) Ky/Kx Ratio: 1



Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

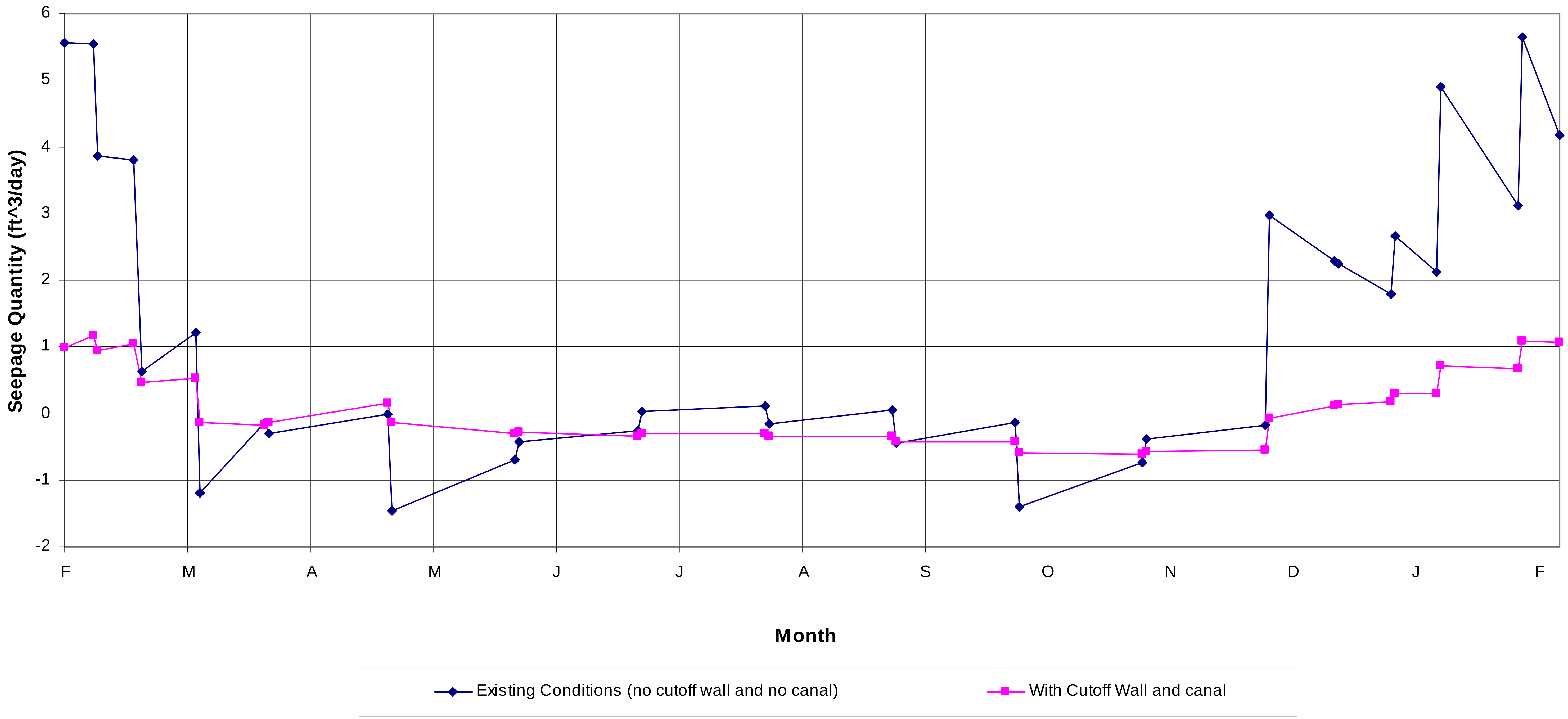
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: Tyler's Original NAVD88
Transient with canal

Evaluation of Cutoff Wall Impact
on Groundwater Recharge
Sacramento River East Levee

PLATE
20

Cutoff Wall Impact on Seepage Quantities

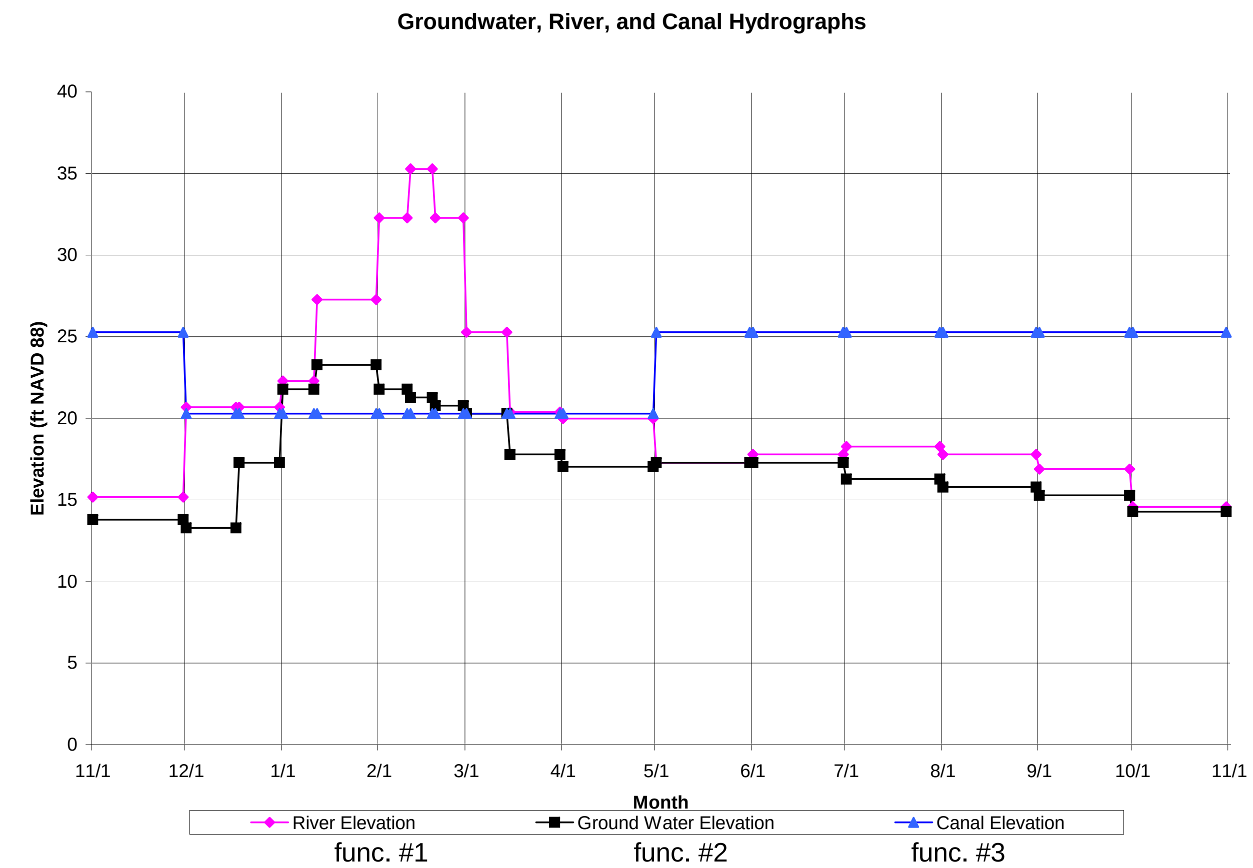


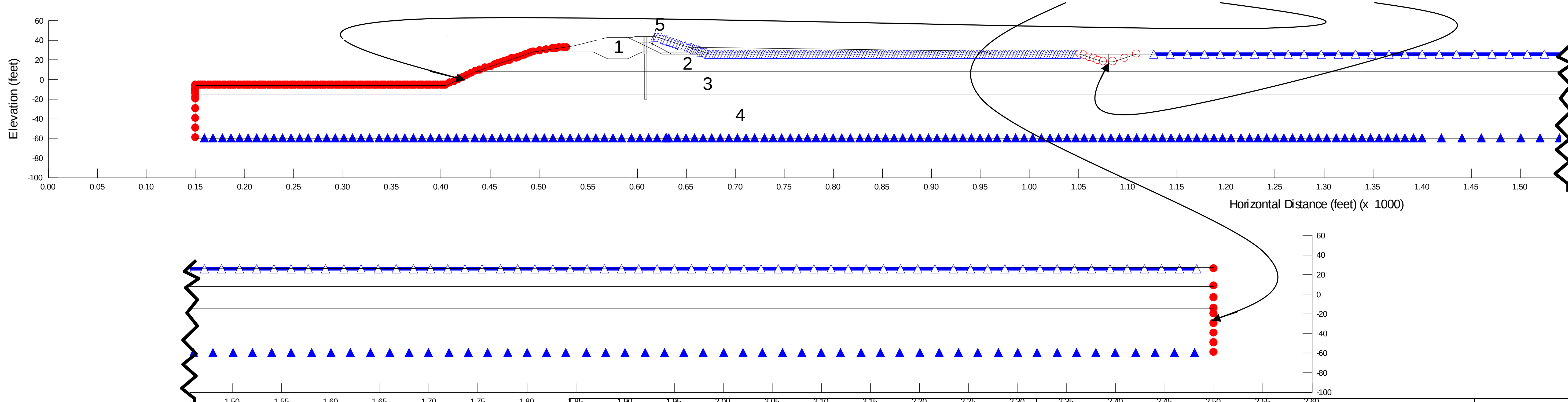
Notes:
1. Seepage quantities were calculated using a flux line placed approximately 40 feet from the landside of the cutoff wall. Positive and negative quantities indicate flow from and into the river, respectively.
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

Graphics by: ESS Project No. 72834	Date: 04/21/09 File: plate 21	Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 21

STA 70+00, boundary conditions, Transient analysis with cutoff wall and canal



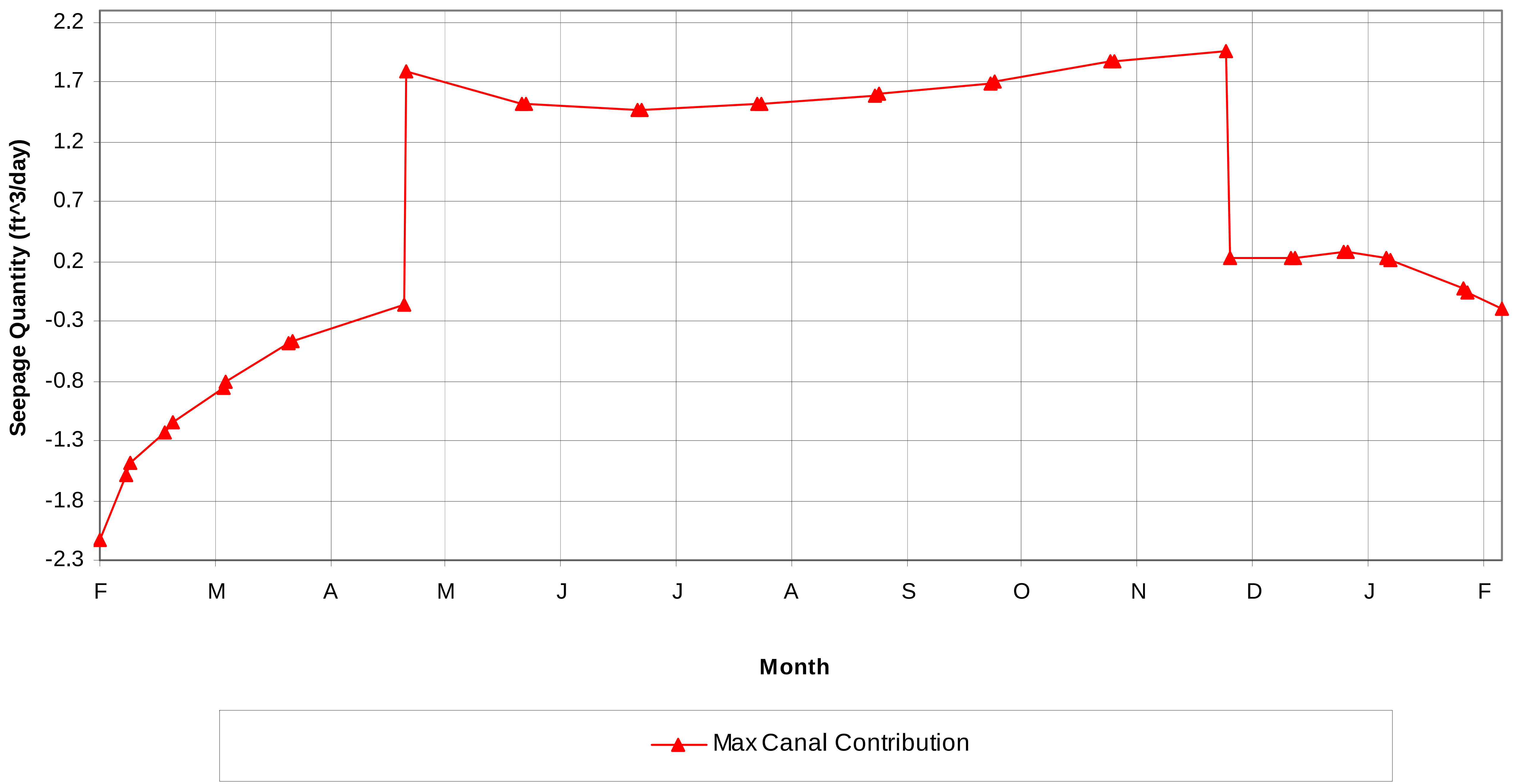


Note: Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

Graphics by: ESS Project No. 72834	Date: 04/21/09 File: 70+00-Plate22_BC	Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 22

Canal Contribution to Groundwater Recharge



Notes:

1. Seepage quantities were calculated using a flux line placed along the perimeter of the canal cross section. Positive and negative quantities indicate flow from and into the canal, respectively.
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER
Bright People. Right Solutions.

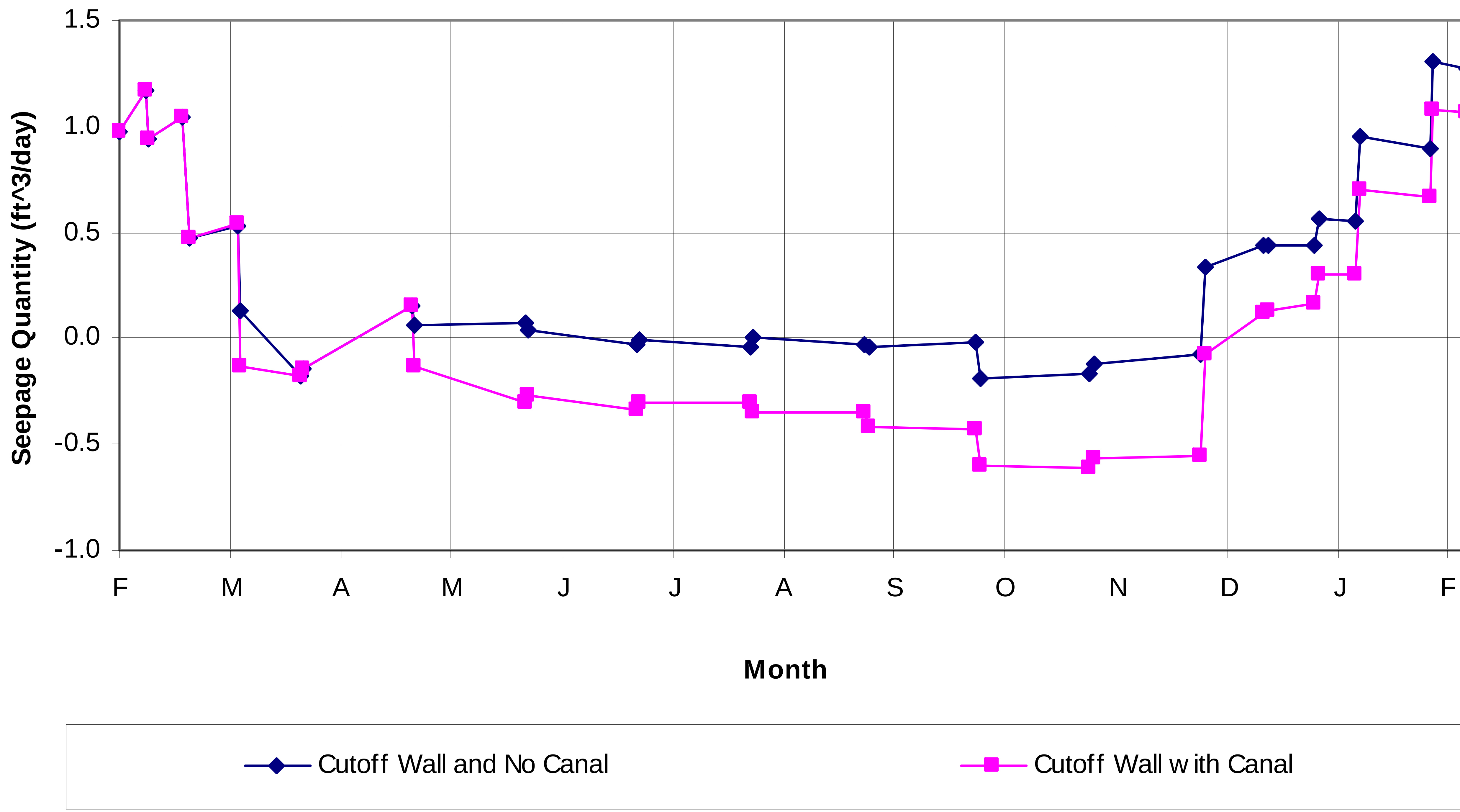
Graphics by: ESS
Project No. 72834

Date: 04/21/09
File: plate 23

Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee

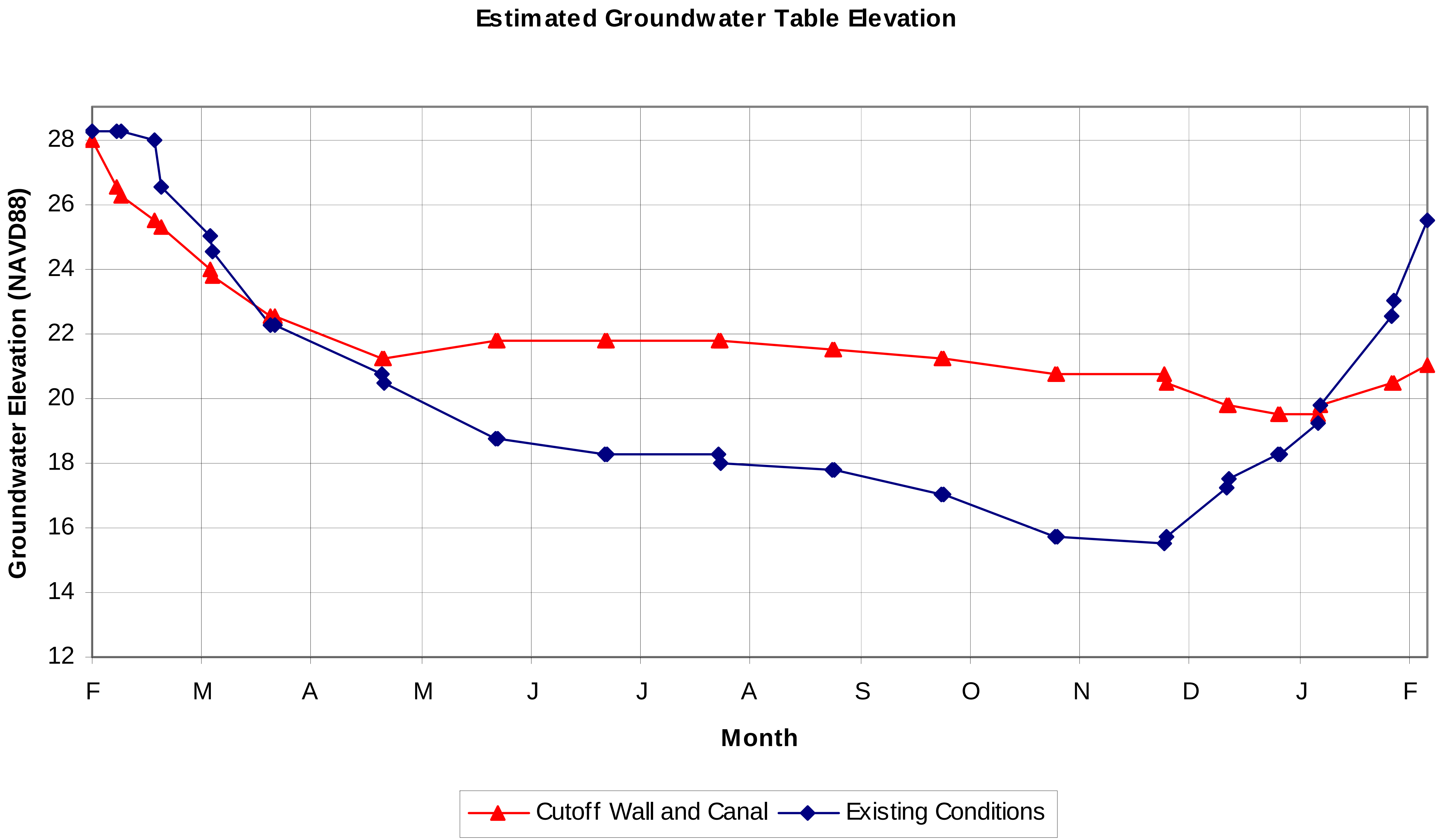
PLATE 23

Combined Impact of Cutoff Wall and Canal on Seepage Quantities



Note:
1. Seepage quantities were calculated using a flux line placed approximately 40 feet from the landside of the cutoff wall. Positive and negative quantities indicate flow from and into the river, respectively.
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 24
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: plate 24		



Note:
1. Groundwater table elevation estimated at the locations halfway between the existing levee and the canal (~187 ft from levee toe).
2. Elevations in the seepage models were adjusted to a nearest mesh node. Model Elevations are lower than elevations in NAVD88 by 0.03 feet.

KLEINFELDER Bright People. Right Solutions.		Evaluation of Cutoff Wall Impact on Groundwater Recharge Sacramento River East Levee	PLATE 25
Graphics by: ESS Project No. 72834	Date: 04/21/09 File: plate 25		

ATTACHMENT A

PIEZOMETER DATA
AND
GROUNDWATER ELEVATION CONTOUR MAP

FINAL OBSERVATION WELLS REPORT I!
For Reaches North and South of Powerline Road

AMERICAN RIVER WATERSHED PROJECT (COMMON FEATURES), CALIFORNIA SACRAMENTO RIVER LEVEE AND BERM STRENGTHENING

Contract No.: DACW05-00-D-0003
Specifications No.:
Drawing File No.:

Prepared by:
URS.

Prepared For:

US Army Corps of Engineers
Sacramento District

24 November 2003

AUTHORITY: WATER RESOURCES DEVELOPMENT ACT OF 1996

General Observations

No major storm events causing high river stages occurred during the entire monitoring period. During both winters, the river stage rose between 15 and 20 feet. The river stages and piezometer levels were generally highest in December through the end of January and gradually decreased after January.

The results of the monitoring program are discussed and evaluated herein in three parts: a general review of the monitoring results, a comparison of river stages and piezometer levels, and a qualitative correlation between analysis results and monitoring results. Conclusions and recommendations are presented subsequently.

General Review of Monitoring Results

A continuous record of monitoring results of river stages and landside piezometer levels was obtained during this monitoring program. Only the relatively deep USACE piezometers gave meaningful results. The RD-1000 piezometers were installed too high to yield meaningful data during this period of relatively low river stages.

As noted, no significant high-river-stage events occurred during the monitoring period. Nevertheless, the piezometer data showed significant rises in the groundwater levels in response to higher river stages. The piezometer levels were always well below the ground surface on the landside of the levee, consequently no evidences of upward seepage were expected, and none were observed.

Comparisons of Piezometer Levels to River Stages

The first comparison is between piezometer levels at the landside levee toe and river stages, made for two locations. The Verona (VON) gage is located near 2F-01-15 (North of Powerline Road) as shown in Figure 2-1. The correlation between river stage recorded at VON and ground water level recorded at piezomter 2F-01-15 is depicted in Figure 5-1. Also shown in this figure is the comparison of piezometer 2F-01-19 with two gages, Bryte (BRY) and RD1000, which are located south of Powerline (see Figure 2-1). The findings from these comparisons are shown in Figure 5-1 and they indicate the following:

2F-01-15 N:

Two distinct trends are evident.

- The river stages were approximately 1 to 3 feet below the ground water levels in the piezometer during low river stage.
- The river stages were approximately 9 to 10 feet above the ground water levels in the piezometer during high river stage.
- Note that Piezometer 2F-01-15 N is installed in an area of reported incidences of seepage and boils.

2F-01-19 S:

Two distinct trends are evident.

- The river stages were approximately 1 to 1.5 feet below the ground water levels in the piezometer during low river stage.
- The river stages were approximately 4 to 5 feet above the ground water levels in the piezometer during high river stage.
- Note that no incidence of seepage and boils were reported at the location of this piezometer

The subsurface conditions at these two piezometer locations are shown in Figures 5-1 b and 5-1c. The sand aquifer in 2F-01-15N and 2F-01-19S starts at depths of 73.5 feet and 32.5 feet, respectively. The soil above the sand aquifer is fine grained soil consisting of clay, silt, and silty sand. The difference between the river stage and water level at the piezometer during the peak river stage is higher for piezometer 2F-01-15N for than piezometer 2F-01-19 S. The reason for the more pronounced time lag in Piezometer 2F-01-15 N is probably caused by the thicker and less pervious blanket which slows the percolation time.

Comparison of Water Levels between Near-field and Far-field Piezometers

The second comparison is between piezometer levels at different distances from the landside levee toe and river stages, at two locations. This comparison was made for piezometers relatively aligned in a transverse direction to the river.

1. Piezometers 2F-01-26 and 2F-01-28 (both north of Powerline Road) are located on the landside toe and about 250 feet from the landside levee toe, respectively. The comparison of the two readings is shown in Figure 5-2.

The ground water level at the near-toe piezometer is generally about 1.25 ft higher than the far-field piezometer during high river stage, while the ground water levels are similar during low river stage.

2. Piezometers 2F-01-68 and 2F-01-69 (both north of Powerline Road) are located about 50 feet and 200 feet, respectively, from the levee toe. The comparisons of these readings are shown in Figure 5-3.

The ground water level at the near-toe piezometer is generally about 3.0 feet higher than the far-field piezometer during high river stage, while the water levels are generally similar during low river stage.

Qualitative Correlation between Monitoring Results and Analysis Results

This correlation was made qualitatively only, using results of previous underseepage analyses (URS 2002d and 2002e). The scope of the monitoring program did not include additional underseepage analyses.

First, there was an apparent slight time lag of not more than several days between river stage peaks and piezometer level peaks, as seen in Figure 5-1. This amount of time lag was expected based on transient seepage analyses. Considering that a high river stage typically lasts several days, use of steady-state underseepage analyses is justified and is not expected to lead to any significant conservatism in analysis results.

Second, as expected, the measured piezometer levels resemble the river stages but show lower amplitude. This is expected as a result of seepage head losses in the aquifer between the seepage entrance point and the landside measuring location. For the same reason, the piezometer levels farther from the levee toe are lower than those near the levee.

Conclusions

The monitoring results demonstrate the rapid response of landside seepage conditions to changes in river stages. The groundwater response to higher river stage has a short time lag and relatively smaller attenuation of the peaking amplitudes. The results did not allow any correlation between measured flood stage and surface seepage effects, because of the lack of high river stages during the monitoring period.

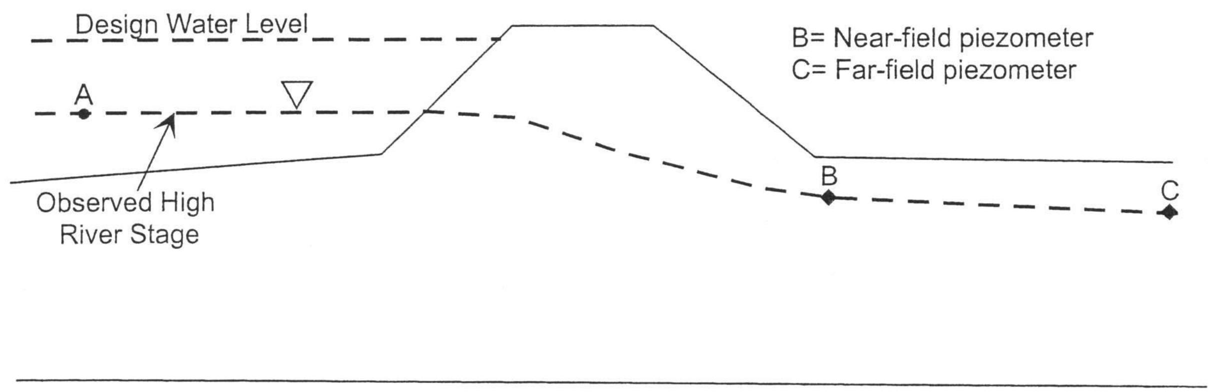


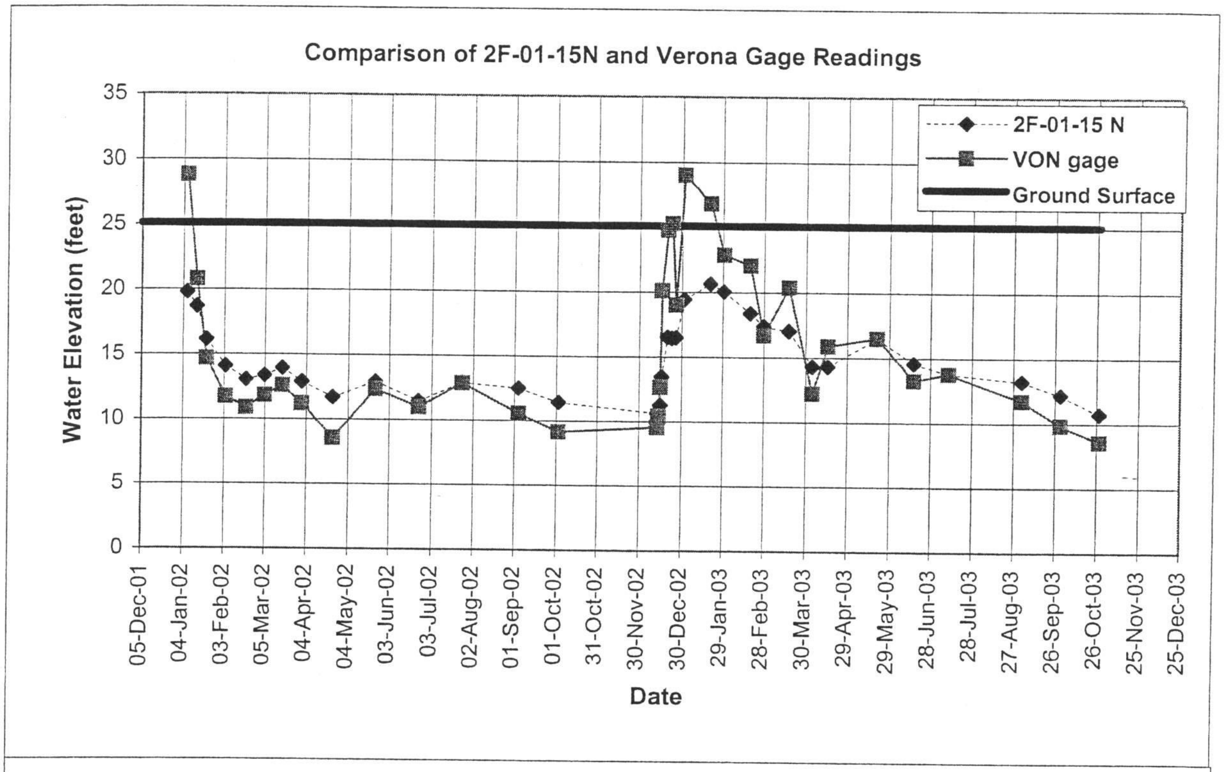
Figure 5-4- Schematic of Locations of Near-field and Far-field Piezometers

Nevertheless, the river stage, near-field and far-field piezometer readings are providing a window into a better assessment of the far-field boundary conditions and overall calibration of the model. As far as numerical seepage modeling is concerned, the observed water levels at points A, B, and C can be used for the calibration. This calibration will serve to minimize the uncertainty in selecting the appropriate boundary conditions, especially the far-field boundary condition and to provide insight into the estimate of the in-situ permeability of the soil. This calibrated model can then be used to predict the seepage response of the levee system for higher design water level.

Recommendations

Two recommendations are drawn from this monitoring program:

- We recommend the continuation of the piezometer and river stage monitoring program. However, the frequency of the monitoring program could be revisited. We also recommend that only Sacramento River and I-Street gages be monitored.



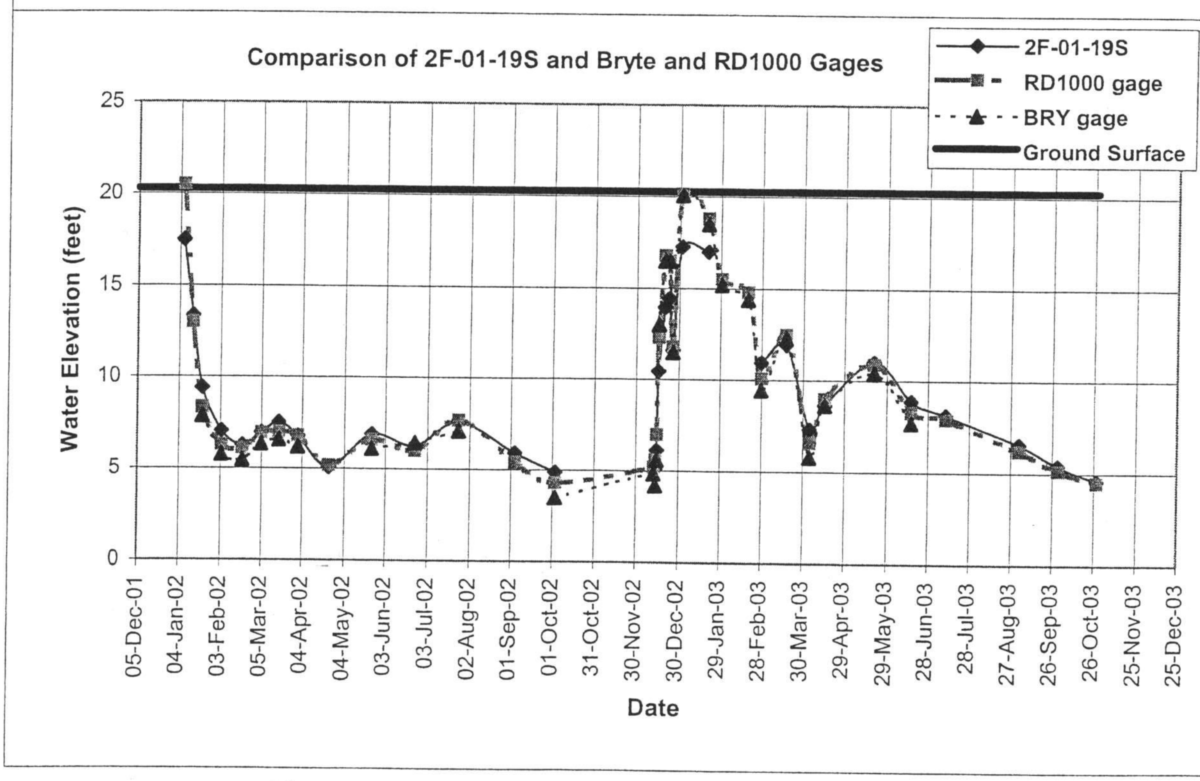
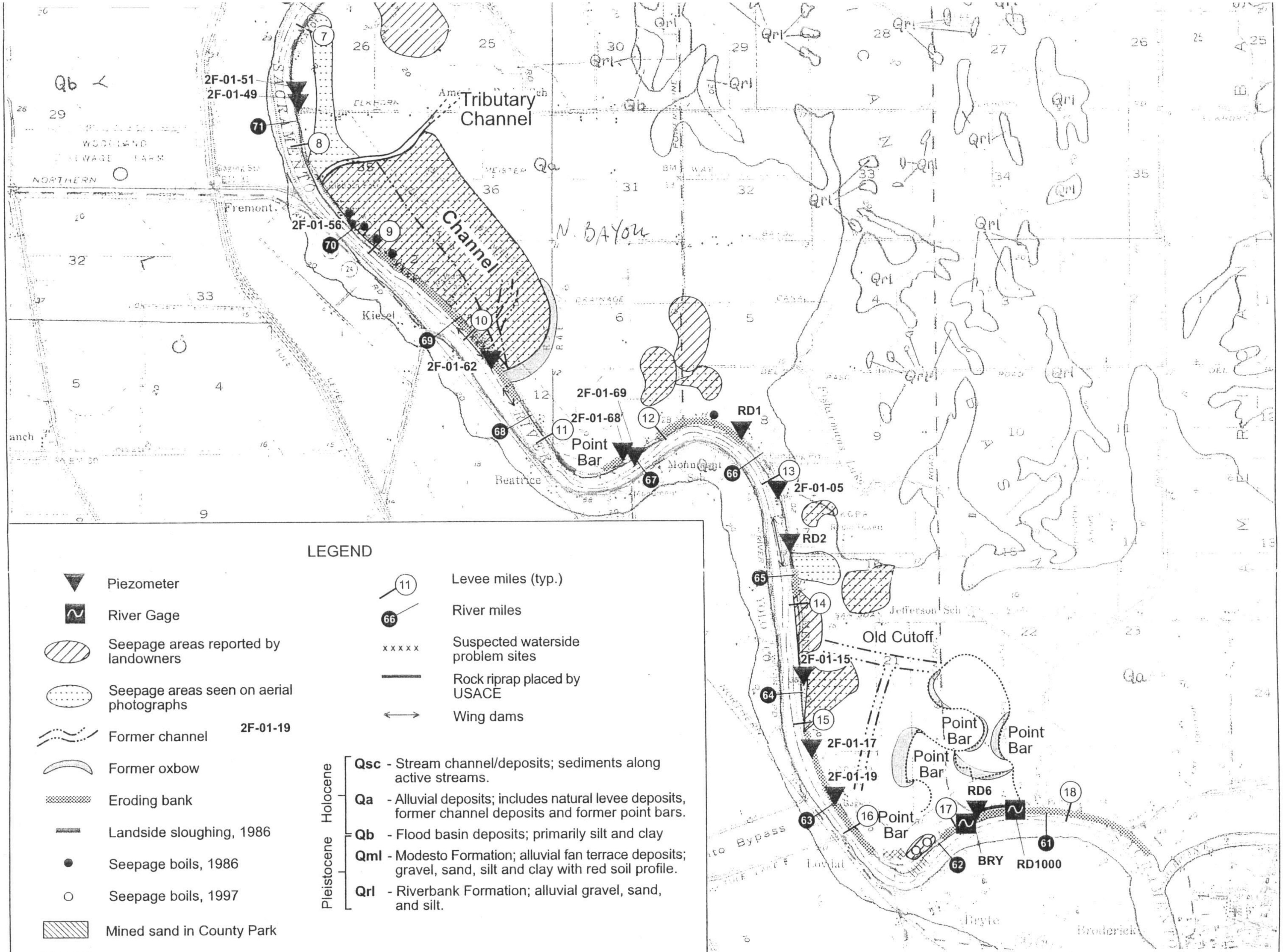


Figure 5-1: Comparison of River Stage and Piezometer Readings



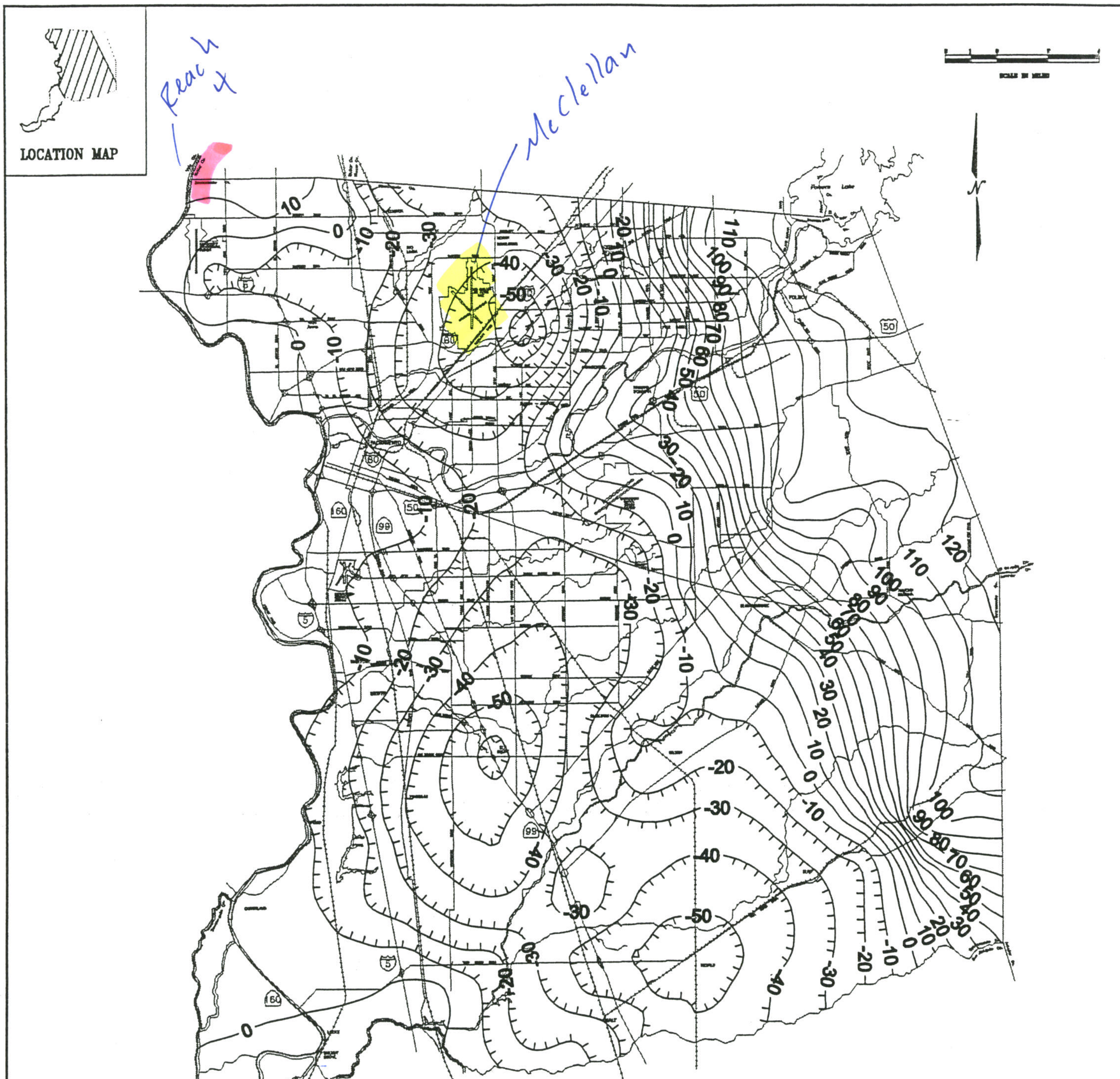
URS Project Nos. 26813892

Sacramento River Adjacent Natomas

PIEZOMETER AND GAGE LOCATIONS

Figure 2-1

26813892.00000/112003/gos



SACRAMENTO COUNTY, CALIFORNIA

GROUNDWATER ELEVATIONS
FALL 2003

MEAN SEA LEVEL

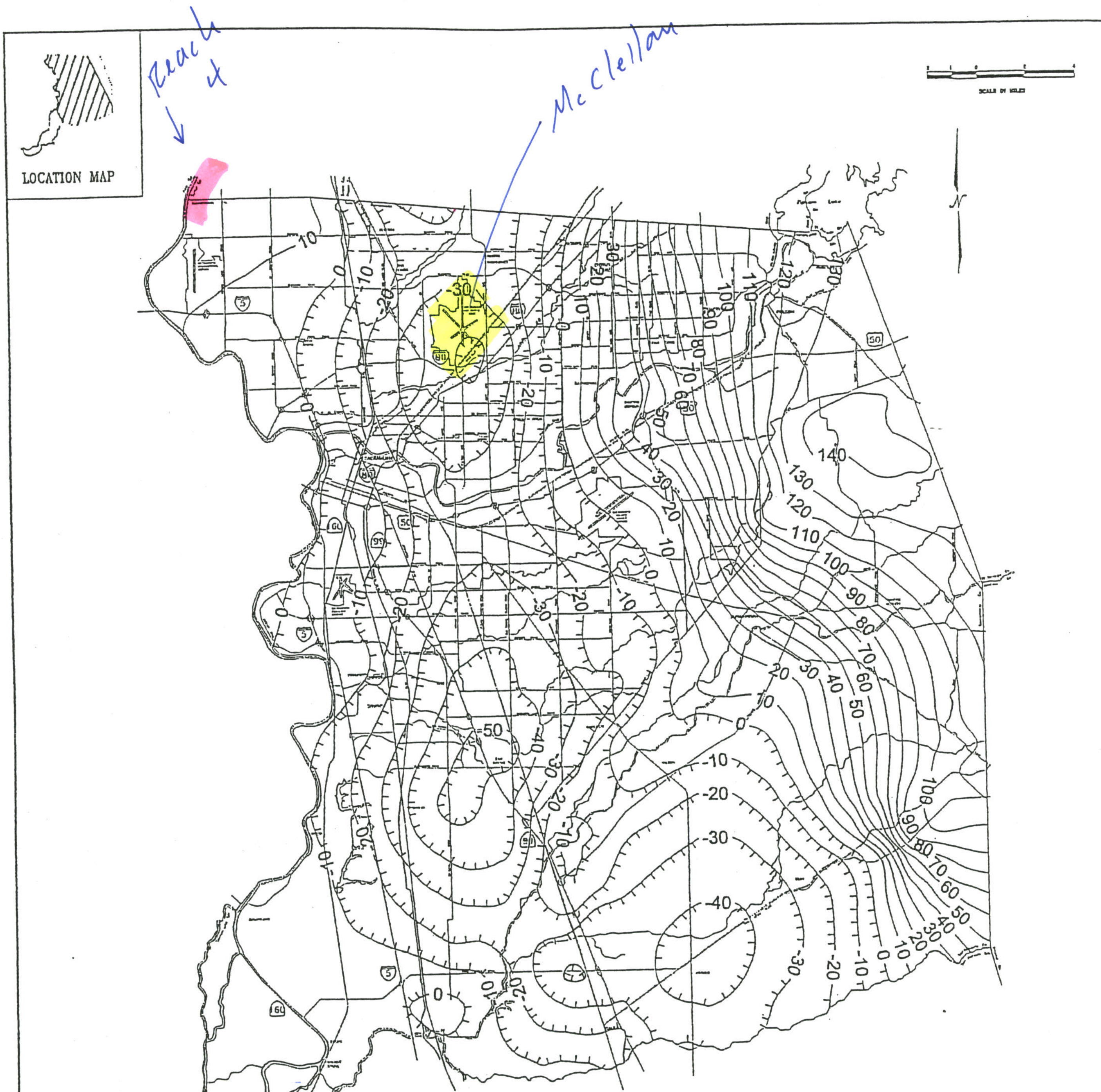
COUNTY OF SACRAMENTO PUBLIC WORKS AGENCY DEPARTMENT OF WATER RESOURCES

FALL 2003

NOTE: THIS GROUND WATER CONTOUR MAP IS FOR COMPARISON PURPOSES ONLY. SPECIFIC INFORMATION SHOULD BE OBTAINED BY INDEPENDENT INVESTIGATION.

DRAWN: MARCH 2004
BY: T. Crick

CAD # P:\Shared Folders\Wsplandev\Zone 13\State Well Program\GW Contour Maps\2003\Fall 2003.dwg



SACRAMENTO COUNTY, CALIFORNIA

GROUNDWATER ELEVATIONS
SPRING 2003

MEAN SEA LEVEL

COUNTY OF SACRAMENTO PUBLIC WORKS AGENCY DEPARTMENT OF WATER RESOURCES

SPRING 2003

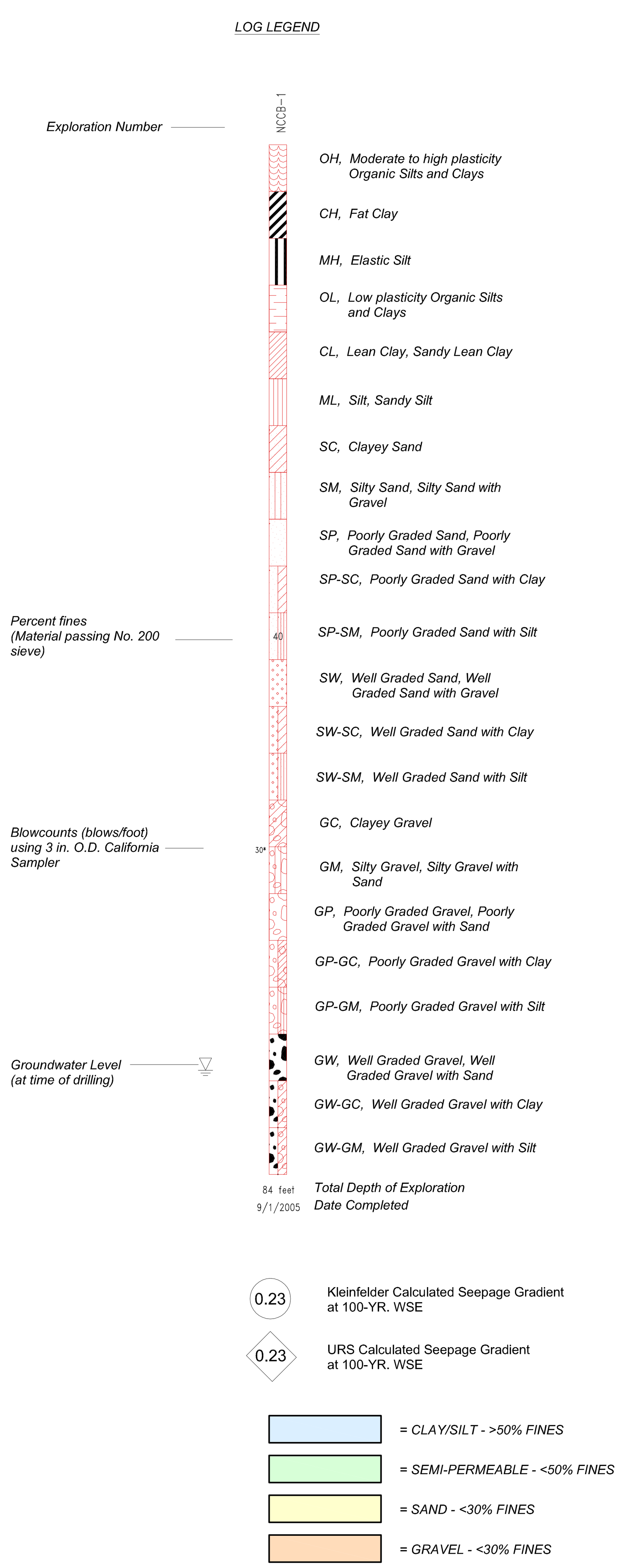
NOTE: THIS GROUND WATER CONTOUR MAP IS FOR COMPARISON PURPOSES ONLY. SPECIFIC INFORMATION SHOULD BE OBTAINED BY INDEPENDENT INVESTIGATION.

DRAWN: JULY 2003
BY: T. Crick

CAD 8 P:\Shared Folders\Wsplandev\Zone 13\State Well Program\GW Contour Maps\2003\Spring 03.dwg

ATTACHMENT B

SUBSURFACE PROFILE
SACRAMENTO RIVER EAST LEVEE



Notes:

1. Base drawings for these levee profiles, obtained in August 2005 from the Sacramento District U.S. Army Corps of Engineers (USACE) and used with their permission, include stick logs of previous explorations, a levee crown profile, a landside levee toe profile, notes regarding levee performance and completed levee improvements, and elevation scale based on the 1929 National Geodetic Vertical Datum (NGVD, 1929).

2. Logs of the following explorations were added to the USACE base drawings: Kleinfelder 2006 borings (SRE-06-XX); Kleinfelder 2005 borings (SRB-XX); Kleinfelder 2003/2004 Borings S-03-1, S-03-2, S-03-3, S-03-4.

3. Locations of explorations shown are approximate. See Plate 2A through 2E for approximate plan locations of explorations.

4. The log legend shown applies to Kleinfelder 2005 borings (SRB-XX) and Kleinfelder 2006 borings (SRE-06-XX). Caution is advised in using the legend for interpretation of other explorations.

5. Logs represent general soil conditions observed at the point of exploration on the date indicated. Refer to Kleinfelder's 2005 report and Kleinfelder's 2006 report for more detail on the Kleinfelder 2005 borings (SRB-XX) and 2006 borings (SRE-06-XX).

6. Lines separating strata on logs represent approximate boundaries only. Actual transitions may be gradual.

7. No warranty is provided as to the continuity of soil conditions between individual sample locations.

8. Approximate top of boring elevations for Kleinfelder 2006 borings (SRE-06-XX) were obtained using GPS equipment survey; Kleinfelder 2005 borings (SRB-XX) were estimated using topographic data obtained by USACE 1997.

9. The 1/100 AEP and 1/200 AEP water surface profiles shown were provided by MBK Engineerson August 18, 2006. See report for an explanation of these profiles and conditions.

10. Details regarding completed levee improvements have been added to those already on the USACE levee profile base drawings and were obtained from the USACE. Extents of completed levee improvements shown are approximate and are the same as indicated on the USACE profiles. Refer to USACE as-built drawings for actual extents.

KLEINFELDER		SACRAMENTO RIVER EAST LEVEE **Basis of Design Report** Sacramento River East Levee Reaches 1 through 4B Natomas Basin Evaluation Sacramento and Sutter Counties, California	PLATE 3A
Drawn By: D. ROSS Project No.: 72834AASRN	Date: 09/24/2007 Filename: 72834_P1.dwg		

NOTE: SOME STICK LOGS HAVE BEEN MOVED IN ORDER FOR ALL DATA TO BE READABLE. REFER TO THE BORING LOCATION MAPS FOR ACCURATE STATIONING OF THESE EXPLORATIONS.

KLEINFELDER		**SACRAMENTO RIVER EAST LEVEE PROFILE** **Basis of Design Report** Sacramento River East Levee Reaches 1 through 4B Natomas Basin Evaluation Sacramento and Sutter Counties, California	PLATE 3B
Drawn By: D. ROSS	Date: 09/24/2007		
Project No.: 72834AASRN	Filename: 72834_p1.dwg		

LEGEND

= CLAY/SILT - >50% FINES

= SEMI-PERMEABLE - <50% FINES

= SAND - <30% FINES

= GRAVEL - <30% FINES

NOTE: SOME STICK LOGS HAVE BEEN MOVED IN ORDER FOR ALL DATA TO BE READABLE. REFER TO THE BORING LOCATION MAPS FOR ACCURATE STATIONING OF THESE EXPLORATIONS.

KLEINFELDER	SACRAMENTO RIVER EAST LEVEE PROFILE **Basis of Design Report** Sacramento River East Levee Reaches 1 through 4B Natomas Basin Evaluation Sacramento and Sutter Counties, California	PLATE
Drawn By: D. ROSS Project No.: 72834AASRN Date: 09/24/2007 Filename: 72834_p1.dwg		3C

LEGEND

= CLAY/SILT - >50% FINES

= SEMI-PERMEABLE - <50% FINES

= SAND - <30% FINES

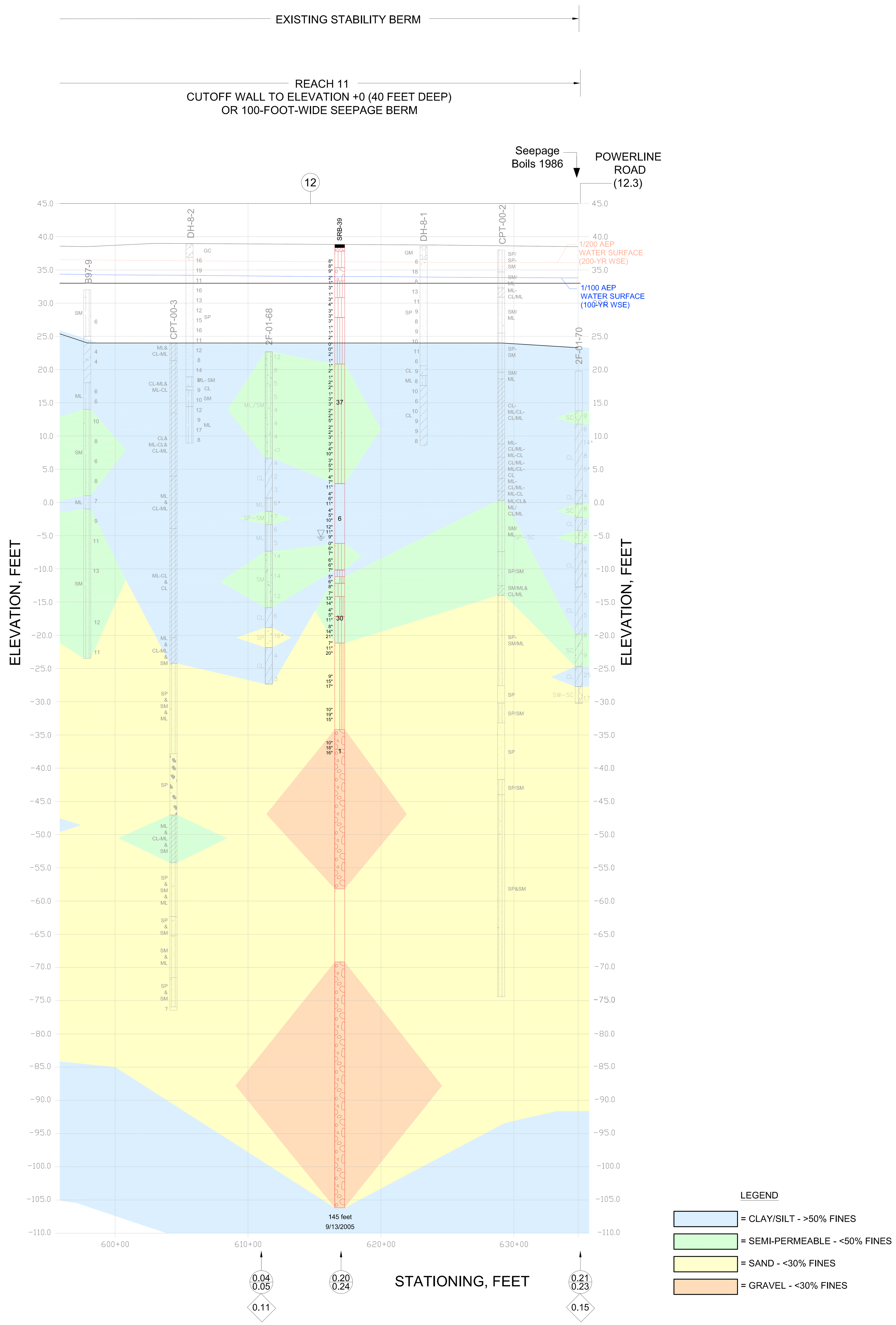
= GRAVEL - <30% FINES

NOTE: SOME STICK LOGS HAVE BEEN MOVED IN ORDER FOR ALL DATA TO BE READABLE. REFER TO THE BORING LOCATION MAPS FOR ACCURATE STATIONING OF THESE EXPLORATIONS.

KLEINFELDER		SACRAMENTO RIVER EAST LEVEE PROFILE	PLATE
Drawn By: D. ROSS	Date: 09/24/2007	NATOMAS BASIN EVALUATION	3D
Project No.: 72834AASRN	Filename: 72834_P1.dwg	SACRAMENTO & SUTTER COUNTIES, CA	

NOTE: SOME STICK LOGS HAVE BEEN MOVED IN ORDER FOR ALL DATA TO BE READABLE. REFER TO THE BORING LOCATION MAPS FOR ACCURATE STATIONING OF THESE EXPLORATIONS.

KLEINFELDER	SACRAMENTO RIVER EAST LEVEE PROFILE	PLATE
Drawn By: D. ROSS; Project No.: 72834AASRN; Date: 09/24/2007; Filename: 72834_P1.dwg	NATOMAS BASIN EVALUATION SACRAMENTO & SUTTER COUNTIES, CA	3E



NOTE: SOME STICK LOGS HAVE BEEN MOVED IN ORDER FOR ALL DATA TO BE READABLE. REFER TO THE BORING LOCATION MAPS FOR ACCURATE STATIONING OF THESE EXPLORATIONS.

KLEINFELDER		SACRAMENTO RIVER EAST LEVEE PROFILE	PLATE
Drawn By: D. ROSS	Date: 09/24/2007	NATOMAS BASIN EVALUATION	3F
Project No.: 72834AASRN	Filename: 72834_P1.DWG	SACRAMENTO & SUTTER COUNTIES, CA	

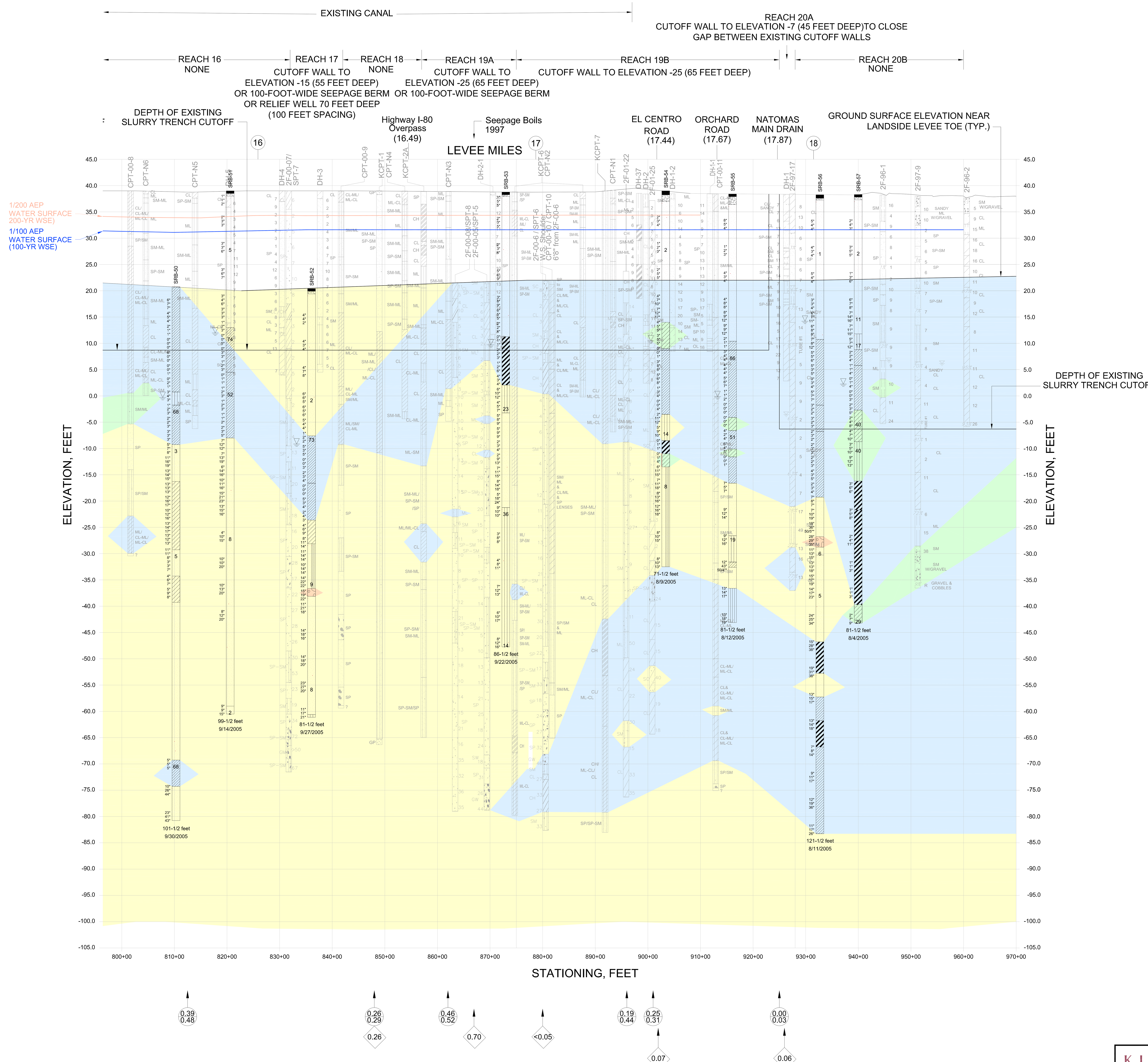
KLEINFELDER

Drawn By: D. ROSS
Project No.: 72834AASRN
Date: 09/24/2007
Filename: 72834_P2.dwg

SACRAMENTO RIVER EAST LEVEE PROFILE

NATOMAS BASIN EVALUATION
SACRAMENTO & SUTTER COUNTIES, CA

PLATE
3G



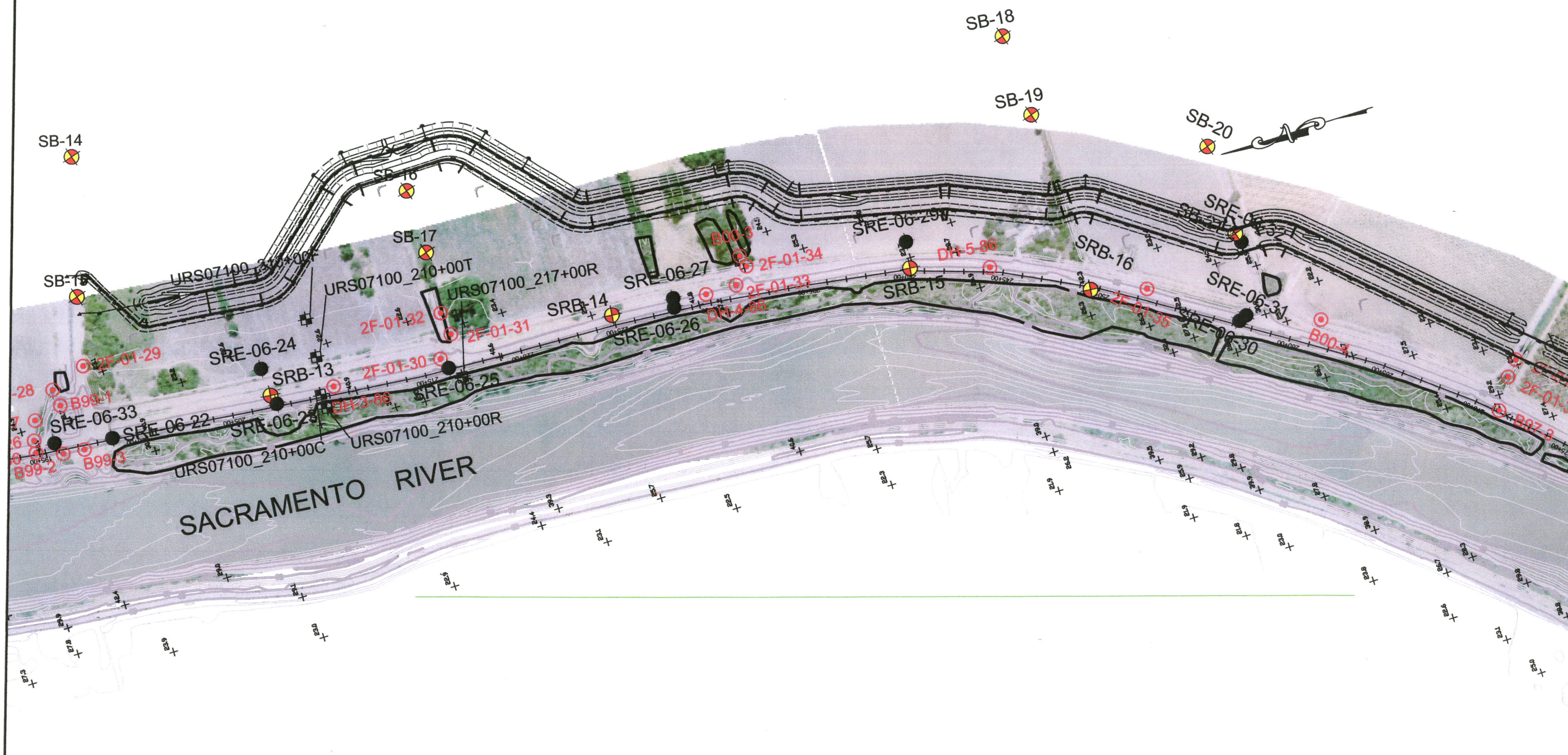
LEGEND

- = CLAY/SILT - >50% FINES
- = SEMI-PERMEABLE - <50% FINES
- = SAND - <30% FINES
- = GRAVEL - <30% FINES

KLEINFELDER	SACRAMENTO RIVER EAST LEVEE PROFILE	PLATE
Drawn By: D. ROSS / Project No.: 72834AASRN	Date: 09/24/2007 / Filename: 72834_p2.DWG	3H
	NATOMAS BASIN EVALUATION / SACRAMENTO & SUTTER COUNTIES, CA	

ATTACHMENT C

PROPOSED CANAL PLAN



LEGEND

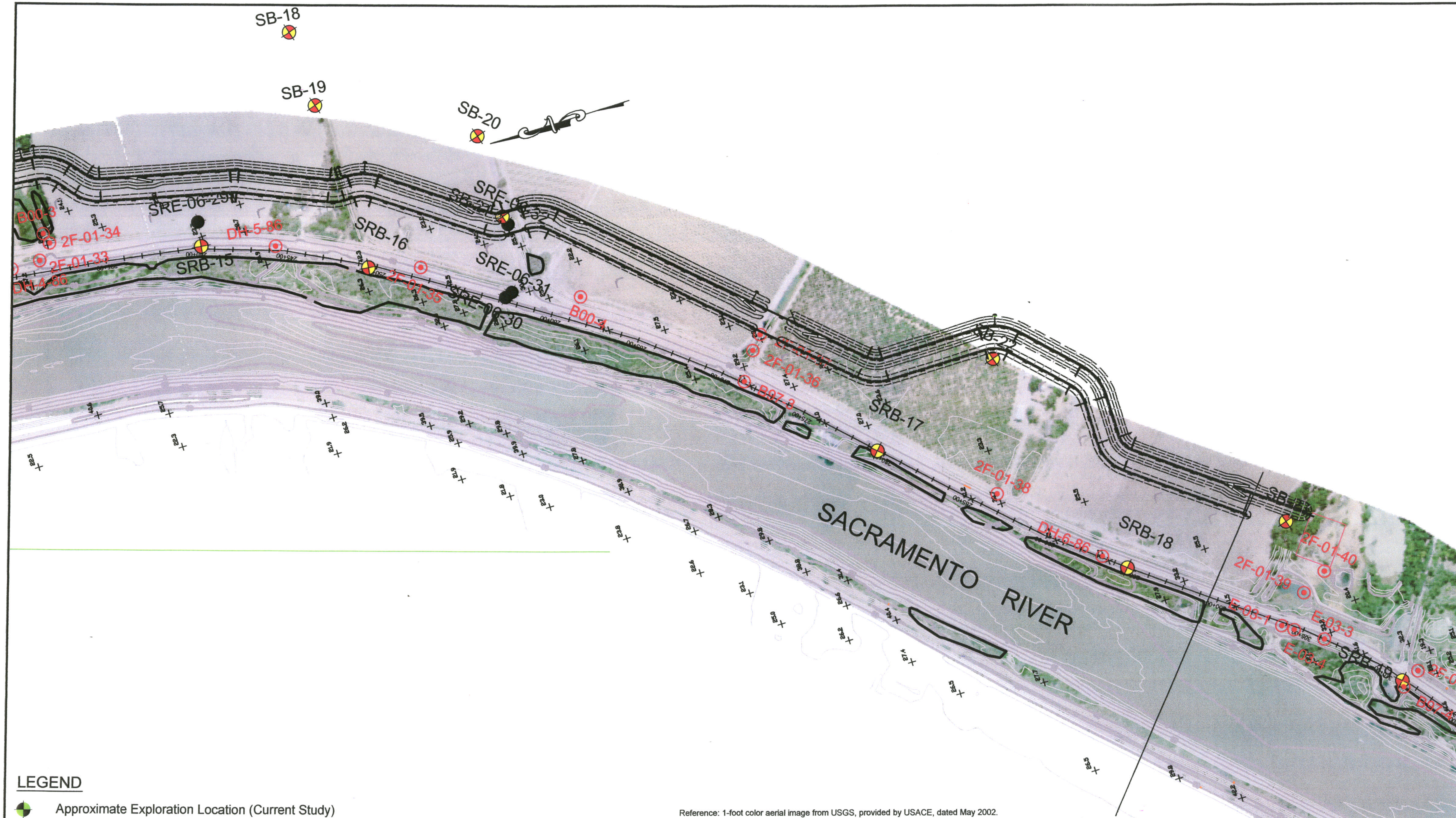
- Approximate Exploration Location (Current Study)
- Approximate URS Exploration (2007)
- Approximate Exploration Location (KA 2006)
- Approximate Exploration Location (KA 2005)
- Approximate Exploration Location (Previous Studies)

500 0 250 500 1,000

APPROXIMATE SCALE: 1 inch = 500 ft.

Reference: 1-foot color aerial image from USGS, provided by USACE, dated May 2002.

KLEINFELDER		BORING LOCATION MAP SACRAMENTO RIVER EAST LEVEE NATOMAS BASIN EVALUATION SACRAMENTO AND SUTTER COUNTIES, CALIFORNIA	PLATE 1
Drawn By: D. ROSS Project No.: 58824/PSRE	Date: 10/21/2005 Filename: 58824SAC2.dwg		



Reference: 1-foot color aerial image from USGS, provided by USACE, dated May 2002.

LEGEND

- Approximate Exploration Location (Current Study)
- Approximate URS Exploration (2007)
- Approximate Exploration Location (KA 2006)
- Approximate Exploration Location (KA 2005)
- Approximate Exploration Location (Previous Studies)

500 0 250 500 1,000

APPROXIMATE SCALE: 1 inch = 500 ft.

KLEINFELDER		BORING LOCATION MAP SACRAMENTO RIVER EAST LEVEE NATOMAS BASIN EVALUATION SACRAMENTO AND SUTTER COUNTIES, CALIFORNIA	PLATE 2
Drawn By: D. ROSS Project No.: 58824/PSRE	Date: 10/21/2005 Filename: 58824SAC2.dwg		

C4 Potential Impacts of Proposed Slurry Cutoff Walls Along Reach 4B of the Sacramento River East Levee

MEMORANDUM

LUHDORFF & SCALMANINI
CONSULTING ENGINEERS

DATE: July 31, 2009 **FILE NO.:** 07-1-084

TO: David Rader, EDAW
Timothy Washburn, SAFCA

FROM: Glenn Browning

SUBJECT: POTENTIAL IMPACTS OF PROPOSED SLURRY CUTOFF WALLS ALONG REACH 4B OF THE SACRAMENTO RIVER EAST LEVEE

The Sacramento Area Flood Control Agency (SAFCA) is proposing to construct slurry cutoff walls along much of the Sacramento River East Levee (SREL) including Reach 4B, which is located north of West Elverta Road and is 3,800 feet long. Luhdorff and Scalmanini, Consulting Engineers (LSCE) evaluated the potential groundwater impacts of slurry cutoff along this and other reaches of the SREL in the report entitled *Evaluation of Potential Groundwater Impacts Due to Proposed Construction for Natomas Levee Improvement Program* (May 4, 2009). The evaluation of cutoff wall impacts contained in that report is summarized below, followed by a discussion of changes to the analysis resulting from revised geologic cross sections and the revised project description for Reach 4B.

The proposed depths and locations of slurry cutoff walls along the SREL is evolving as the design process proceeds. The most recent summary of proposed SREL cutoff walls was prepared by HDR Engineering, Inc. on June 24, 2009 based on recommendations provided by Kleinfelder, Inc. (Kleinfelder). However, because further changes are anticipated, the Phase 4a Environmental Impact Statement (EIS)/Environmental Impact Report (EIR) currently in preparation by EDAW does not describe specific cutoff wall depths or locations in Reach 4B. The EIR describes the Reach 4B cutoff walls as generally ranging in depth from 20 to 75 feet but does not identify specific locations.

Previous Evaluation of Groundwater Impacts Due to Reach 4B Slurry Cutoff Walls

LSCE (May 4, 2009) includes an evaluation of the predicted impacts of all proposed slurry cutoff walls on groundwater conditions in the Natomas Basin. The locations of slurry cutoff walls evaluated in the report are shown on **Figure 6-1**, and the effects of all proposed slurry cutoff walls were summarized on **Table 6-6** (both attached). Cutoff walls planned for the SREL were predicted to slightly reduce recharge from the Sacramento River, and calculations for each reach were shown on Table 6-4 for existing conditions and Table 6-5 for future conditions. For Reach 4B, the evaluation included a 57-foot deep cutoff wall from Station 190+00 to Station 201+50 and a 14-foot deep cutoff wall for the remainder of the reach (Stations 201+50 to 228+00). Based on existing conditions, the total impact of these cutoff walls was predicted to be 37 afy or about 11 percent of the total recharge estimated for that reach (342 afy).

Recharge from the Sacramento River and the impacts of slurry cutoff walls were both estimated to be slightly higher in 2030 due to a steeper gradient resulting from additional M&I pumping proposed for the Natomas Basin. Based on projected future conditions, the total impact of the Reach 4B cutoff walls was predicted to be 51 afy (also about 11 percent of the total recharge estimated for the reach [462 afy]).

For all reaches of the SREL, slurry cutoff walls were predicted to reduce groundwater recharge by 884 afy (about 10 percent of the total) based on existing conditions and 992 afy (about 11 percent of the total) based on future conditions. The reduced recharge would be more than offset by increases in groundwater storage resulting from SAFCA's proposed canal improvements and changes in land use and water supply at planned borrow sites.

Updated Evaluation of Reach 4B Cutoff Walls

The evaluation of the impacts of slurry cutoff walls planned for the Reach 4B calculated for LSCE (May 4, 2009) has been updated to reflect the most current geologic cross section provided by Kleinfelder. The purpose of the update is to allow a direct comparison with impacts discussed below based on different cutoff walls depths. The Reach 4B cutoff wall depths used for these calculations are the same as those in LSCE (May 4, 2009). The predicted impacts discussed below are summarized in **Table 1** for all scenarios. Based on existing conditions, the total impact of the Reach 4B cutoff walls was predicted to be 23 afy or about 6 percent of the total recharge estimated for that reach (389 afy). Based on projected future conditions, the total impact of the Reach 4B cutoff walls was estimated to be 30 afy (also about 6 percent of the total recharge estimated for the reach [526 afy]).

For all reaches of the SREL, slurry cutoff walls were predicted to reduce groundwater recharge by 869 afy (about 10 percent of the total) based on existing conditions and 972 afy (also about 10 percent of the total) based on future conditions.

Evaluation of Reach 4B Cutoff Walls Based on Assumptions in HDR (June 24, 2009)

A revised configuration of cutoff walls proposed for Reach 4B of the SREL was provided by HDR Engineering, Inc. on June 24, 2009. The revised plan includes a 37-foot deep cutoff wall for Stations 190+00 to 191+50; a 62-foot deep cutoff wall for Stations 191+50 to 201+50; a 19-foot deep cutoff wall for Stations 201+50 to 214+00; and no cutoff wall for Stations 214+00 to 228+00. Using the same approach as in the LSCE (May 4, 2009) report for existing conditions, the total impact of the these cutoff walls is predicted to be 24 afy or about 6 percent of the total recharge estimated for that reach (389 afy). Based on future conditions in 2030, the total impact of the Reach 4B cutoff walls is predicted to be 34 afy (also about 6 percent of the total estimated recharge of 526 afy).

For all reaches of the SREL, currently proposed slurry cutoff walls are estimated to reduce groundwater recharge by 871 afy (about 10 percent of the total) based on existing conditions and 974 afy (also about 10 percent of the total) based on future conditions.

Evaluation of Reach 4B Cutoff Walls Based on Assumptions in Phase 4a EIS/EIR

The Phase 4a EIS/EIR makes a more conservative assumption about the configuration of cutoff walls in Reach 4B of the SREL, stating that the cutoff walls in that reach will range in depth from 20 to 75 feet without identifying specific locations. Based on previous analysis by Kleinfelder and HDR, LSCE assumes that the deep cutoff wall (up to 75 feet deep) would extend from Station 190+00 to Station 201+50, and the shallow cutoff wall (up to 20 feet deep) would be constructed along the remainder of the reach from Station 201+50 to Station 228+00. Due to their greater cross-sectional area, these cutoff walls would have slightly larger impacts than those previously analyzed, but the overall groundwater impacts are still estimated to be small.

Based on existing conditions, the total impact of cutoff walls in Reach 4B ranging in depth from 20 to 75 feet is predicted to be 36 afy or about 9 percent of the total recharge estimated for that reach (389 afy). Based on future conditions, the total impact of these cutoff walls is predicted to be 49 afy (also about 9 percent of the total estimated recharge of 526 afy).

For all reaches of the SREL, slurry cutoff walls were estimated to reduce groundwater recharge by 882 afy (about 10 percent of the total) based on existing conditions and 990 afy (about 11 percent of the total) based on future conditions.

Summary

Slurry cutoff walls proposed for the levees surrounding the Natomas Basin are predicted to slightly affect groundwater conditions in the area. In general, slurry cutoff walls along the SREL and the Natomas Cross Canal will reduce recharge from the Sacramento River and other groundwater inflow into the Natomas Basin. Cutoff walls along the Pleasant Grove Creek Canal, Natomas East Main Drainage Canal, and the American River will reduce groundwater outflow from the Natomas Basin.

The cross-sectional area of slurry cutoff walls proposed for Reach 4B represents a very small fraction of all the cutoff walls proposed for levees surrounding the Natomas Basin. The cumulative impact of all proposed cutoff walls along the SREL ranges from 869 afy to 884 afy based on existing conditions and from 972 afy to 992 afy based on future conditions. The impact ranges from 10 to 11 percent of the total estimated recharge for all scenarios. Differences due to the depth and location of slurry cutoff walls in Reach 4B are considered to be negligible and will not have measurable effects on groundwater conditions in the area.

Table 6-6
Effects of Proposed Slurry Cutoff Walls on Groundwater Flow

Levee	Time Period	Total Length of Levee (ft)	Saturated Thickness for Ground-Water Flow (ft)	Cross-Sectional Area for Flow (ft²)	Total Flow Without Cutoff Walls[1] (afy)	Flow per Cross-Sectional Area (afy/ft²)	Length of Proposed Cutoff Walls (ft)	Average Depth of Cutoff Walls (ft)	Cross-Sectional Area of Cutoff Walls (ft²)	Flow Through Cross-Sectional Area of Cutoff Walls (afy)	Flow Through, Beneath, or Around Cutoff Walls (afy)	Flow Reduction Due to Cutoff Walls[8] (afy)	Flow Reduction Due to Cutoff Walls[8] (%)
Sacramento River East Levee	Existing	96,000	200	19,200,000	8,450 [2]	4.40E-04	53,500	65	3,474,300	1,262	7,566	884	10
	2030				9,341 [3]	4.40E-04				1,417	8,349	992	11
NCC South Levee	2004	28,700	400	11,480,000	459 [4]	4.00E-05	28,700	70	2,009,000	80	403	56	12
	2030				3,918 [5]	3.41E-04				686	3,438	480	12
PGCC West Levee	2004	17,400	400	6,957,600	-4,451 [6]	-6.40E-04	14,000	38	532,500	-341	-4,212	-238	5
	2030				-246 [7]	-3.53E-05				-19	-233	-13	5
NEMDC West Levee (North)	2004	35,700	400	14,276,000	-9,132 [6]	-6.40E-04	22,800	37	845,200	-541	-8,753	-378	4
	2030				-504 [7]	-3.53E-05				-30	-483	-21	4
NEMDC West Levee (South)	2004	31,900	400	12,750,000	-8,156 [6]	-6.40E-04	23,100	45	1,040,000	-665	-7,690	-466	6
	2030				-450 [7]	-3.53E-05				-37	-425	-26	6
American River North Levee	2004	11,600	200	2,312,000	1,086 [6]	4.70E-04	11,600	55	640,400	301	875	211	19
	2030				-500 [7]	-2.16E-04				-139	-403	-97	19
Total (Existing or 2004)					**-11,743**					**97**	**-4,106**	**68**	
Total (2030)					**11,559**					**1,879**	**10,244**	**1,315**	
Total (All)		**221,300**					**153,700**		**8,541,400**				

1. Positive values indicate groundwater inflow; negative values indicate goundwater outflow.
2. Source of total flow estimate = Table 6-4.
3. Source of total flow estimate = Table 6-5.
4. Source of total flow estimate = groundwater inflow from 2004 IGSM simulation (241 afy) plus canal seepage estimated by Kleinferlder (218 afy).
5. Source of total flow estimate = groundwater inflow from 2030 IGSM simulation (3,700 afy) plus canal seepage estimated by Kleinferlder (218 afy).
6. Source of total flow estimate = IGSM 2004 simulation.
7. Source of total flow estimate = IGSM 2030 simulation.
8. Increased groundwater inflow (or decreased outflow) shown as positive value; increased outflow (or decreased inflow) is shown as negative. 70% flow reduction assumed for slurry cutoff walls based on Kleinfelder (2009).

Table 1
Effects of Assumptions about Slurry Cutoff Wall Depths in SREL Reach 4B on Groundwater Recharge from Sacramento River

Basis for Assumptions about Reach 4B Slurry Cutoff Walls	Time Period	Flow Reduction Due to Reach 4B Cutoff Walls		Flow Reduction Due to All Cutoff Walls	
		(afy)	(%)	(afy)	(%)
Cutoff Wall Depths in LSCE Report (May 4, 2009)	Existing	37	11	884	10
	Future	51	11	992	11
Cutoff Wall Depths in LSCE Report (May 4, 2009) with Revised Geologic Interpretation	Existing	23	6	869	10
	Future	30	6	972	10
Cutoff Wall Depths in HDR Table (June 24, 2009)	Existing	24	6	871	10
	Future	34	6	974	10
Cutoff Wall Depths in Phase 4a EIS/EIR	Existing	36	9	882	10
	Future	49	9	990	11

FILE: \\server_pe2900\Public\SAFCA\GIS\Fig 6-1 SlurryCutoffLocation map.mxd Date: 5/4/2009

LUHDORFF & SCALMANINI CONSULTING ENGINEERS

Figure 6-1
Proposed Slurry Cutoff Walls Surrounding Natomas Basin

C5 Potential Impacts of Proposed Phase 4a Habitat Mitigation Wells

MEMORANDUM

LUHDORFF & SCALMANINI
CONSULTING ENGINEERS

DATE: August 5, 2009 **FILE NO.:** 07-1-084

TO: David Rader, EDAW
Timothy Washburn, SAFCA

FROM: Glenn Browning

SUBJECT: POTENTIAL IMPACTS OF PROPOSED PHASE 4A HABITAT MITIGATION WELLS

The Sacramento Area Flood Control Agency (SAFCA) plans to construct five wells for habitat mitigation as part of the Phase 4a Natomas Levee Improvement Project. The impacts of these five wells are being evaluated in the Phase 4a Environmental Impact Statement (EIS)/Environmental Impact Report (EIR) currently in preparation by EDAW. Because these wells are in the very early planning stages, no definite information is available about well design, location, or capacity. All wells would be located east of the Sacramento River East Levee (SREL), and tentative locations are shown in **Figure 1**. The five proposed habitat mitigation wells and adjacent reaches are as follows:

- Giant Garter Snake (GGS) Backup Well – Reach 6A
- Woodland Planting Well (North) – Reach 7
- Woodland Planting Well (South) – Reach 14
- Fisherman's Lake Marsh Well (North) – Reach 13
- Fisherman's Lake Marsh Well (North) – Reach 13

The impacts of the habitat mitigation wells will depend on various factors in addition to the final well locations. Other assumptions required to evaluate the potential well impacts are summarized in **Table 1**. These include well usage, water demand, pumping rate, and well construction (including depth and perforated interval). **Table 1** shows that the maximum annual water demand estimated for the five wells is relatively small except for the GGS Backup Well, which could pump up to 3,550 acre-feet (af) in a critically-dry year. During those years, the total water demand for all five wells is estimated be about 4,300 af. Between 1906 and 2008, a total of 14 years (about 14 percent of the total) have been identified as critically-dry based on the Sacramento River Basin 40-30-30 Index developed by the State Water Resources Control Board. If the GGS Backup Well is only pumped during critically-dry years, its average annual water demand would be about 490 af. The average annual water demand for all wells would then be about 1,200 af. After the woodland planting wells are no longer needed, the total average annual water demand would decrease to about 1,100 af.

There are a number of potential impacts that can occur as a result of increased groundwater pumping, but the evaluation of the potential impacts addressed in this memo is limited to reductions in the yields of existing nearby wells due to drawdowns caused by the new wells. Other potential impacts of increased groundwater extraction listed below were considered unlikely to occur and were not specifically analyzed for this study:

- Overdraft – Groundwater levels in the western portion of the Natomas Basin are high and have remained relatively stable over time, and those conditions are not expected to change due to pumpage from the proposed habitat mitigation wells. As discussed above, the average annual pumpage from the five new wells is projected to range from about 1,100 to 1,200 af/yr. This represents a small percentage of the total pumpage in the Natomas Basin and will not cause chronic groundwater level declines.
- Land subsidence – Subsidence due to groundwater extraction is most likely to occur during periods when groundwater levels reach new historical lows during the irrigation season or fail to fully recover at the end of the year. Such conditions are not expected to occur in the western portion of the Natomas Basin with or without the habitat mitigation wells.
- Groundwater quality impacts – There are no known areas of groundwater contamination near the proposed wells, and no groundwater quality impacts are expected due to the increased pumping.
- Surface water impacts – Pumping of the habitat mitigation wells will tend to increase seepage from the Sacramento River and nearby canals. This will offset some of the reduction in recharge from the River that is expected as a result of slurry cutoff walls to be installed by SAFCA along the SREL. Increased seepage from the River and nearby canals due to the proposed pumping will not be measurable.

Giant Garter Snake Canal Backup Well

Water for the GGS Canal will be supplied primarily by surface water purchased from the Natomas Central Mutual Water Company (NCMWC), which has relatively senior rights to water from the Sacramento River. NCMWC has adequate water supplies during most years, but it can experience cutbacks of up to 25 percent of its contract supply in critically-dry years. The GGS Canal Backup Well would be installed near the canal to provide supplemental water during years when NCMWC receives less than its full allocation of surface water. The tentative location for the GGS Canal Backup Well is on the Horangic property, now owned by SAFCA, which is located north of the Teal Bend Golf Club in Reach 6A, as shown on **Figure 1**.

The high point of the GGS Canal will be in Reach 6A, and the canal is designed to flow both north and south from that location. The design flow rate is about five cubic feet per second (cfs) in each direction, and losses are estimated to be about 9.6 cfs for seepage and a maximum of 0.4 cfs for evaporation. Therefore, the normal water demand will be about 20 cfs (Mead and Hunt, 2009). During a critically-dry year, NCMWC would be expected to supply only 75 percent of this amount, and the remaining 25 percent (five cfs) would be supplied by groundwater. As shown in **Table 1**, a pumping rate of about 2,200 gallons per minute (gpm) would be required to supply five cfs of water to the GGS Canal. If the well was pumped continuously, it could supply about 295 af in a month or 3,550 af during the year.

Table 1 also shows assumptions about the depths and perforated intervals of the habitat mitigation wells, but these should not be considered as recommendations. A test hole should be drilled at each site prior to designing the wells, and the well design should be determined by a geologist or engineer based on results of electrical logging conducted in the test hole. Estimates made by DWR (2003) indicate that the average capacity of irrigation wells in the Natomas Basin is about 1,600 gpm (LSCE, 2008). In some areas, larger capacities can be obtained by constructing deeper wells. It is generally recommended that new large-capacity irrigation wells located near the Natomas Basin levees not be perforated in the upper 100 feet of the aquifer system for two reasons:

- Deep slurry cutoff walls (75 feet or more) are planned for a number of reaches of the SREL. It is preferable that large-capacity wells constructed near these cutoff walls be completed below the bottom of the cutoff walls in order to not increase seepage through the cutoff walls. The cutoff wall currently planned for the southern portion of Reach 6A (adjacent to the GGS Backup Well location) would have depth of 115 feet from the top of the levee.
- Domestic wells in the area are often completed partially in shallow sands, and new large-capacity wells pumping from those zones would have greater impacts on nearby domestic wells.

For planning purposes, it is assumed that a perforated interval of 100 to 500 feet in depth would be required to obtain a sustained yield of 2,200 gpm. The GGS Backup Well would only be used intermittently (primarily during critically-dry years) but would cause larger drawdowns than the other proposed habitat mitigation wells during those years because it would pump at a relatively high rate. Well mapping conducted by Mead and Hunt (2008) shows only four existing wells within a one-half mile radius of the proposed location of the GGS Backup Well. One of these is an active domestic well, one is an unused domestic well, and two wells are identified as “other” (unknown use). The unused domestic well is located on the Horangic property now owned by SAFCA near the proposed location of the GGS Backup Well. Only one of the other three wells has a known completion (161-188 feet). The three active wells are located almost one-half mile from the tentative location of the GGS Backup Well shown on **Figure 1**.

Estimates of drawdown due to pumping of the GGS Backup Well were made using a single-layer analytical groundwater flow model based on the Theis (1935) equation. A transmissivity of 7,600 ft^2/day and a storage coefficient of 0.005 were used in the model based on aquifer testing conducted in the area. Using the analytical model, drawdowns of about 12 feet after 30 days of pumping or 17 feet after 90 days of pumping were predicted at a distance of one-half mile from the well. These drawdown estimates are conservative because continuous pumping for such long periods is unlikely. Most of the water pumped by the GGS Backup Well would come from deeper, semi-confined aquifers; and drawdowns in shallower wells would be less than those estimated with the single-layer model.

Under current conditions, groundwater levels are relatively high in the western portion of the Natomas Basin, and chronic groundwater level declines are not anticipated even with the increased pumping. The proposed GGS Backup Well would not be expected to significantly reduce the yield of existing wells, and no mitigation is considered necessary.

Woodland Planting Wells

SAFCA plans to install two wells to irrigate young trees to be planted in woodland corridors east of the SREL. The northern woodland corridor consists of about 21 acres in Reaches 7 and 8. For planning purposes, it is assumed that the northern well would be located near the center of the corridor in the southern portion of Reach 7. The southern woodland corridor will consist of about 40 acres in Reaches 12A to 15. It is assumed that the southern well would be located near Radio Road in Reach 14. The tentative well locations are shown on **Figure 1**.

Woodland planting corridors will only be irrigated for the first three to five years until the trees become established. Continued irrigation will be unnecessary after the roots reach the water table, which is relatively shallow along the SREL. Irrigation would be most frequent in the summer months, especially during the first two years, and the frequency would decrease beginning in the third year. Assumptions about the irrigation schedule and flow rates are based on data provided by River Partners for existing woodland plantings in Reach 2. The irrigation schedule and water demand based on the existing woodland plantings are shown in **Table 2**. The irrigation schedule ranges from 24 hours every other week in March and November to 24 hours three times a week in July and August during the first two years. The average plant spacing is 12.5 feet, resulting in a plant density of about 280 plants per acre. The plants are irrigated with a drip system, and each emitter has an output of two gallons per hour (gph). If all plants are irrigated simultaneously, the flow rate would need to be 560 gph or 9.3 gpm per acre. This is a conservative estimate because the drip system would likely be divided into sets so that the irrigation schedule could be staggered.

Based on a pumping rate of 9.3 gpm per acre, the woodland planting well capacities would need to be about 195 gpm and 372 gpm for the northern and southern wells, respectively. These capacities were rounded off to 200 and 400 gpm in **Table 1**. The maximum water demand is estimated to be seven af/mo (total of 37 af/yr) for the northern woodland corridor and 14 af/mo (total of 70 af/yr) for the southern woodland corridor. In order to obtain sustained yields of 200 to 400 gpm, it is assumed that the well depths would range from 250 to 300 feet. As discussed above for the GGS Backup Well, the woodland planting wells would not be perforated above a depth of 100 feet.

Well mapping conducted by Mead and Hunt (2008) shows nine existing wells within a one-half mile radius of the proposed location of the northern Woodland Planting Well. Seven of these are identified as domestic wells and two as “other”. As shown in **Table 1**, these wells range in depth from 115 to 269 feet with an average of 158 feet. A total of 13 wells are mapped within a one-half mile radius of the proposed location of the southern Woodland Planting Well. Ten of these are identified as domestic wells, two as irrigation wells, and one as “other”. These wells range in depth from 115 to 225 feet, with an average of 152 feet.

Estimates of drawdown caused by the woodland planting wells were made using the groundwater flow model discussed above. Drawdowns due to the northern Woodland Planting Well are predicted to be about one foot after 30 days of pumping and about two feet after 90 days of pumping at a distance of one-half mile from the well. Drawdowns due to the southern Woodland Planting Well are predicted to be about two feet after 30 days of pumping and about three feet after 90 days of pumping at a distance of one-half mile from the well. The estimated drawdowns are conservative because the irrigation schedule does not require that the wells be pumped continuously. Predicted drawdowns due to pumping of the woodland planting wells are considered to be negligible and will not impact the yield of any nearby existing wells.

Fisherman's Lake Marsh Wells

SAFCA plans to install two wells to irrigate managed marsh planned for the Sharma and AKT properties west of Fisherman's Lake. The original proposed well locations were in the southwest corner of the Sharma property and the northwest corner of the AKT property, which would made the wells very close to each other and too close to existing Natomas Basin Conservancy (NBC) wells on the Natomas Farms property (north of Sharma) and the Cummings property (south of AKT). In order to reduce mutual interference among these wells, the tentative locations of SAFCA's Fisherman's Lake marsh wells have been moved to the eastern edges of the two properties (**Figure 2**). This provides a minimum well spacing of at least one-quarter mile between each of the four wells.

SAFCA plans to transfer ownership and management of the Sharma and AKT properties (including the proposed wells) to the NBC for creation of wetland and grassland habitat. Up to 50 acres of managed marsh are planned for the eastern portions of both properties. The managed marsh would be irrigated primarily with surface water purchased from NCMWC, and the Fisherman's Lake marsh wells would supplement surface water supplies during November through March when NCMWC does not normally deliver water. NCMWC has a permit to deliver up to 10,000 af of surface water during the fall and winter months, so it may be feasible to irrigate the Sharma and AKT properties with surface water throughout the year. In that case, the Fisherman's Lake Marsh wells would only be needed for backup supply during critically-dry years.

The water demand for managed marsh areas to be created on the Sharma and AKT properties was estimated based on data for an existing well on NBC's Natomas Farms property, which is used to irrigate about 36 acres of managed marsh. Pumpage from the Natomas Farms Well is not metered, and the 2005-2009 pumpage estimates shown on **Table 3** are based on SMUD power use records. The Natomas Farms Well is 290 feet deep and has perforated intervals of 120-140 feet, 180-200 feet, and 270-290 feet. The capacity of the well is approximately 1,200 gpm at present. Based on the power use records and an estimated pump efficiency of 65 percent, the estimated annual pumpage ranged from a low of 75 af a high of about 220 af, as shown in **Table 3**. The maximum annual pumpage (220 af) occurred over a period of three months (January through March) in both 2007 and 2009. Since it began operation in 2005, the Natomas Farms Wells has not pumped for more than three consecutive months in any year. On a per acre basis, the highest annual water demand was 6.1 af/ac.

Based on a water demand of 6.1 af/ac over a three-month period, the maximum monthly pumpage required to irrigate 50 acres of managed marsh on the Sharma and AKT properties would be 105 af/month or about 800 gpm (**Table 1**). A perforated interval of approximately 100 to 400 feet in depth is estimated to sustain this level of production.

Well mapping conducted by Mead and Hunt (2008) shows six existing wells within a one-half mile radius of the tentative location of the northern Fisherman's Lake Marsh Well. Four of these are identified as domestic wells and two as irrigation wells (the NBC Natomas Farms and Cummings wells). As shown in **Table 1**, the domestic wells range in depth from 91 to 160 feet, with an average of 130 feet. Three existing wells have been mapped within a one-half mile radius of the proposed location of the southern Fisherman's Lake Marsh Well. Two of these are identified as domestic wells and one as an irrigation well (the NBC Cummings Well). Construction information is not available for the Cummings Well, but the two domestic wells are 113 and 120 feet deep.

Estimates of drawdown due to pumping of the Fisherman's Lake marsh wells were also made using the groundwater flow model. Pumping of the two Fisherman's Lake Marsh wells and the two existing NBC wells was simulated together, so that potential mutual interference among these wells could be evaluated. Mutual interference would be largest at the southern Fisherman's Lake Marsh Well, and a total drawdown of about 35 feet is predicted at this well after 30 days of pumping. This represents a drawdown of 22 feet due to pumping of the well itself and 13 feet due to mutual interference with the other three wells. The Fisherman's Lake Marsh wells are predicted to cause about seven feet of additional drawdown at the NBC Natomas Farms Well and ten feet of additional drawdown at the NBC Cummings Well after 30 days of pumping. This increased drawdown would not be expected have a measurable effect on the yields of the NBC wells.

The closest domestic wells are located almost one-half mile west of the proposed Fisherman's Lake marsh wells (**Figure 2**). Using the analytical model, the additional drawdown due to both Fisherman's Lake Marsh wells is predicted to be about nine feet after 30 days of pumping and 12 feet after 90 days of pumping at this location. This is slightly more than the drawdown estimated due the two existing NBC wells (eight feet after 30 days and ten feet after 90 days). No problems have been reported at any nearby wells due to pumping of the NBC wells.

Pumping of the Fisherman's Lake marsh wells is predicted to cause nine to 12 feet of additional drawdown depending on the pumping period. Drawdowns in shallow domestic wells would be less than those estimated with the single-layer model because most of the water pumped by the irrigation wells would come from deeper, semi-confined aquifers. This drawdown would occur primarily during the winter months when groundwater levels are normally high and other pumpage in the area is minimal. The additional drawdown due to this pumping would not be expected to cause reductions in the yield of nearby domestic wells.

Summary

This study evaluated the potential effects of drawdowns due to SAFCA's proposed habitat mitigation wells on existing nearby wells (primarily domestic wells). The increased pumping is not expected to significantly reduce the yield of any existing wells.

Other potential impacts of increased groundwater extraction (overdraft, land subsidence, groundwater quality impacts, and surface water impacts) were considered unlikely to occur and were not specifically analyzed for this study. The habitat mitigation wells could pump up to about 4,300 af during a critically-dry year, but the average annual pumpage would be expected to range from 1,100 to 1,200 af. The planned pumpage from the five new wells represents a small percentage of the total pumpage in the Natomas Basin and will not cause chronic groundwater level declines. Groundwater levels in the western portion of the Natomas Basin are high and have remained relatively stable over time, and these conditions are not expected to change due to pumpage from the proposed habitat mitigation wells.

Table 1
Proposed SAFCA Wells for Phase 4a Habitat Mitigation

		GGS Canal Backup Well[1]	Woodland Planting Well (North)[2]	Woodland Planting Well (South)[3]	Fisherman's Lake Marsh Well (North)[4]	Fisherman's Lake Marsh Well (South)[5]
Reach		6A	7-8	12-14	13	13
Duration		Indefinite	3-5 Years	3-5 Years	Indefinite	Indefinite
Frequency of Use		Only during critically-dry years	Annually (primarily April - October)	Annually (primarily April - October)	Annually (primarily Nov. - March)	Annually (primarily Nov.-March)
Irrigated Area	**(ac)**	NA	21 ac woodland corridor	40 ac woodland corridor	Up to 50 ac managed marsh	Up to 50 ac managed marsh
Estimated Well Depth	**(ft)**	500	250	300	400	400
Estimated Well Completion	**(ft)**	100-500	100-250	100-300	100-400	100-400
Estimated Well Capacity	**(gpm)**	2,200	200	400	800	800
Maximum Monthly Pumpage	**(af/mo)**	295	7	14	105	105
Maximum Annual Pumpage	**(af/yr)**	3,550	37	70	315	315
Existing Wells Within 1/2 Mile Radius		2 domestic (1 unused) 2 other	7 domestic 2 other	10 domestic, 2 irrigation, 1 other	4 domestic 2 irrigation	2 domestic 1 irrigation
Depth Range of Wells Within 1/2 Mile Radius	**(ft)**	125-204	115-269	115-225	91-290	113-120
Average Depth of Wells Within 1/2 Mile Radius	**(ft)**	165	158	152	162	117

1. GGS Canal flow requirements estimated by Mead & Hunt to be 20 cfs. GGS Canal will be supplied primarily by NCMWC surface water. Well would be used only during critically-dry years when NCMWC surface water could be reduced by 25%. Projected pumping rate (2,200 gpm) = 4.9 cfs.
2. Temporary well to water woodland plantings in Reaches 6-9B for 3-5 years until tree roots are deep enough to reach water table. Estimated pumping rate and water demand based on data from River Partners for woodland plantings in Reach 2.
3. Temporary well to water woodland plantings in Reaches 12-15 for 3-5 years until tree roots are deep enough to reach water table. Estimated pumping rate and water demand based on data from River Partners for woodland plantings in Reach 2.
4. Well to be used by Natomas Basin Conservancy (NBC) to supplement NCMWC surface water for irrigation of up to 50 acres of managed marsh on the Sharma property. Well would be used only during months when NCMWC water is not available (typically November-March). Estimated pumping rate and water demand based on data from NBC's Natomas Farms well.
5. Well to be used by NBC to supplement NCMWC surface water for irrigation of up to 50 acres of managed marsh on the AKT property. Well would be used only during months when NCMWC water is not available (typically November-March). Estimated pumping rate and water demand based on data from NBC's Natomas Farms well.

Table 2
Water Demand Estimate for Woodland Planting Corridors[1]

Year	Month	Irrigation Schedule	Monthly Operation (hours)	Water Demand (gph/ac)	Water Demand (gpm/ac)	Water Demand (gal/ac)	Water Demand (af/ac)	21-ac Corridor Water Demand (af)	21-ac Corridor Pumping Rate (gpm)	40-ac Corridor Water Demand (af)	40-ac Corridor Pumping Rate (gpm)
1 & 2	Jan	-	-	-	-	-	-	-	-	-	-
	Feb	-	-	-	-	-	-	-	-	-	-
	Mar	24 x 2	48	558	9.3	26,784	0.08	1.73	195	3.29	372
	Apr	16 x 4	64	558	9.3	35,712	0.11	2.30	195	4.38	372
	May	24 x 4	96	558	9.3	53,568	0.16	3.45	195	6.58	372
	Jun	24 x 6	144	558	9.3	80,352	0.25	5.18	195	9.86	372
	Jul	24 x 8	192	558	9.3	107,136	0.33	6.90	195	13.15	372
	Aug	24 x 8	192	558	9.3	107,136	0.33	6.90	195	13.15	372
	Sep	24 x 6	144	558	9.3	80,352	0.25	5.18	195	9.86	372
	Oct	24 x 4	96	558	9.3	53,568	0.16	3.45	195	6.58	372
	Nov	24 x 2	48	558	9.3	26,784	0.08	1.73	195	3.29	372
	Dec	-	-	-	-	-	-	-	-	-	-
	Total		1,024			571,392		36.82		70.14	
3	Jan	-	-	-	-	-	-	-	-	-	-
	Feb	-	-	-	-	-	-	-	-	-	-
	Mar	24 x 2	48	558	9.3	26,784	0.08	1.73	195	3.29	372
	Apr	16 x 4	64	558	9.3	35,712	0.11	2.30	195	4.38	372
	May	24 x 4	96	558	9.3	53,568	0.16	3.45	195	6.58	372
	Jun	24 x 4	144	558	9.3	80,352	0.25	5.18	195	9.86	372
	Jul	24 x 4	192	558	9.3	107,136	0.33	6.90	195	13.15	372
	Aug	24 x 4	192	558	9.3	107,136	0.33	6.90	195	13.15	372
	Sep	8 x 4	144	558	9.3	80,352	0.25	5.18	195	9.86	372
	Oct	-	-	-	-	-	-	-	-	-	-
	Nov	-	-	-	-	-	-	-	-	-	-
	Dec	-	-	-	-	-	-	-	-	-	-
	Total		880			491,040		31.65		60.28	

1. Estimates based on data provided by River Partners for existing woodland plantings in Reach 2.

Table 3
Pumpage Estimate for Natomas Basin Conservancy Natomas Farms Well Based on Power Use Records

	Estimated Pumpage					Estimated Irrigation Rate				
Month	2009 (af)	2008 (af)	2007 (af)	2006 (af)	2005 (af)	2009 (af/ac)	2008 (af/ac)	2007 (af/ac)	2006 (af/ac)	2005 (af/ac)
Jan	133	48	77			3.7	1.3	2.1		
Feb	63	27	76	56		1.7	0.7	2.1	1.5	
Mar	23		69			0.6		1.9		
Apr				10	78				0.3	2.1
May					17					0.5
Jun										
Jul				13					0.4	
Aug										
Sep										
Oct				52	10				1.4	0.3
Nov										
Dec				51					1.4	
Total	**219**	**75**	**221**	**183**	**104**	**6.1**	**2.1**	**6.1**	**5.0**	**2.9**

Assumptions:

1. Estimated well efficiency = 65 percent (based on pump curve and current well capacity of 1,200 gpm)
2. Assumed energy usage = 200 kwh/af (based on data for other wells with similar size pumps and similar efficiencies)
3. Estimated irrigated acreage = 36.2 acres (managed marsh and open water areas only)

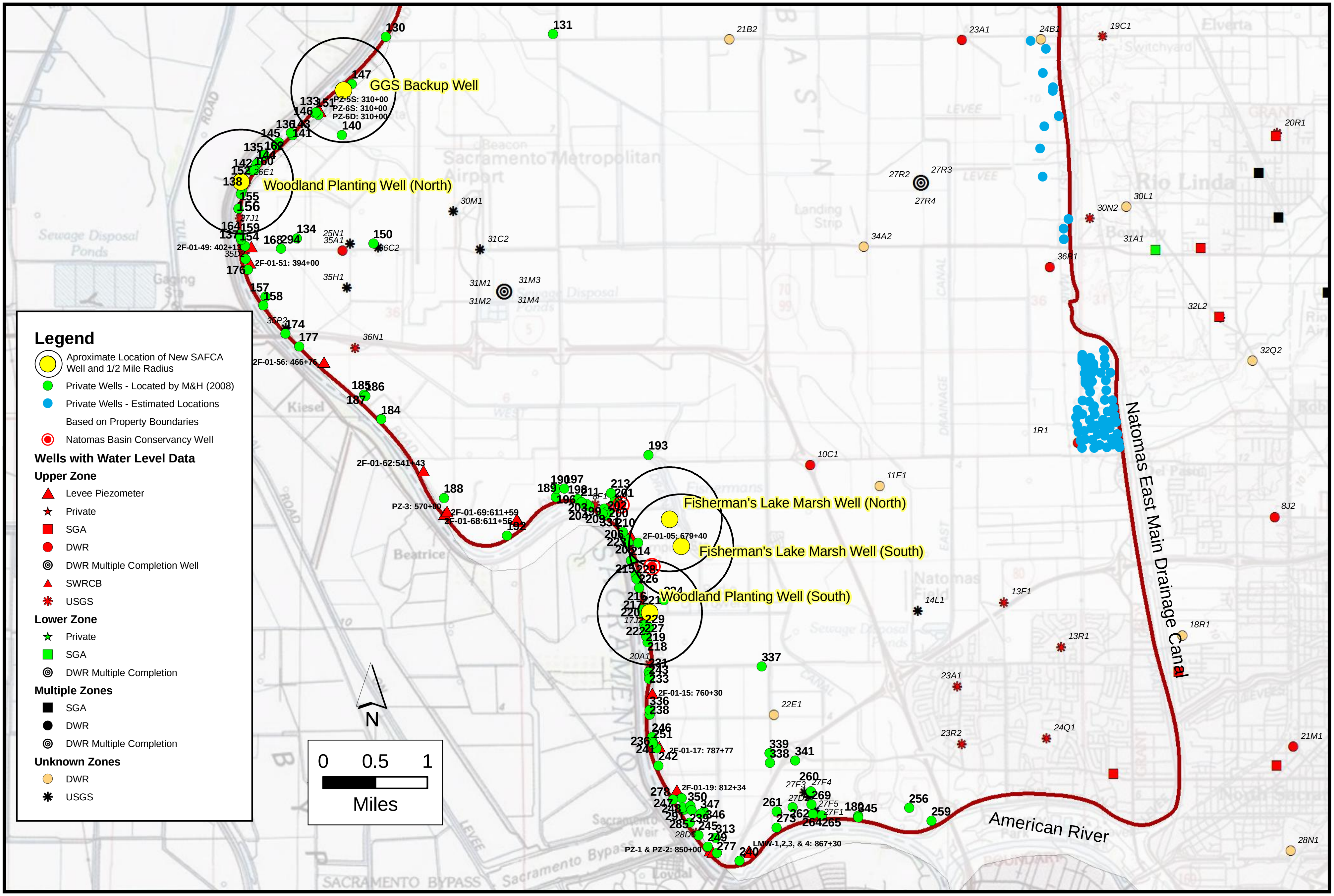


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Figure 1
Proposed SAFCA Wells for Habitat Mitigation and Existing Wells In and Near the Natomas Basin

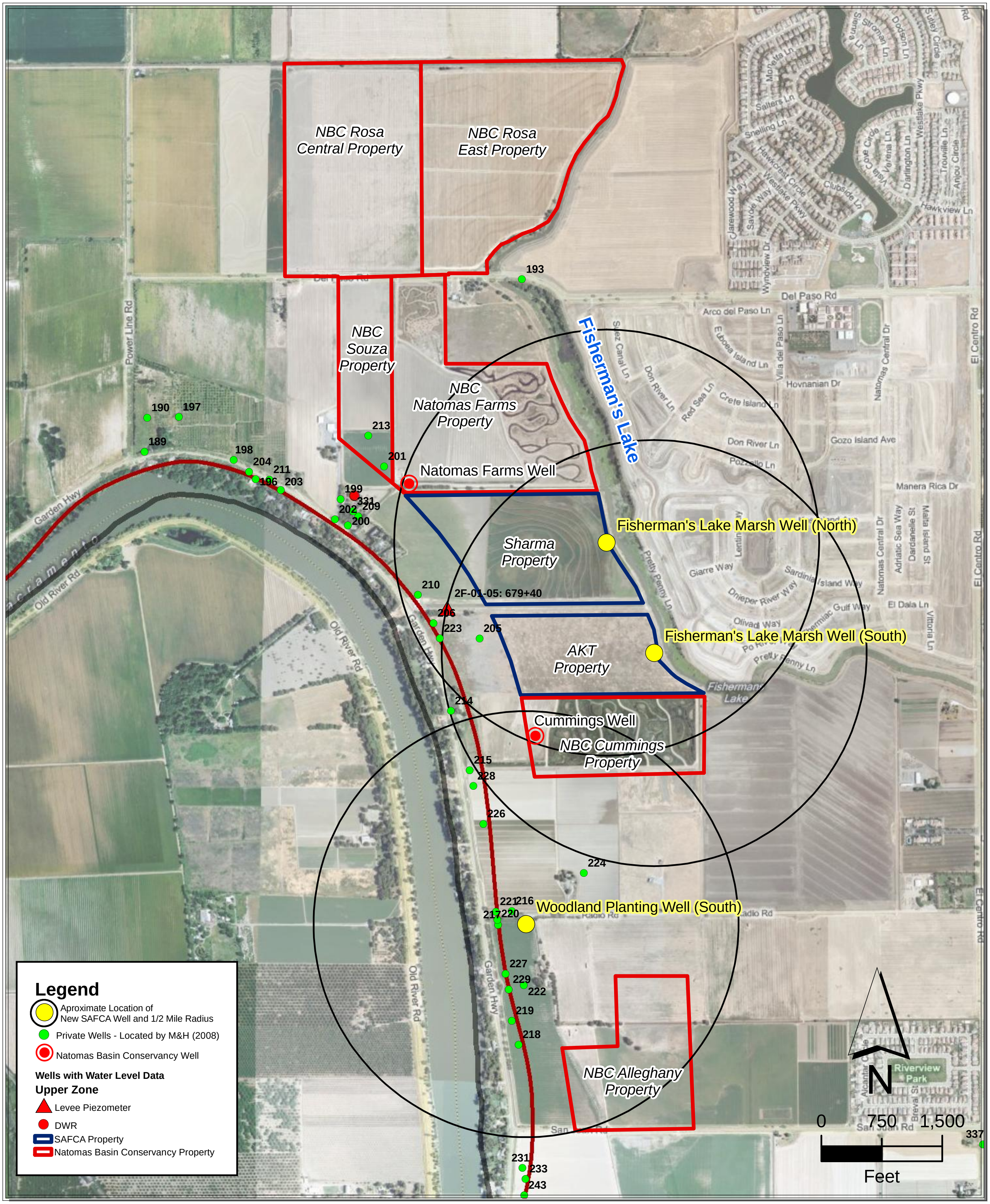

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Figure 2
SAFCA and Natomas Basin Conservancy Properties and Wells Near Fisherman's Lake