

## Memo

**To:** Pete Ghelfi (SAFCA) and Ric Reinhardt (MBK)  
**From:** Alberto Pujol and Dan Wanket (GEI)  
**CC:** Barbara Gualco, Graham Bradner (GEI), Mark Stanley (HDR)  
**Date:** October 27, 2015  
**Re:** Sacramento River East Levee Improvement Project (SRELIP)  
Alternatives Evaluation - Summary Memorandum  
GEI Project No. 1328580

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The purpose of this Summary Memorandum is to present an overview of the process that has been followed to identify Sacramento River East Levee deficiencies, identify and evaluate alternative remedial measures, and recommend remedial measures for implementation.

## 1. Background and Purpose

### 1.1 Introduction and Project Purpose

After examining the cause of more than 30 levee breaches in the Central Valley of California in 1997 and the levee breaches during the Katrina event in New Orleans, a new urban levee standard was established by the U.S. Army Corps of Engineers (USACE). This new standard requires that underseepage deep under existing levees be addressed. Consequently, the USACE has undertaken the American River Watershed Common Features General Reevaluation Report (GRR) to evaluate what work needs to be done to Sacramento's flood control system to bring the levees into compliance with the new standard and to further reduce flood risk to the most at-risk urban area in the country.

The GRR will be completed and sent by the Administration to Congress for authorization in 2016. However, historically, Congress has taken several years to authorize projects. Waiting to reduce flood risk to the most vulnerable areas, including the levees along the Sacramento River, is not acceptable. Therefore, the Sacramento Area Flood Control Agency (SAFCA) has decided to take advantage of a provision in Federal law that allows for early implementation of a Federal project by non-Federal cost-sharing partners and construct the portions of the USACE GRR project that will provide the most immediate flood risk reduction to the public.

The State of California has agreed to provide the majority of the funding for this early implementation project on the condition that the USACE agrees to credit the work towards the non-Federal share of the USACE GRR project. Therefore, the early implementation project must meet the USACE and State requirements.

SAFCA and its consultant team have decided to set the scope of the early implementation to include the work required to obtain 1-percent-annual-chance of exceedance (100-year) flood protection accreditation from the Federal Emergency Management Agency (FEMA) and to achieve compliance of the levee system with the California Department of Water Resources (DWR) Urban Levee Design Criteria (ULDC) for 200-year level of protection. Accordingly, the goal of the Sacramento River East Levee Improvement Project (SRELIP) is to obtain FEMA accreditation for the SREL and to evaluate where the levee is deficient in accordance with the ULDC. Since along this reach of the Sacramento

River the difference between the 100-year (for FEMA) and 200-year (for ULDC) water surface elevations is typically only on the order of 1 foot, the levee is being evaluated using the 200-year water surface elevations which also meet FEMA criteria.

## **1.2 Project Constraints**

Constraints that may affect the project objectives are as follows:

- The primary objective is that the project must achieve acceptance by the USACE, the State of California Department of Water Resources (DWR) and other agencies with jurisdiction, primarily including FEMA and Central Valley Flood Protection Board.
- The project must be economically feasible
- The project must consider and minimize temporary construction impacts
- The project must consider environmental constraints and minimize environmental impacts as practicable
- The project must consider real estate and encroachment constraints and minimize property (right-of-way) impacts as practicable

## **1.3 Previous Geotechnical Studies**

There have been numerous geotechnical studies of the SREL system over the last 50 years. The most recent and pertinent reports are described below.

- DWR recently completed a screening-level feasibility study referred to as the Urban Levee Evaluations project, which addressed approximately 350 miles of levees in the Central Valley protecting populations of 10,000 people or more. DWR retained URS (now part of AECOM) to conduct analyses of the Sacramento River Study Area, which includes the SREL study area. The evaluations were performed using a 200-year water surface developed by URS, and represent screening-level analyses and cost estimates of conceptual remedial alternatives. The screening-level analyses results do not constitute a final opinion about the condition of a levee reach or sub-reach relative to either FEMA accreditation or ULDC. The evaluation included collection of historical information, exploration and testing, and geotechnical analyses. The work is documented in a *Phase 1 Geotechnical Data Report* dated November 2008, *Supplemental Geotechnical Data Report* dated September 2011, *Geotechnical Evaluation Report Volume 1, Existing Conditions* dated July 2014, and *Geotechnical Evaluation Report Volume 2, Remedial Alternatives* dated January 2015.
- The USACE prepared the General Reevaluation Report (GRR) for the American River Common Features Project, which also includes the SREL study area. A Geotechnical Office Report was prepared as a supplemental report to the Geotechnical Appendix of the GRR. The Geotechnical Office Report presents the results of geotechnical analyses and feasibility level geotechnical recommendations to address levee height, geometry, erosion, access, vegetation, seepage, and slope stability deficiencies within the GRR study area. The Geotechnical Office Report included review of available geology, geomorphology, and geotechnical information, past performance and flood control system construction history/improvements, and identification of levee performance deficiencies through geotechnical analysis and engineering judgment. USACE's work is summarized in the *Geotechnical Office Report*,

*American River Watershed Common Features Project General Reevaluation Report* dated October 2013.

- SAFCA retained Kleinfelder to perform an initial evaluation of the Sacramento River East Levee (SREL) south of the confluence with the American River and other levees that protect Sacramento (excluding Natomas) for potential FEMA accreditation. Kleinfelder identified those segments of levee it could certify as being in compliance with FEMA geotechnical criteria for embankment and foundation stability for FEMA's 100-year flood event (FEMA Certifiable Reaches). Kleinfelder also identified a number of reaches that potentially may not meet FEMA geotechnical criteria and need further investigations and more detailed evaluations. This work was summarized in a *Geotechnical Data Report* dated June 2013 and a *Problem Identification Report* dated August 2013, and is summarized in Table 1. Kleinfelder also analyzed the SREL system using the DWR criteria for a 0.5-percent annual chance of exceedance (200-year) flood event and Hydraulic Top of Levee water surface elevation, as outlined in the ULDC. The results of Kleinfelder's additional analysis are documented in the *ULDC Geotechnical Results Summary* dated March 2014. In this report, Kleinfelder concluded that the reaches that met criteria at the 100-year water surface elevations also met ULDC at the 200-year and Hydraulic Top of Levee water surface elevations.

As shown on Table 1, of the 14.6 miles of SREL south of the confluence with the American River, Kleinfelder identified 6.5 miles of levee meeting FEMA geotechnical criteria and 8.1 miles of levee judged as being potentially deficient with respect to embankment and/or foundation seepage and stability requirements. Levee segments identified by Kleinfelder as meeting and not meeting geotechnical criteria are shown on Figure 1. The 8.1 miles of potentially deficient levee, located south of R Street and north of the East Bay Municipal Utility District Freeport facility, constitute the study area for the additional, more detailed, geotechnical evaluations summarized in this memorandum.

#### **1.4 SRELIP Project Scope**

SAFCA retained the team formed by GEI Consultants, Inc. and HDR Engineering, Inc. (Design Team) to conduct further evaluation of the 8.1 miles of the SREL identified by Kleinfelder as potentially not meeting FEMA's geotechnical criteria for embankment and foundation stability. The Design Team is evaluating the existing levee and developing remedial designs to meet FEMA geotechnical criteria for the 100-year flood event and achieve compliance with the ULDC. In summary this work involves:

- Conducting additional subsurface investigations and more detailed engineering evaluations of the potentially deficient levee reaches.
- Identifying and evaluating potential remedial alternatives for the levee reaches that are confirmed to be deficient.
- Supporting SAFCA in the development of a Locally Preferred Plan encompassing the selected levee improvements for those levee reaches
- Preparing designs of the improvements to meet FEMA and ULDC criteria.

### **1.5 Role of USACE and DWR**

Since SAFCA is planning an early implementation of the Federal project, the levee improvements to a Federal Project Levee, such as the SREL, require approval from the USACE and Central Valley Flood Protection Board. Separately, as a funding agency, DWR also has approval authority over the design of the project. Since the levee improvements are advanced work towards a Federal Project, there are additional criteria that must be met to make sure that work is creditable.

### **1.6 Geotechnical Design Criteria**

The geotechnical design criteria adopted for this project follow FEMA guidelines, USACE criteria, and DWR's ULDC. If it is determined that a levee reach does not meet foundation and embankment stability criteria for the FEMA 100-year water surface, remedial measures will be designed to meet both USACE criteria and ULDC. If portions of the levees are found to meet FEMA (100-year) criteria but not the 200-year criteria, remedial measures will be evaluated to meet DWR ULDC criteria. Geotechnical design criteria utilized by the Design Team for the SREL is described in the *Geotechnical Design Criteria and Technical Approach Memorandum*, Revision 2 dated October 2015.

### **1.7 Relationship Between the SREL Project and USACE General Reevaluation Report**

The USACE is preparing the GRR for the American River Watershed Common Features Project. The GRR is a Federal interest effort in evaluating alternatives to reduce flood risk in the Sacramento region, which includes the Sacramento River (including SAFCA's SREL study area) and American River Watersheds, and most of the developed portions of the City of Sacramento, the Natomas basin, and portions of Sacramento and Sutter Counties. The GRR study area also includes other flood control facilities, including the levees within the study area, Fremont and Sacramento Weirs, and the Sacramento and Yolo Bypasses.

As discussed in Section 1.1, the purpose of SAFCA's SRELIP is to implement portions of the USACE GRR project ahead of the USACE to provide immediate flood risk reduction. This work will increase the levee's performance by developing and implementing remedial designs that meet FEMA criteria for the 100-year base flood event, and conform with the ULDC. It is anticipated that this work will be completed over the next 3 to 5 years with a combination of state and local funding. SAFCA is also pursuing higher levels of flood protection that exceed the State's ULDC minimum requirement. The primary vehicle to accomplish this is the GRR and the State of California's Central Valley Flood Protection Plan. Accordingly, SAFCA's SREL project will address the most pressing seepage, slope stability, erosion protection, and high-hazard vegetation and encroachment issues along critical locations of the levee in advance of the implementation of the USACE project.

Proposed improvements to the SREL as part of the USACE American River Watershed Common Features Project may include, but are not limited to, actions that improve the resiliency and robustness of the levee system such as improving geotechnical stability, freeboard or reducing the susceptibility of the levee to erosion. Levee improvements implemented as part of the USACE project would be in addition to what is implemented by SAFCA as part of the SRELIP. The USACE will not begin design of the project until the GRR is completed and authorized by Congress and funding for project implementation has been appropriated.

## 2. Summary of Identified Deficiencies

Geotechnical evaluations of the 8.1 miles of potentially deficient levee along the SREL were performed to refine or confirm those reaches of levee in the study area that have deficiencies that require remediation. The evaluations included the following:

- Review of Previous Levee Modifications
- Review of Past Levee Performance During High-Water Events
- Evaluation of Levee Surface Conditions
- Assessment of Subsurface Conditions
- Geotechnical Analyses

A summary of the evaluations performed by the Design Team is provided below. Details are presented in the *Embankment & Foundation Stability Memorandum* dated October 2015.

### 2.1 Review of Previous Levee Modifications

Review of available information on previous levee modifications was performed. As-built documentation for previous levee remediation projects was obtained from USACE, DWR, and SAFCA. Previous levee modifications in the study reach over the past approximate 40 years include:

- Re-alignment of an approximate 1,500-foot long portion of the levee near Sutterville Road.
- Installation of shallow cutoff walls by the Corps in the early 1990's along significant portions of the levee in the study area.
- Installation of deep-mixing-method (DMM) cutoff walls between 2003 and 2006 in two locations in the Pocket and one location in the Little Pocket.
- Installation of a seepage berm and relief wells at Pioneer Reservoir.
- Installation of relief wells at Sump 132.

The above-listed levee modifications and improvements were incorporated into the Design Team's geotechnical analyses as existing conditions.

### 2.2 Review of Levee Past Performance

A review of levee performance records was performed to identify reaches of levee that are more prone to heavy seepage and seepage-related problems during actual high-water events. The past performance records are based on observations recorded by levee maintenance personnel, levee inspectors, and private citizens. Past performance can be a useful indicator of future performance, assuming levee conditions do not significantly deteriorate (through mechanisms such as rodent activity, damage from seepage, human action, or waterside erosion), and can also indicate areas along the levee system that may be most prone to deteriorating conditions. Thus, the past performance records provide valuable data helpful in identifying levee reaches where future problems are more likely to occur and assessing the need for remediation.

Performance records reviewed included available levee inspection records, historic documents and reports, USACE and DWR records, media reports, and personal accounts from adjacent residents and individuals involved in levee monitoring. Based on review of the available levee performance records, the project area has experienced numerous seepage and erosion issues, with limited deep-seated slope stability problems. Reports of past performance issues are notably more frequent within the southern portion of the project area, in the Pocket and Little Pocket neighborhoods, than within the northern project area.

### ***2.3 Evaluation of Surface Conditions***

Surface conditions in the project area were reviewed and evaluated including the following:

- Levee construction materials and methodologies.
- Review of site topography, including the levee structure, waterside berm, and landforms landward of the levee for approximately 2,000 feet.
- Review of surficial mapping, including existing structures, roads, parks, and other infrastructure and features.
- Review of geologic and geomorphic studies.

### ***2.4 Assessment of Levee Subsurface Conditions***

Assessment of levee subsurface conditions began with review of existing geotechnical explorations within the study area. The Design Team reviewed 349 existing geotechnical explorations performed within the study area between 1962 and 2013 by DWR, USACE, and several geotechnical consultants. Review of the existing subsurface data revealed gaps in the existing data, including large distances between explorations, insufficient data at critical locations along the landside levee toe, or insufficient explorations at depth to fully characterize key soil strata.

The Design Team added 159 explorations to address the identified gaps in the existing data and support identification and design of remedial measures. The added explorations consisted of 63 geotechnical borings, 84 cone penetration tests (CPTs), 3 borings with piezometers, and 9 test pits. Laboratory testing was performed on samples taken from the explorations to classify soils and support development of soil properties for seepage and stability analyses.

The levee typically consists of 15 to 20 feet of levee fill, primarily sandy soils with occasional layers of silt or clay. The upper foundation layer under the levee is formed by silt or clay and silty sand. Below the upper foundation layer is a sand and gravel aquifer, and below the aquifer is a lower foundation silt or clay. The upper foundation silt or clay soils were found to range from less than 5 feet to more than 50 feet in thickness. The aquifer thickness varied widely but was found to exceed 120 feet in some locations.

### ***2.5 Geotechnical Analyses of Existing Conditions***

The levee system was subdivided into “reaches”, which are characterized as having reasonably consistent geotechnical characteristics. The levee within the study area was divided for analysis into 27 reaches (numbered Reach 1 through Reach 27), based on interpreted stratigraphy, geology, geomorphology, soil properties, and limits of previous remediation. Geotechnical analyses were performed for the reaches using a total of 46 cross sections, with each reach analyzed by at least one cross section, and some reaches having multiple cross sections to address particular nuances along the

system. Once stratigraphy and soil properties were assigned with associated cross sections, seepage and stability analyses were performed.

Control of seepage beneath the embankment (underseepage) and through the embankment (through seepage) is critical to the performance of the levee. Excess pore pressures due to seepage can result in sand boils, loss of soil due to internal erosion, embankment instability, and foundation instability. Seepage analyses were performed using SEEP/W, a two-dimensional finite element modeling computer program, developed by GEO-SLOPE International, Ltd.

Stability analyses were generally performed on the same analysis cross sections evaluated for seepage. The load cases typically considered for stability evaluation were “rapid drawdown” conditions for the waterside slope and “steady-state seepage” conditions for the landside slope. Stability analyses were performed using SLOPE/W, a slope stability analysis software program also developed by GEO-SLOPE International, Ltd.

## ***2.6 Identified Levee Geotechnical Deficiencies***

Based on the results of the subsurface investigation, evaluations and geotechnical analyses described above, it was concluded that seepage under and through the existing levee is the primary cause for high exit gradients and low slope stability factors of safety in reaches that do not meet FEMA or ULDC criteria. Approximately 5.6 miles of the 8.1 miles of levee evaluated require remediation to address seepage and/or stability concerns, while 2.5 miles of levee do not require remediation to address geotechnical deficiencies. Table 2 presents a summary of levee reaches evaluated and the identified geotechnical deficiencies for those reaches that require remediation.

## **3. Levee Remediation Measures Evaluated**

The Design Team conducted an evaluation to identify potential remedial measures that could be implemented to address geotechnical deficiencies in the study area. The evaluation included an initial identification and review of potential remedial measures, evaluation of the performance of remedial measures implemented for levee projects in the Sacramento Valley, and an Alternatives Identification workshop with SAFCA and the Design Team. The workshop was held on October 30, 2013 and focused on seepage remediation measures since seepage is considered the primary geotechnical deficiency in the levee system based on past performance and site conditions. An initial understanding of advantages and disadvantages of the alternatives was discussed in the workshop. Factors such as cost, schedule, property impacts and constraints, environmental impacts, impacts on existing infrastructure, geotechnical considerations, hydraulic considerations, environmental permitting issues, levee safety regulatory issues, temporary construction impacts, and operational and maintenance considerations were considered during the workshop to evaluate alternatives.

### ***3.1 Remedial Measures Carried Forward***

Based on the conceptual evaluations, and comments obtained during the Alternatives Identification workshop, the following remedial alternatives were selected to carry forward for analysis in the evaluation of remedial measures for those levee reaches that were determined to require remediation. The relative advantages and disadvantages listed for each alternative were evaluated in selecting the recommended remedial measures described in Section 4 below. Typical conceptual details for each alternative are shown in Figures 2 through 6.

**Conventional slurry trench cutoff wall**

Cutoff walls provide a vertical low-permeability barrier to seepage flows (Figure 2). The most common cutoff walls constructed in the Central Valley, including along the SREL, is the conventional slurry trench cutoff wall. Slurry trench cutoff walls are typically installed by excavating a 3-foot-wide trench along the length of the levee, either at the crest or at the waterside toe, and backfilling it with a fluid mixture of excavated soil and bentonite. Excavation is performed with a long-reach excavator, and the backfill materials are mixed near the trench. The trench is stabilized with bentonite slurry between excavation and backfill. The practical reach of the long-reach excavators is about 85 feet below ground surface.

The depth of temporary levee degrade and requirements for temporary staging areas are important considerations for cutoff wall construction. During construction of the shallow cutoff walls in the Pocket in the early 1990s, the pressure of the slurry in the excavated trench caused cracking of the levee and foundation (hypothesized to result from hydraulic fracturing of the foundation) and loss of slurry to the river and/or backyards of adjacent homes at five separate locations. Repair of these failures involved the excavation of the entire levee within the cracked reach, reinforcement of the foundation, and reconstruction of the levee. After those experiences, the USACE began to require a temporary levee degrade of half the height of the levee to minimize the potential for hydraulically fracturing the levee when there is an open trench filled with fluid. With subsequent successful experience in the installation of conventional slurry trench cutoff walls, the minimum temporary levee degrade required by the USACE has been reduced to one-third of the levee height to mitigate the potential for hydraulic fracturing. This levee degrade also provides a sufficient working platform for the large equipment needed for cutoff wall construction.

Staging areas for bulk material silos, bentonite hydration facilities, and mixing facilities are also required for cutoff wall construction. These facilities need to be located near the landside or riverside toe of slope (if a riverside bench is present) and staged no further than about 2,000 feet apart, which is the maximum distance to pump slurry to the excavation or equipment.

- Advantages:
  - Low cost cutoff wall alternative
  - Passive seepage reduction; addresses both underseepage and through-seepage
  - No operation and maintenance requirements
  - Lower gradients and reduced seepage volume on landside of levee
  - No permanent impacts to adjacent property owners
- Disadvantages:
  - Limited to approximately 85 feet deep
  - Need to degrade at least the upper one-third of levee
  - Need for additional temporary right-of-way for slurry mixing ponds, temporary stockpiles, etc.
  - Overhead needs to be cleared of vegetation for long-stick excavator

**Deep Mixing Method (DMM) cutoff walls**

DMM cutoff walls are constructed by mixing soil in-place with a bentonite and cement slurry using mixing augers (Figure 3). In the DMM method, the wall is constructed in panels, with no open trench. DMM walls can generally be constructed deeper than conventional trench slurry walls, with



depths of at least 135 feet being attainable. Recently soil-bentonite (without cement) DMM walls have been constructed in the Sacramento area but are not yet widely accepted due to the observed settlement behavior of the mixed wall material immediately following mixing. As a result of problems with soil-bentonite DMM walls, the USACE is currently requiring cement be added to the mix.

For DMM cutoff walls, hydraulic fracturing is typically not a concern, so the amount of levee degrade required is governed by the required working platform width. DMM cutoff walls require a working platform with a width of at least 35 feet, which typically results in a levee degrade of at least three feet. Staging area requirements for a DMM cutoff wall would be somewhat less than that required for conventional slurry trench cutoff wall since DMM construction requires less extensive bentonite hydration and conveyance facilities.

Installation of DMM walls uses specialized crane-mounted triple augers, with height greater than the depth of the wall. All overhead vegetation needs to be removed to enable unobstructed passage of the crane-mounted equipment. Panel construction is slow. Maintaining verticality of the augers at depth is a major concern that affects continuity of the wall. Accordingly, quality control measures are more involved than for conventional slurry trench cutoff walls. The need for specialized equipment, slow productivity, and difficult quality control all contribute to an installation cost that typically is 2-3 times the cost of a conventional cutoff wall. As a result, DMM walls are usually only employed at locations where the required wall depth exceeds the capability of conventional slurry trench cutoff wall construction.

- Advantages:
  - Maximum wall depth up to about 135 feet
  - Passive seepage reduction; addresses both underseepage and through-seepage
  - No operation and maintenance requirements
  - Lower gradients and reduced seepage volume on landside of levee
  - No permanent impacts to adjacent property owners
  - Requires less degrade than conventional slurry trench method
- Disadvantages:
  - Two to three times the cost of conventional slurry trench cutoff wall
  - Use of high crane needs clearing all vegetation above the working platform
  - Need to degrade the levee at least three feet
  - Slow installation
  - Wall continuity is a quality concern
  - Need for additional temporary right-of-way for grout and slurry mixing plant, temporary stockpiles, etc
  - The addition of cement makes the repair less resilient to damage from deformation in an earthquake.

### **Relief wells**

Pressure relief wells work by capturing underseepage flows from within the aquifer and transmitting them to a conveyance system, typically an open ditch or pipeline located near the landside toe of the levee. By providing a filtered exit for the pressurized seepage within the aquifer, the relief well

system provides an exit path for seepage flows that may otherwise emerge in an uncontrolled manner on the landside ground surface (Figure 4). Relief wells are installed along the landside levee toe or adjacent street using techniques typically used for drilling water wells. To install a relief well a drill rig is used to bore a hole into the ground to the required depth of the well, the well casing and well screen sections are then installed, and the well is developed by pumping water from the well to clean out the bentonite drilling fluid and to consolidate the well's filter pack. Water discharging from the well needs to be conveyed to a drainage pipeline or a collection ditch, which in turn drains laterally to a pump station or other discharge facility.

- Advantages:
  - Typically lower cost than cutoff walls (unless new pump station is required)
  - Passive seepage pressure reduction; addresses only underseepage
  - Can be used for deep aquifers where cutoff walls cannot be constructed economically
- Disadvantages:
  - Right-of-way required on the landside of the levee for wells and discharge collection and conveyance system
  - Relief wells tend to reduce in effectiveness over time, requiring maintenance of wells and collection system, including periodic rehabilitation and replacement
  - Needs pump stations to return collected flows to the river during high stages
  - Need to evaluate relief well discharge water quality for potential contaminants
  - Applicable only to conditions where the aquifer is overlain by a low permeability strata – not effective in areas where the aquifer is unconfined
  - Not effective for reduction of through-seepage
  - Lower level of reliability than other remediation measures due to the need for an “actively” functioning water removal system as opposed to the passive nature of slurry walls and seepage berms.

### **Stability berms**

A stability berm is a prism of compacted soil placed on the slope of a levee to act as a buttress to increase stability factors of safety (Figure 5). When placed on the landside slope, a filter/drain zone can be incorporated into the stability berm to capture seepage that would otherwise exit on the unprotected slope, potentially eroding embankment material. Stability berms can be used to address through-seepage or through-seepage-driven landside slope stability problems. Stability berms are not appropriate for remediating excessive uplift gradients associated with underseepage, because the high gradients simply shift landward to the toe of the stability berm. However, drained stability berms do provide a measure of protection for shallow, unconfined seepage from the foundation by providing a controlled, filtered exit point for subsurface seepage.

Typical stability berms are about 10 feet high and about 10 to 25 feet wide, and generally require additional right-of-way landward of the existing levee to accommodate the berm footprint. Alternatively, an “inset” stability berm could be constructed within the existing levee in areas where the existing levee is very wide and access along the landside levee toe is severely constrained. The inset stability berm would be constructed by excavating the landside levee slope, constructing the filter/drain zone, then rebuilding the levee slope to approximately the original grade with compacted fill (Figure 6).

- Advantages:
  - Passive through-seepage mitigation
  - Generally less expensive than cutoff walls
  - Also increases landside slope stability
- Disadvantages:
  - Not effective for reduction of confined underseepage
  - Permanent right-of-way may be needed along landside levee toe
  - Filter design and construction critical to performance

### **Toe drains**

The primary purpose of a toe drain is to capture through-levee seepage before it exits the lower embankment and control and filter the discharge in such a way as to reduce velocity and soil-carrying capacity of the discharge. A toe drain would typically be used when through-seepage or through-seepage-driven landside slope stability is problematic. Toe drains would be constructed by excavating into the levee prism and constructing a filtered drain within the downstream toe of the levee embankment.

- Advantages:
  - Passive seepage reduction
  - Less expensive than cutoff wall
- Disadvantages:
  - Not effective for reduction of underseepage
  - Permanent right-of-way may be needed along landside levee toe
  - Filter design and construction critical to performance

### **Seepage berm**

The primary purpose of a seepage berm is to (1) increase vertical effective stresses to counteract uplift pressures near the landside levee toe and (2) increase seepage path lengths so that high seepage gradients are reduced and shifted farther away from the levee toe.

Seepage berms are generally designed to be on the order of 100 to 300 feet wide (minimum 4 times the levee height), measured from the levee toe with thicknesses varying from about 5 feet at the levee toe to about 3 feet at the berm toe. Most of the areas landward of the SREL are heavily developed. Therefore, this alternative is not feasible except possibly in limited locations along the northern end of the study area.

- Advantages:
  - Passive seepage mitigation
  - Construction less expensive than a deep DMM cutoff wall
  - Minimal operation and maintenance costs (i.e. vegetation maintenance)
- Disadvantages:
  - Seepage berm width is typically at least four times the levee height, so there are significant ROW requirements and resulting impacts to adjacent development.

- Significant embankment material requirements, including hauling and access issues.

### **3.2 Remedial Measures Not Carried Forward**

The following potential remedial measures were reviewed and discussed during the workshop and were not carried forward for alternatives evaluation at this time:

- Pervious toe trenches - due to lack of subsurface visibility at the discharge location to confirm performance and current difficulty of gaining regulatory acceptance.
- Sheet pile cutoff walls – due to high cost and difficulty of gaining regulatory acceptance, specifically from the USACE Sacramento District.
- Alternative trenching machine (“chainsaw”) cutoff wall method such as DeWind or the Trench Remixing and Deep wall method (TRD) – these cutoff wall methods have not been used in the Central Valley and are currently not accepted for use by the USACE Sacramento District.

## **4. Recommended Levee Remediation Measures**

In support of developing the recommended levee remediation measures, an alternatives evaluation was conducted of potential suitable levee repairs to address geotechnical deficiencies, and geotechnical analyses were repeated incorporating the recommended remedial alternative as needed. These evaluations and recommended remedial measures are summarized below.

### **4.1 Alternatives Evaluation**

An alternatives evaluation was conducted to assess the most appropriate remedial measure for each reach needing remediation. The potential remedial measures that could be feasibly implemented as possible mitigation for identified levee deficiencies were screened against the identified constraints in assessing which levee rehabilitation measure would be recommended for implementation. Feasible remedial alternatives were identified for each reach of levee requiring remediation and were ranked according to the following factors (or criteria) for selecting the preferred remedial measures:

- Performance: Ranking was based upon how well the proposed measure addresses the identified problems and, if there are multiple potential measures, upon how the proposed measures compare in terms of their robustness and redundancy.
- Ease of Implementation: Ranking was based upon how readily the measure could be implemented.
- Comparative Cost: Comparative costs were developed for each alternative and then ranked from lowest to highest.
- Minimize Environmental Impacts: Ranking focused on the degree to which the proposed remedial measure may impact the surrounding environment from a ground disturbance perspective, including whether construction would enlarge the project footprint or impact sensitive habitat.
- Minimize Impacts to Residents: Ranking focused on the degree to which the proposed remedial measure could impact nearby residences and the community, including expanding the footprint onto adjacent parcels, disrupting necessary access across or adjacent to the

levee, disrupting current public access to trails on or along the levee, and need for construction access through adjacent neighborhoods.

- **Maximize Flexibility to Changing Criteria:** Ranking was based upon how easily the remedial measure could be augmented or expanded to address potential future changes in design criteria.
- **Regulatory Acceptance:** Ranking reflected the design team's assessment of regulatory agency acceptance of the remedial measure to address the identified deficiency.

Details of the alternatives evaluations and ranking for each reach are provided in the *Alternatives Evaluation Memorandum* dated October 2015. The geotechnical evaluations for remediated conditions are presented in the *Embankment & Foundation Stability Memorandum* dated October 2015. A summary of the recommended remedial measures based on the alternatives evaluation is provided in Section 4.3 below.

## **4.2 Geotechnical Evaluation of Remediated Conditions**

Geotechnical analyses of levee remediated conditions were performed at analysis sections which either did not meet criteria or had past seepage or stability performance issues. The remediated conditions analyses approach and design criteria followed the same approach used for the existing conditions analyses described above. Remediated condition models were based on existing conditions models, but with the proposed remediations in place. Remediated conditions were analyzed with a design 200-year water surface elevation that was slightly higher (0.5 to 1.0 foot) than the existing conditions 200-year water surface elevation to provide an additional measure of robustness in consideration of hydrologic uncertainties and the potential for climate change.

## **4.3 Recommended Levee Remediation Measures**

Table 3 summarizes the recommended levee remediation measures based on the alternatives evaluations and remediated conditions analyses described above. The extent of recommended remediation measures is shown in plan-view on Figures 7 through 10.

In general, the recommended levee remediation measures rely heavily on (1) drained stability berms to address through-seepage deficiencies, and (2) conventional slurry trench cutoff walls to address underseepage deficiencies. These remediation measures are recommended because of locally available expertise, cost considerations, reliability, minimal property impacts, and lack of maintenance requirements. Alternative remedial measures were determined to be more appropriate in the following locations:

- North of Highway 50 – additional relief wells have been included to supplement existing relief wells around Pioneer Reservoir.
- Central Little Pocket – a DMM cutoff wall has been recommended at a location where the required cutoff depth exceeds the capacity of conventional slurry trench equipment.
- Pocket – relief wells have been recommended at three locations where a thick aquifer and availability of adjacent pump stations make relief wells a practical alternative that is more cost effective than a DMM cutoff wall.

## 5. Riverbank Erosion Repairs

An evaluation of existing riverbank erosion sites and erosion potential was performed by MBK Engineers in collaboration with Kleinfelder and is summarized in a report entitled *SAFCA Levee Certification Erosion Report* dated January 2014. The evaluation considered historical performance, hydraulic analysis of the 100-year flood event, geometric criteria, geotechnical soil conditions, and field observations. As part of this work, a boat survey was conducted of the east (left) bank of the Sacramento River extending from the confluence of the American River to Freeport. In summary, one erosion site was recommended for immediate repair prior to FEMA accreditation, eight erosion sites were recommended for corrective action within a three-year time window of accreditation, and 11 sites were identified as requiring regular monitoring before and after a high-water event but not requiring immediate attention. SAFCA's intent is to include in the SRELIP the repair of the nine sites that have been identified to need work over the relative short term. The locations of these nine erosion sites are shown on Figures 7 through 10. The 11 monitoring sites will be monitored and addressed by the levee maintaining agencies (LMAs) as needed as part of ongoing routine maintenance actions.

The nature of erosion at the sites requiring repair appears to range from shallow, wave-generated erosion to deeper toe scour erosion. Consequently two erosion repair concepts are recommended to address the two primary erosion mechanisms: 1) wave erosion; 2) toe scour. Both concepts include resistive measures to address wave erosion. The repair approach incorporates bioengineered features to add habitat value to the repairs and aims to preserve important riparian habitat and berm width where practical. The conceptual design is illustrated on Figure 11.

To provide resistance to wave erosion, reconstruction of the riverbank will incorporate a rock berm at mean summer water elevation to buffer the impacts of wave wash and to provide geotechnical stability for the upper bank. Soil fill will be installed above the rock bench to re-establish the riverbank. The soil fill slope will be re-vegetated with a variety of native woody and herbaceous plants for future cover and terrestrial/aquatic habitat as well as erosion protection (i.e., to attenuate wave action, reduce flow velocity, and stabilize the soil. In stream woody material will be incorporated at and below mean summer water elevation to develop aquatic habitat, with the intent to provide hydraulic variability and cover from predators for listed anadromous fish species. Wetland terraces will be included on the waterside of the rock bench where possible to allow for tule planting, which is intended to provide wave attenuation and shallow water refugia habitat for fish. For those sites that also require toe scour mitigation, the portion of bank below water will be reconstructed with rip rap.

## 6. Next Steps

The design process for the recommended Sacramento River East Levee Improvement Program (SRELIP) remediation measures is currently at approximately 30 percent completion. Over the next 10 to 12 months SAFCA's consultant team will work closely with the Central Valley Flood Protection Board and Department of Water Resources (DWR) staff to flesh out the details of the design in a manner that is consistent with the state's Urban Levee Design Criteria. This effort will enable SAFCA to enter into an agreement with the DWR to implement the SRELIP with the state contributing up to 70 percent of the project cost. The agreement will stipulate that the state's contributions are contingent on receiving USACE's permission to implement the SRELIP and USACE's agreement to credit state and local expenditures on the project toward the non-federal cost of the American River Common Features Project. These determinations will be made when the project design is 90 percent complete and will require USACE to conclude that the design is consistent with applicable USACE levee design criteria.

**Tables:**

Table 1 – Summary of Findings from Kleinfelder Problem Identification Report

Table 2 – Sacramento River East Levee - Identified Geotechnical Deficiencies

Table 3 – Sacramento River East Levee - Recommended Remedial Measures

**Figures:**

Figure 1 – Sacramento River East Levee Overview

Figure 2 – Soil – Bentonite Cutoff Wall Conventional Slurry Trench Method

Figure 3 – Soil-Cement-Bentonite Cutoff Wall Deep Mixing Method

Figure 4 – Relief Well and Piezometer Details

Figure 5 – Drained Stability Berm

Figure 6 – Inset Drained Stability Berm

Figure 7 – Proposed Remediation Plan, Sheet 1 of 4

Figure 8 – Proposed Remediation Plan, Sheet 2 of 4

Figure 9 – Proposed Remediation Plan, Sheet 3 of 4

Figure 10 – Proposed Remediation Plan, Sheet 4 of 4

Figure 11 – Erosion Repair Concepts