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| **Project** | Non-Urban Levee Evaluations Project<br>Contract 4600008101, Task Order U115 |
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| **Subject** | Risk Analyses of Burrowing Mammal Activities in State Plan of Flood Control Systems |
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## INTRODUCTION

This technical memorandum (TM) evaluates the impact of burrowing animals on the geotechnical performance of levees. This TM is prepared in compliance with Task Order U115's Task 1 scope of work, dated November 8, 2013, under Master Agreement 4600008101.

The Department of Water Resources' (DWR) Levee Evaluations Program includes the Urban Levee Evaluations Project (ULE), which covers Project and appurtenant non-Project levees in highly populated areas of the Sacramento River and San Joaquin River system portions of California's Central Valley, and the Non-Urban Levee Evaluation Project (NULE), which covers the remaining Project and appurtenant non-Project levees in these river systems.

The primary purpose of ULE/NULE, as established by DWR in the State Plan of Flood Control, is to evaluate state-federal Project levees and appurtenant non-Project levees to determine whether they meet defined geotechnical criteria and, if appropriate, identify remedial alternative(s) to meet those criteria.

## BACKGROUND

Animal burrowing in levees can cause or contribute to a levee breach by amplifying one or more of the following common failure modes:

- Through Seepage
- Underseepage
- Landside and/or Waterside Slope Instability

Animal burrowing activity contributes to these failure modes by creating extensive void systems which significantly reduce both seepage paths, and weaken levee embankments. These potential failure mechanisms are illustrated in Figure 1.

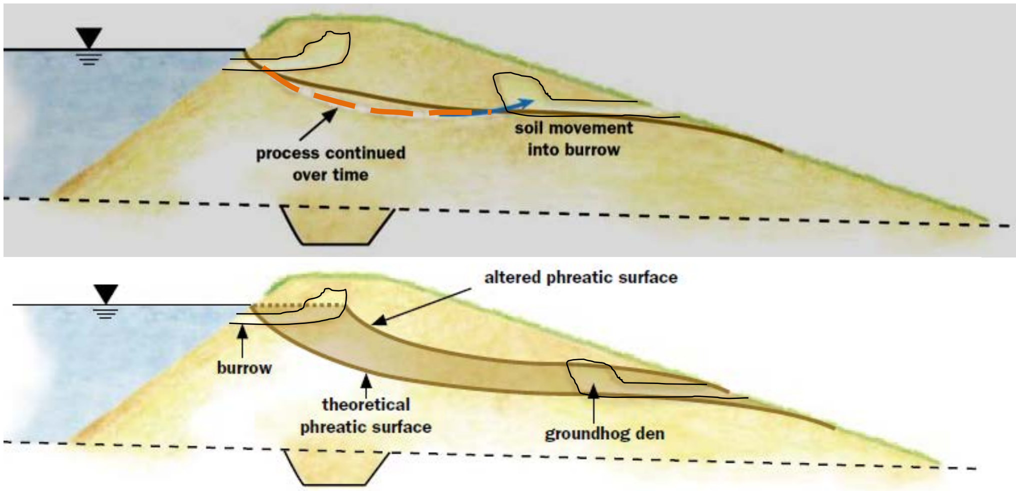


**Figure 1. Illustration Showing Seepage Related Levee Failure Mechanism Due To Burrowing Animals (FEMA, 2005).**

A University of California research project, titled *Mammal Burrow Characterization and Effectiveness of Burrow Grouting* (Cobos, 2012), was presented at the 2012 Levee Vegetation Research Symposium. The presentation highlighted a project that assessed and mapped the actual extent of animal burrowing activity using cement and urethane grout injected into burrows. Animal burrowing is proven to create extensive networks within the levee embankment. Figure 2 shows a levee embankment where the burrow holes on the landside slope were grouted and then carefully exposed. The grouted burrow holes were also painted for clarity. Additionally, a three dimensional model was created and is also shown in plan in Figure 3. The plan view shows the burrow network penetrating completely through the levee. More discussion about the potential role of burrowing animals in levee failure can be found in the presentation (Cobos 2012).

## Common Species of Burrowing Animals

Common species of burrowing animals within the Central Valley include:

- California ground squirrels (*Otospermophilus beecheyi*) whose burrow holes can range from 2.5 to 6 inches in diameter and can create extensive networks below ground.
- Botta's pocket gophers (*Thomomys bottae)*, whose burrowing activities can displace large volumes of soil. Burrow holes are typically 2 to 3 inch diameter.
- Beavers (genus *Castor*), which are semi-aquatic mammals that excavate burrows on the waterside of the levee, with entrances located underwater (up to several feet).
- Muskrats (*Ondatra zibethicus)*, which are semi-aquatic mammals that excavate burrows on a levee's waterside, creating burrow entrances located underwater (up to several feet).

- California voles (*Microtus californicus)*, which forage on the water surface but may excavate shallow (i.e., less than 6-inch-diameter) underground burrows. Burrow holes are typically 2 to 3 inches in diameter.
- Carnivores such as coyotes (*Canis latrans)*, gray foxes (*Urocyon cinereoargenteus)*, red foxes (*Vulpes vulpes)*, striped skunks (*Mephitis mephitis)*, and raccoons (*Procyon lotor).* These species may excavate dens in a levee embankment. Carnivore burrow hole diameters vary widely in diameter, but in most cases are greater than 6 inches in diameter.

The most commonly observed burrowing animals are gophers and squirrels in California's Central Valley (DWR, 2011).

**Figure 2. Photo Showing Investigation of Animal Burrowing Activity.**

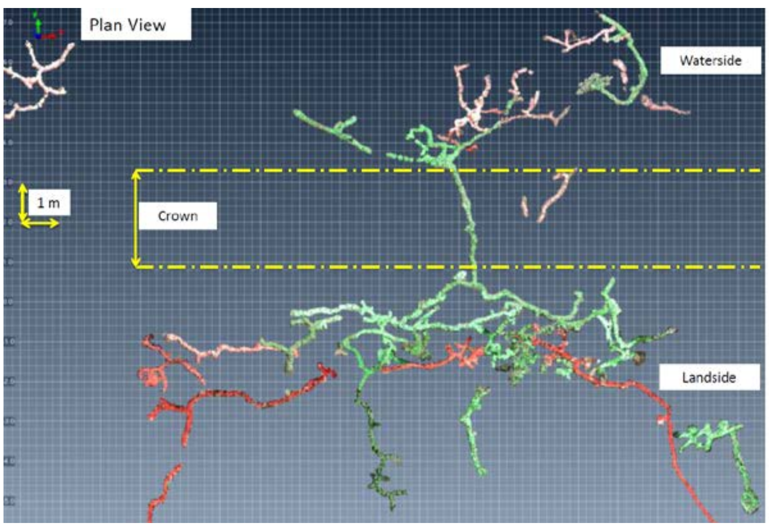


**Figure 3. Illustration Showing the Network of Animal Burrowing Activity.**

## STUDY APPROACH

The current study was performed in three phases:

- Phase 1: collecting available documentation concerning burrowing animal activity on levees.
- Phase 2: reviewing and summarizing each case history.
- Phase 3: geotechnically analyzing a conceptual model of levees for seepage and stability, both with and without burrowing animal activity. Study results were used to corroborate the effect of burrowing animal activity with the levee performance.

## PHASE 1: COLLECTION OF DOCUMENTATION

Phase 1 of the study involved collecting case histories, searching through the levee evaluations database, and corresponding with experts working on levee-related research projects. The compiled results were divided into two groups:

- Burrowing animal activity that resulted in a significant breach or failure
- Burrowing animal activity impacted levee performance but did not result in a breach or failure

### Levee Evaluations Database

Data collection entailed systematically searching existing state, federal, and local agency information sources, cataloging this information in the levee evaluations database, and developing data search and GIS interface features to facilitate methodical review of the collected data. Data collection efforts also included collecting historical reports, interviewing personnel from over 75 local maintenance agencies, and performing field reconnaissance surveys of 900 miles of levee. This unprecedented effort conducted as part of NULE project, resulted in the compilation of the levee evaluations database, which is the most comprehensive database about levee conditions and history in the Central Valley. The levee evaluations database consists of over 9,000 records that provide information about levees ranging from construction records to levee performance history during high water events.

### Levee-related Research Projects Compilation

In addition of the above NULE collected information, URS contacted experts working on levee-related research projects to obtain animal burrowing case histories throughout the United States.

## PHASE 2: SUMMARY OF CASE HISTORIES

The compiled information from Phase 1 was reviewed and summarized as selected case histories in Phase 2. The case histories, which are spanning throughout the United States, are examples of the potential consequences burrowing animal activity has had on levees.

Ten selected case studies are summarized below, and were reviewed to determine the potential impact of burrowing animals on levee performance.

- Upper Jones Tract, California
- Dry Creek near Wheatland, California
- Glenn Colusa Canal, California
- Truckee Canal, Nevada
- Pin Oak Levee System, Missouri
- Pleasant Grove Creek Canal, California
- Medford Island, California
- Wright Elmwood Tract, California
- Staten Island, California
- Hat Creek Forebay Embankment, California

The summary below is grouped into two categories: cases that resulted in a breach or a major failure, and cases where there was a significant performance issue (seepage, stability etc) or near failure.

### Case Histories with Breach Records Or Major Failures

#### Upper Jones Tract

A levee failed along the Middle River levee protecting the western edge of the Upper Jones Tract. The breach was located approximately 1 mile south of the BNSF Railroad crossing at Middle River, which is about 10 miles west of Stockton, California. The breach occurred at high tide on a sunny day on June 3rd, 2004. Eyewitness accounts support the likelihood that the breach occurred due to through seepage or underseepage.

Post-breach seepage analysis performed by engineering consultants HDR Inc. supports the likelihood that the breach occurred due to burrowing animal activity. After the breach, seepage analysis was performed at two locations: the breach site and a site located north of the breach site with historical seepage boils. The seepage analysis results indicated a higher gradient at the site located north of the breach. Therefore, an underseepage breach would have been more likely to have happened at the site to the north were it not for burrowing animal activity lowering the resistance causing failure.

This conclusion is supported because beaver activity was prevalent in the area and there was a large population of beavers on Beaver Island, which is adjacent to the Middle River levee's waterside slope. There was also beaver population noted in a landside canal approximately 750 feet upstream of the breach site. No data is available about the size or extent of animal burrowing at this location, as the levee breach washed away evidence. Figure 4 shows a photograph of the levee breach.


**Figure 4. Levee Breach along Middle River in Upper Jones Tract.**

### Dry Creek

A levee failed in 1997 on Dry Creek, upstream of Jasper Lane near Wheatland, California, as shown on Figure 5. According to RD 2103 personnel who were on site, the breach happened near the flood peak and only flowed for 2 to 3 hours before the water receded below the levee toe. There was minimal flooding associated with the breach. The levee is approximately 8 feet above the landside toe with a narrow crown at the breach site.

RD 2103 personnel stated there was burrowing animal (ground squirrel) activity in that reach prior to the event (Engler, 2013), and they are confident this activity caused the breach. The United States Army Corps of Engineers (USACE) believes the breach was due to under or through-seepage, and installed a small drained seepage berm using Public Law 84-99 funding to construct the berm after the event. It is difficult to prove the cause of this breach because evidence of animal burrowing was washed away during the breach.

The following facts support burrowing animal activity being the cause:

- There is an orchard on the landside, which is known to be a significant attractor for burrowing animals.
- Dry Creek experiences flash flows, so water is not against the embankment for extended periods (usually less than 12 hours for peak and recede) and this steady state seepage conditions were not likely to have occurred.

- Finally through and underseepage (that is non-burrowing animal related) is less likely, as the levee and foundation materials in this area are clay materials.

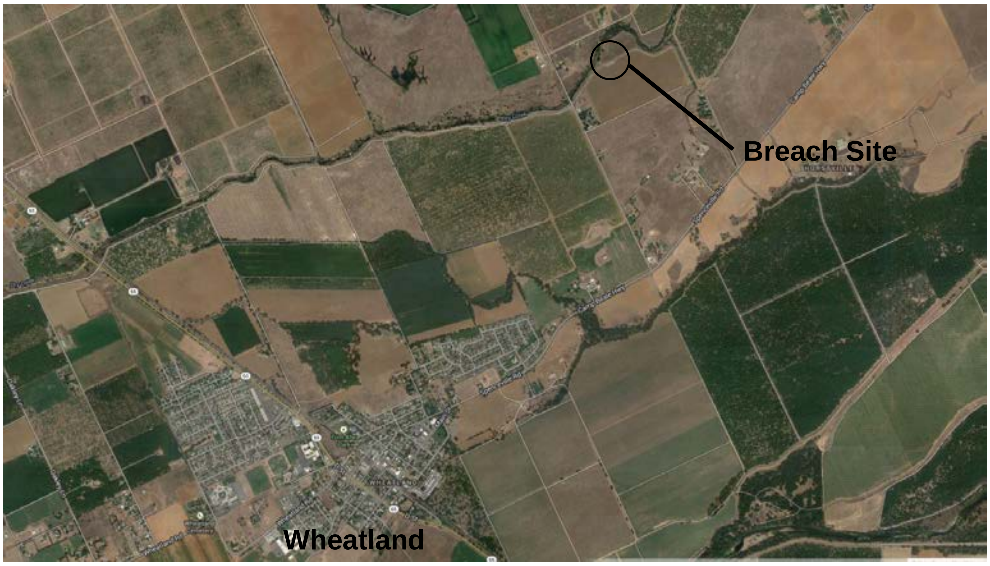


**Figure 5. Location Map Showing the Dry Creek Levee Breach.**

**Glenn-Colusa Canal Near Ord Bend**

A canal embankment failed near Ord Bend on October 22, 2013. Ord Bend is located just south of County Road 29, about a mile west of Highway 45 in Glenn County, California. The breach was approximately 25 feet wide and reached a depth of 6 to 8 feet below crest (the embankment is approximately 12 feet high) (Figure 6).

At the time of the failure, Glenn-Colusa Irrigation District Communications Director, Cynthia Davis, stated that the likely cause was due to a gopher hole. At the location of the breach there is an orchard on the landside of the embankment. There are no data available about the size or extent of animal burrowing at this location, as the levee breached and evidence was washed away.

**Figure 6. Levee Breach along Glenn-Colusa Canal near Ord Bend.**

**Truckee Canal at Fernley, Nevada**

A canal embankment failed on the morning of January 5, 2008 leading to the flooding of the City of Fernley, Nevada. The breach occurred following a storm event that led to a sudden rise of 3 feet in the water surface elevation. The canal embankments are about 8 foot above the landside toe elevation and the breach was approximately 70 feet wide. Water flowed through the breach for approximately 9 hours with water depths ranging from 1 to 4 feet throughout the adjacent housing developments. Damages were estimated at approximately $50 Million.

An analysis/investigation at the breach site was performed by URS for the Bureau of Reclamation and the leading theory was that the breach occurred as a result of animal burrowing activity. It is theorized that the sudden rise in water surface elevation led to a surge and increased pressure through the burrow holes and eventually seepage (URS, 2008).

There are no data available about the size or extent of animal burrowing at this location, as the levee breached and evidence was washed away.

Further analysis was performed at a section of embankment near the breach site shown in Figure 7. Several cracks were observed that parallel the embankment. Stratathane, an injectable two-component urethane, was injected into several burrows, and the embankment was carefully excavated. The excavation revealed several burrow tunnels made by muskrats. One t-shaped burrow was observed to run about 9 feet from the face of the waterside slope into the levee. The burrowing extended from the waterside slope to nearly the landside slope. Truckee-Carson Irrigation District personnel informed the investigation team burrowing animals were highly active in the area, and upon arrival at the scene burrowing animals were observed in the residual water.

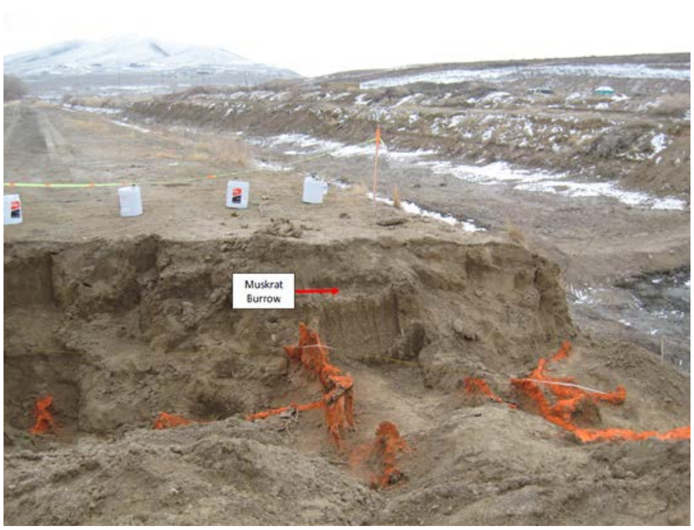


**Figure 7. Section of Embankment Analyzed and Excavated Near the Truckee Canal Breach at Fernley.**

### Pin Oak Levee System, Missouri

A levee failure occurred in the Pin Oak Levee System near Winston, Missouri on June 27, 2008. The levee system protects the city of Winston from backwaters of the Mississippi River. The levee parallels irrigation canals/ditches along the landside toe and along the waterside. According to information from the USACE St. Louis District, the levees protect the city from a 50-year storm event.

During the 2008 storm, a 2- to 3-foot foot parapet sandbag wall was constructed on the levee crown in anticipation of high water levels. As the water level increased, sliding on the landside slope and heavy through seepage were observed at two locations. The seepage was flowing from the levee toe just above the canal. Sandbag rings were constructed at both sites and Visqueen tarps were placed along the waterside slope. At the location of levee that eventually failed, large chunks of clay were emerging from the flow. Observers also noted muskrats diving in the area where the tarp was placed on the waterside slope.

After the breach, 2- to 3-inch-diameter burrow holes were observed along the perimeter of the breach site and there were indications of burrow holes mid-waterside slope near the base of the levee. Both sites were appealing to muskrats because the levee had water-filled ditches/canals. Animal burrows in the breached section of the levee can be seen in Figure 8.


**Figure 8. Levee Breach along Pin Oak Levee System.**

## Case Histories With Significant Performance Issue Or A Near Failure

### Medford Island

A levee nearly failed on the southern portion of Medford Island on January 24, 2009. Medford Island is located about 4 miles south of Highway 12 and 10 miles northwest of the city of Stockton, California. A sinkhole developed on the landside edge of the crown. At high tide water could be seen exiting mid-landside slope and at low tide the seepage was not observed.

The sinkhole on the landside edge of the crown exposed a large beaver den. The void left by the beaver den was approximately 5 feet high, 9 feet wide and 12 feet across the top of the levee. The thickness of the crown was about 2 feet. Water at high tide was filling the void left by the beaver den and could be seen exiting mid-landside slope. At lower tides, seepage was not occurring, so construction crews had time to collapse the beaver den shown in Figure 9 and backfill the void. Construction crews also observed several beaver dens in the nearby area and repaired those sites as well. Many of the beaver dens were exposed when Arundo vegetation was cleared along the waterline.

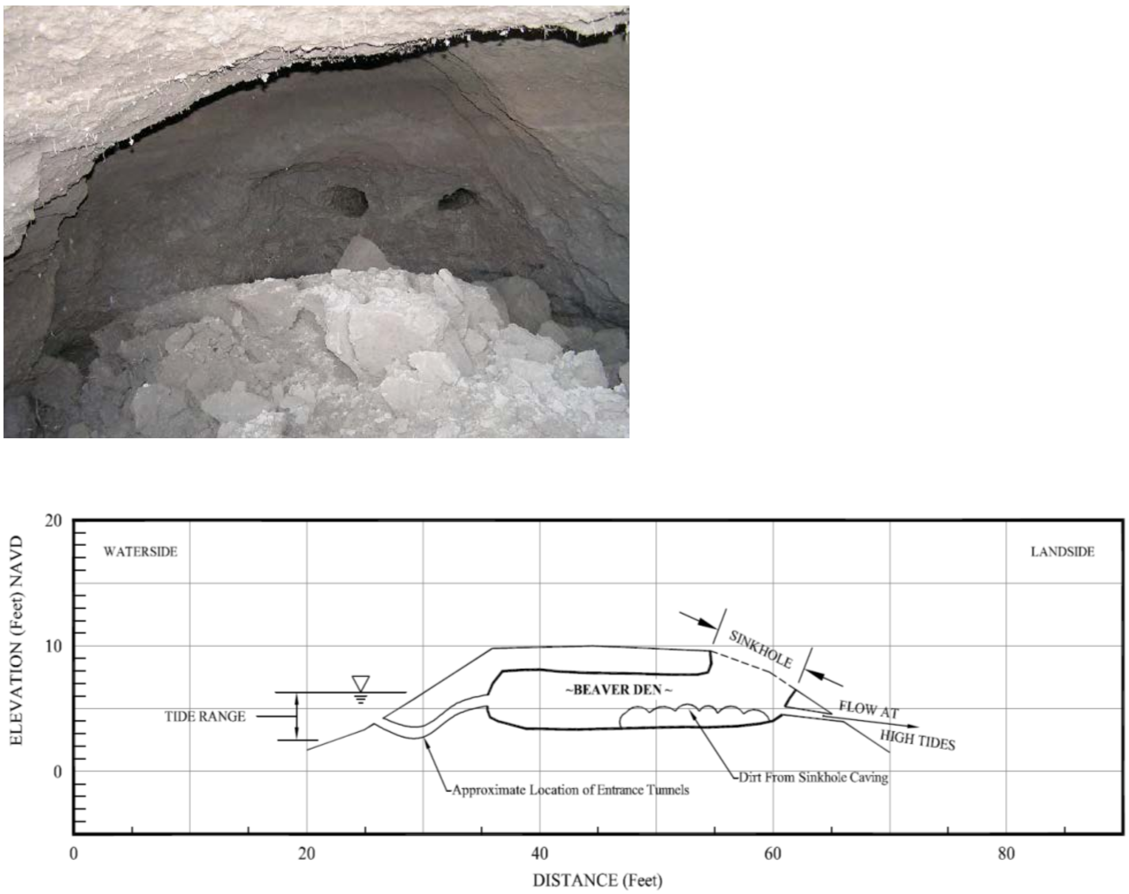


**Figure 9. Profile of Beaver Den and Image of Den along Medford Island.**

## Wright Elmwood Tract Northern Levee

A levee nearly failed along the northern levee of the Wright Elmwood Tract in December 2005. The Wright Elmwood Tract is adjacent to the Lincoln Village and Brookside communities located on the west side of Stockton, California (Figure 10). At the peak water surface elevation there was approximately 1 foot of freeboard. A sinkhole developed on the levee crown and seepage was observed emanating from the lower half of the landside slope.

The sinkhole was assumed to be caused by the collapsing of a beaver den, and squirrel holes observed on the landside slope were concentrating flows out from the landside slope. A contractor collapsed the beaver den and backfilled the levee, which stopped the seepage. It is theorized that the collapsing and filling of the beaver den prevented the levee failure.

**Figure 10. General location map showing the Wright Elmwood Tract Northern Levee.**

## Staten Island, California

A levee nearly failed on Mokelumne River along Staten Island in June of 2007. The near breach occurred during the summer when there was no rainfall. A large boil was found exiting the landside levee slope near the toe as shown on Figure 11. It was believed that the boil was a result of a collapsed beaver den (Harder, 2013). A barge-mounted crane was brought in to drive sheet piles, and an excavator partially dug out and filled the beaver den. Construction activities were successful in stopping the through seepage.


**Figure 11. Sand Bag Ring Around Landside Boil and Sheet Pile Wall along Staten Island Levee to Prevent Near Breach.**

**Hat Creek 1, Forebay Embankment**

The Hat 1 Forebay is located in Shasta County, about seven miles northeast of Burney, California. The forebay embankment nearly failed on March 14, 2012 when a sinkhole was observed on the crown that was approximately 3.5 feet long and 2 feet wide. The forebay was drained following the observation to prevent a breach. Historically, seepage had occurred in the area several times. Several repair attempts were made prior to the 2012 incident, including construction of a seepage berm shown in Figure 12. The sinkhole was located near the interface of the original embankment and the 2009 repair seepage berm. The seepage increased when the water surface elevation of the forebay was raised by 1 foot. After the forebay was drained. water could be seen emanating from the waterside slope at several locations between new and old shotcrete joints (Bowers et. al).

Cone penetration test soundings were performed and revealed a large void near the sinkhole just below the ground surface. Several holes from the cone penetration test probe could not be filled with grout or required more grout than expected. The sinkhole was backfilled with controlled low strength material (CLSM) and an exploration trench was dug, revealing numerous and extensive burrowing activity in the vicinity. Additionally, burrow openings with diameters as large as 4 inches were observed on the landside of the embankment.


**Figure 12. Arial View of Hat Creek Forebay Embankment Showing History of Repairs.**

## Pleasant Grove Creek Canal

The Pleasant Grove Creek Canal (PGCC) is part of the Natomas East Main Drainage Canal (NEMDC) west levee system, which protects approximately 55,000 acres of land in the Natomas Basin in Sacramento, California. The Natomas Basin is bounded on the west by the Sacramento River, on the south by the American River, on the east by the PGCC and NEMDC, and on the north by the Natomas Cross Canal. Within the basin are the North and South Natomas communities, the Sacramento International Airport, Interstate 5, Interstate 80, Highway 99, and thousands of acres of agricultural land.

An animal burrow was observed during inspections in January and February of 2008. Collapse features such as depressions and holes were documented along the waterside toe of the PGCC levee north of Howsley Road. These features were documented along an approximately 950 foot long section of levee from Station 830+50 to 840+00 (Figure 13). The levee was repaired prior to a high water event; therefore, no further damage occurred.

The collapse features and holes were associated with numerous 1- to 3-foot diameter tunnels or burrow holes along the waterside toe. The collapse feature extended greater than 10 feet into the levee and appeared to be caused by beaver activity.

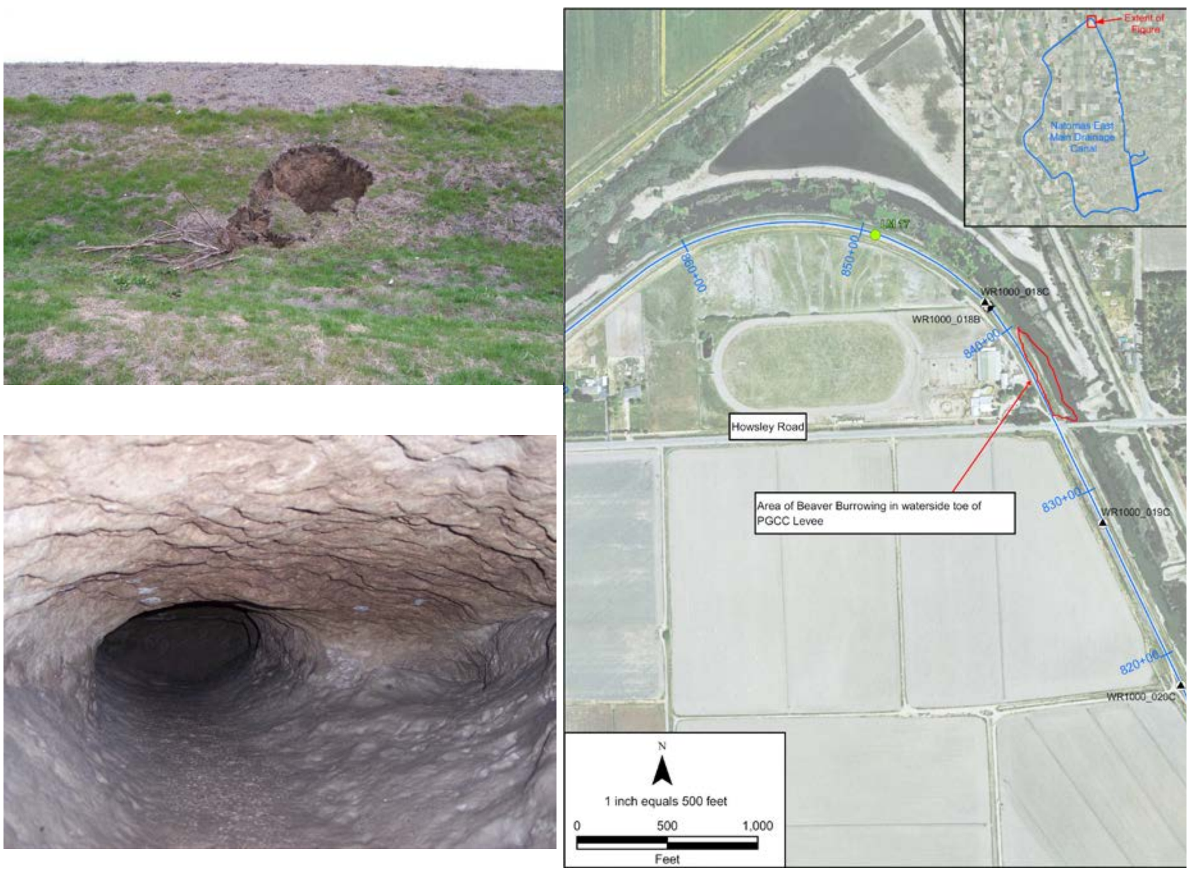


**Figure 13. Burrowing Activity Observed along Pleasant Grove Creek in Natomas.**

## Other Levee Performance Records

In addition to the case histories identified above, numerous performance records were identified in the levee evaluations database. The following five cases are a selected sample of performance records related to animal burrowing activity.

### Sacramento River, Left Bank, Station 12269+55

An interview with the LMA (Tehama County Public Works) took place in 2011, and a Levee Condition Questionnaire was also completed. The LMA stated that there is historical through-seepage in this area associated with animal activity, and that the landside slope was sandbagged in the recent past. Animal activity was noted in the questionnaire as occurring in the levee crest and both slopes. The levee’s waterside and crest were covered with visqueen in the recent past, and revetment is present.

### Jackson Creek, North of Elder Creek, Station SRGL-R 1072+34

The levee evaluations database contains a reference to a document indicating a history of floods in Gerber, California. The document notes a levee failure due to burrowing beavers in 1937 (The Gerber Terminal Early Years into the Nineties)

### San Joaquin River, Left Bank at LM 2.96

According to the San Joaquin River System Levee Repair Prioritization Report (URS, 2007), there is a 50-foot-long erosion site with 3 feet of erosion at the lower to mid-slope in this location. The report also states that there is a vertical pocket of erosion just above the bank protection (revetment), and a muskrat hole was observed.

### Chowchilla Bypass, Left Bank from LM 11.17 to 13.87

According to the San Joaquin River System Levee Repair Prioritization Report (URS, 2007), this location of the levee experienced boils, piping and sinkholes during the 2006 high water event. The report also indicates sink holes were the result of boiling and piping caused by a silty, sandy levee foundation and embankment composition, and a “network” of large burrows through and under the levee.

According to the Lower San Joaquin Levee District representative interviewed during 2009 Kleinfelder site reconnaissance, numerous sink holes developed along the waterside slopes of the levees in 2006. The levee is also report to experience underseepage during high water events but did not experience significant boils prior to 2006 (URS, 2007)

## PHASE 3: CONCEPTUAL ANALYSES ON THE IMPACTS OF BURROWING ANIMALS ON LEVEE PERFORMANCE

The third phase of study involved developing and analyzing a levee conceptual mathematical model for seepage and stability failure modes with and without animal burrows in the levee. Analysis results with and without animal burrowing activity were compared to understand the impact of animal burrowing on levee performance.

The conceptual cross section for analysis was developed considering an 8-foot-high, 20-foot-wide levee crown that was 3 horizontal to 1 vertical (3H:1V) on the waterside slope and 2H: 1V on the landside slope. The embankment material is sandy silt (layer 1) underlain by a 2-foot-thick foundation clay (layer 2), which is underlain by an 11-foot-thick silty sand (layer 3). Layer 3 is underlain by a 5-foot-thick lean to fat clay (layer 4), which is underlain by a 25-foot-thick poorly-graded sand layer (layer 5). The soil parameters and layering were selected as a fairly typical representation for Central Valley levees. The blanket layer (layer 2) thickness is chosen to simulate an underseepage gradient at the threshold of piping.

Table 1 lists the strength and hydraulic parameters values considered for the embankment and foundation materials which were selected in accordance with the ULE Program Guidance Document for Geotechnical Analyses (Revision 14; URS, 2014).

**Table 1. Conceptual Model Parameters**

| Layer No. | Layer Thickness (feet) | Material Description | Drained Cohesion (psf) | Drained Friction Angle (degrees) | Total Unit Weight (pcf) | Vertical Conductivity, Kv, (cm/sec) | Anisotropy Ratio |
|---|---|---|---|---|---|---|---|
| 1 | 8.0 | Sandy Silt (ML) | 50 | 32 | 120 | 1.0E-05 | 0.25 |
| 2 | 2.0 | Lean Clay (CL) | 100 | 32 | 120 | 5.0E-06 | 0.25 |
| 3 | 11.0 | Silty Sand (SM) | 0 | 32 | 120 | 2.0E-04 | 0.25 |
| 4 | 5.0 | Lean to Fat Clay (CL/CH) | 100 | 32 | 120 | 1.0E-06 | 0.25 |
| 5 | 25.0 | Poorly Graded Sand (SP) | 0 | 35 | 120 | 1.0E-04 | 0.25 |

The construction and analysis of the conceptual model for performing seepage and stability analysis was developed in Geostudio software in accordance with procedures established in the Guidance Document (URS, 2014). Analyses were performed using Geo Studio software (Version 7.23, 2013). Saturated material model was utilized for seepage analysis and Mohr-Coloumb model for stability analysis.

## Analysis Results

Seepage and stability analysis were performed on the conceptual model under the following cases:

- Case 1: Conceptual model without animal burrowing
- Case 2: Conceptual model with animal burrowing on waterside
- Case 3: Conceptual model with animal burrowing on both landside and waterside (landside burrowing located at toe)
- Case 4: Case 3 sensitivity study; conceptual model with waterside and landside burrows (landside burrowing located at toe) and WSE to top of waterside burrow opening
- Case 5: Conceptual model with burrow on the landside slope (landside slope burrow located 1.5 feet below the water surface elevation)

Based on a review of the case histories, the water surface elevation varied at the time of failure, but appeared to generally be located at half the levee height or above. Seepage and landside stability analyses were performed considering an assumed water surface elevation at about half of the levee height (Cases 1, 2, and 3). Additional sensitivity analyses were performed considering a higher WSE, which is located above the waterside animal burrow (Case 4). An additional model was developed and analyzed with a burrow located on the landside slope below the water surface elevation, keeping the waterside burrow as considered in earlier cases (Case 5).

The burrow voids were mathematically modeled as material with no strength or unit weight. An average exit gradient above 0.5 indicates potential piping distress due to underseepage and factor of safety less than 1.4 indicates possibility for levee instability. A factor of safety 1.0 or lower indicates movement of the slope is likely to occur. The phreatic surface break out above the levee toe on the landside slope in erodible material indicates potential for through seepage related piping failure. Sands and silts are considered erodible material. Table 2 summarizes results, which are also illustrated in Figures 14 through 23. Results are compared to existing United States Army Corps of Engineers (USACE) and ULDC (DWR, 2012) criteria.

**Table 2. Analysis Results**

| Case | Analysis Description | Breakout point above levee toe (ft) | Average Exit Gradient | FS for Stability |
|---|---|---|---|---|
| 1 | Conceptual Model with No Burrows | 0.6 (silt) | 0.50 | 1.74 |
| 2 | Conceptual Model with Waterside Burrow | 0.6 (silt) | 0.55* | 1.70 |
| 3 | Conceptual Model with Waterside and Landside Burrows | $0.0^{+}$ | 0.76* | 1.25* |
| 4 | Conceptual Model with Waterside and Landside Burrows and WSE to Top of Waterside Burrow Opening (Case 3 Sensitivity) | $0.0^{+}$ | 1.06* | 1.25* |
| 5 | Conceptual Model with Landside Burrow on Landside Slope at 1.5 feet Below the Water Surface Elevation | 1.7 (silt) | 0.50 | 1.26* |

Note: (*) indicates a value that does not meet the Guidance Document criteria (USACE/ULDC criteria)
($^{+}$) breakout point based on burrowing at landside toe

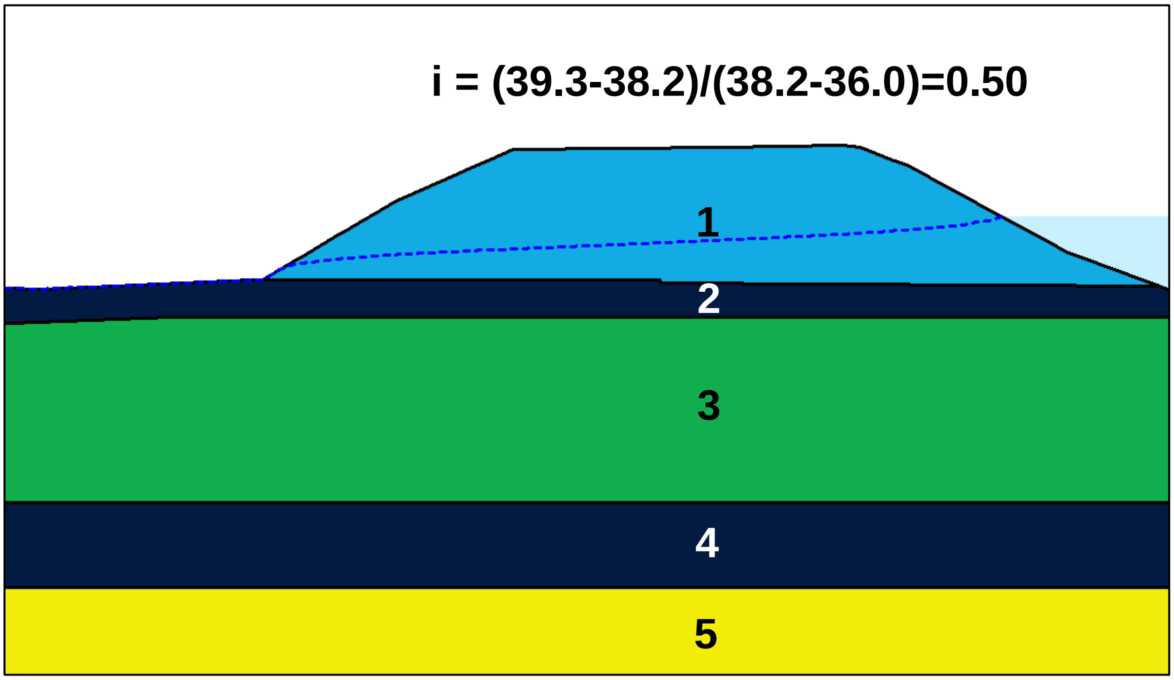


**Figure 14. Seepage Analysis Model - No Burrow Holes (Case 1)**

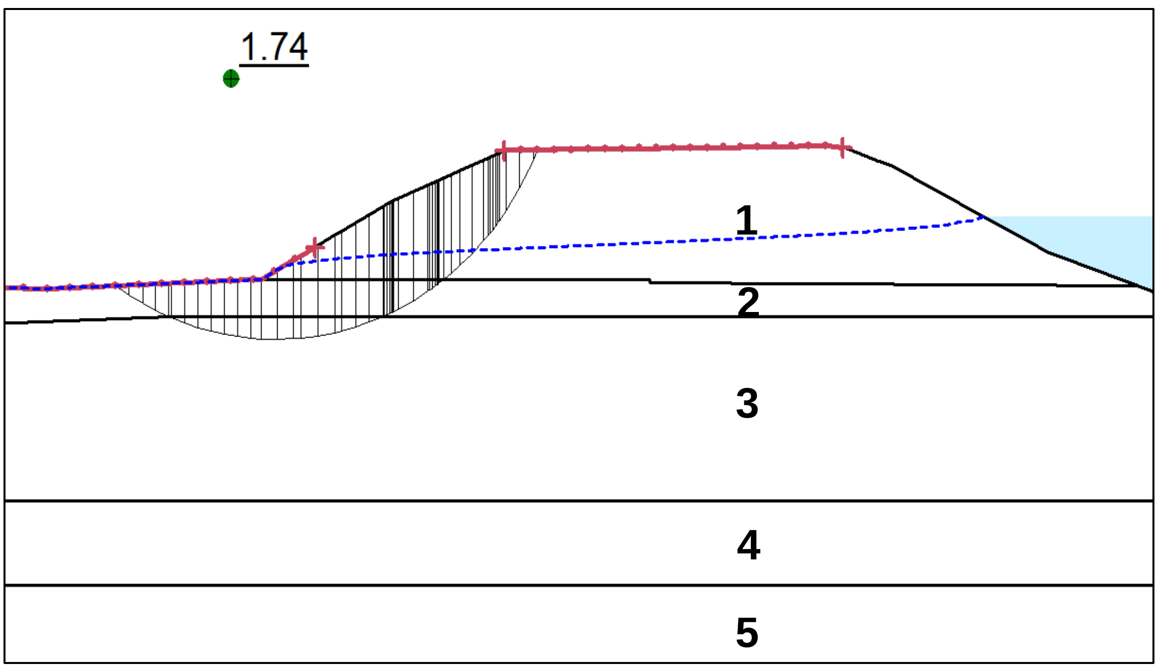


**Figure 15. Stability Analysis Model- No Burrow Holes (Case 1)**

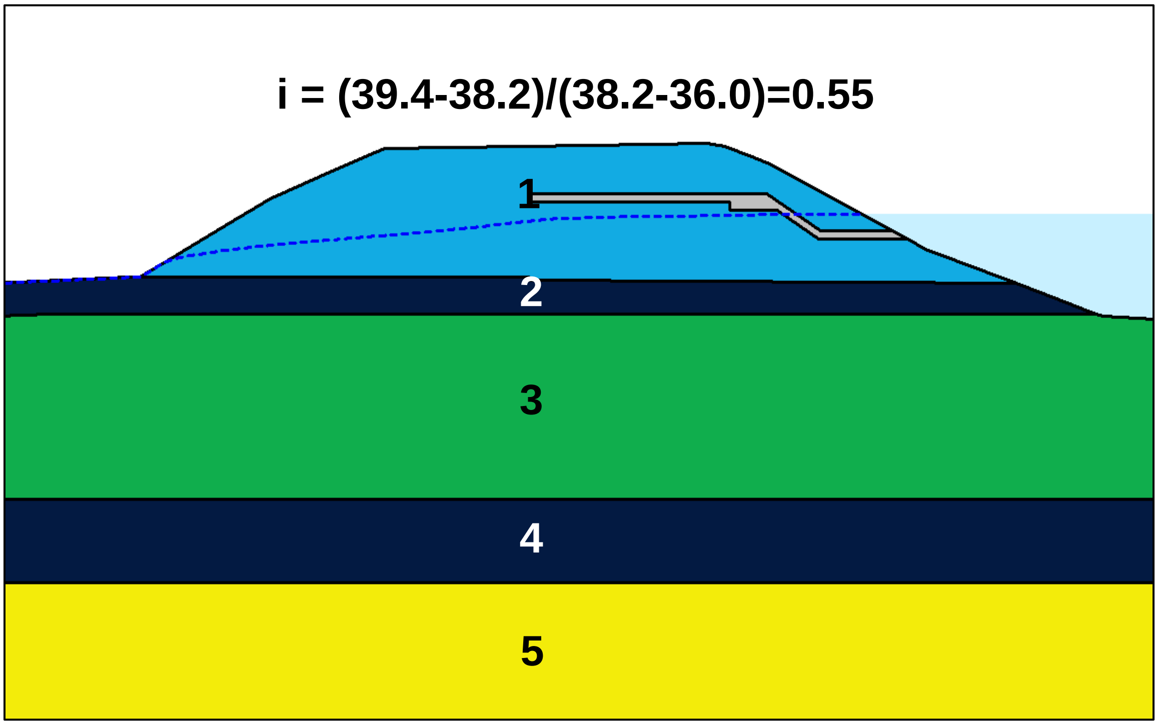


Figure 16. Seepage Analysis Model - Waterside Burrow Hole (Case 2)

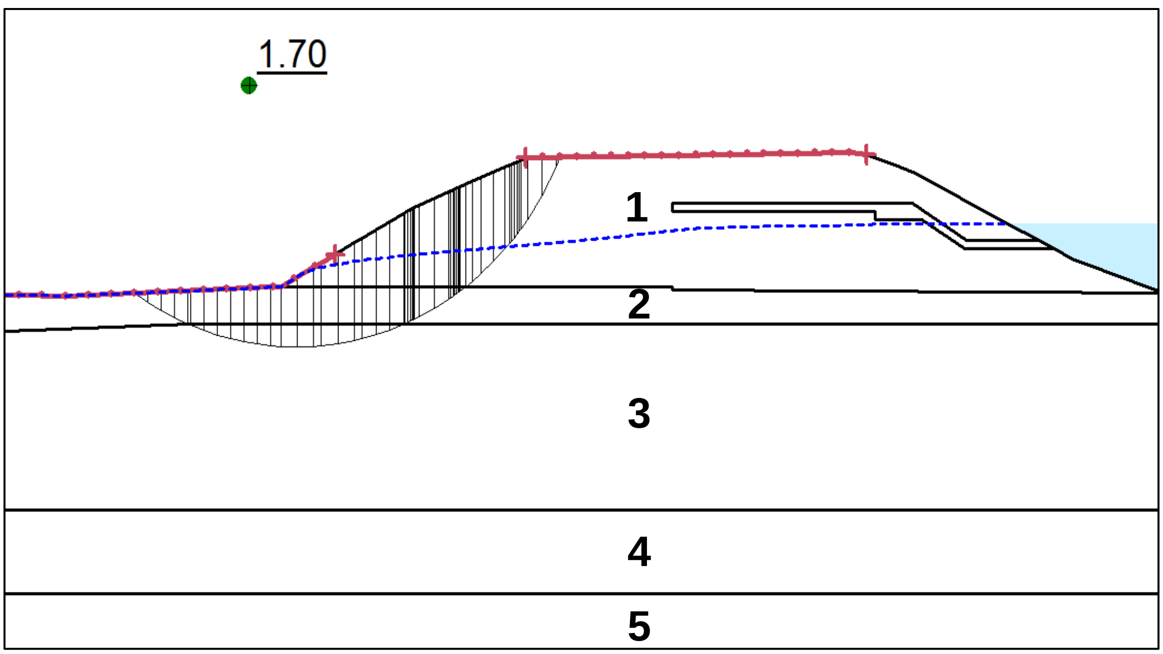


Figure 17. Stability Analysis Model - Waterside Burrow Hole (Case 2)

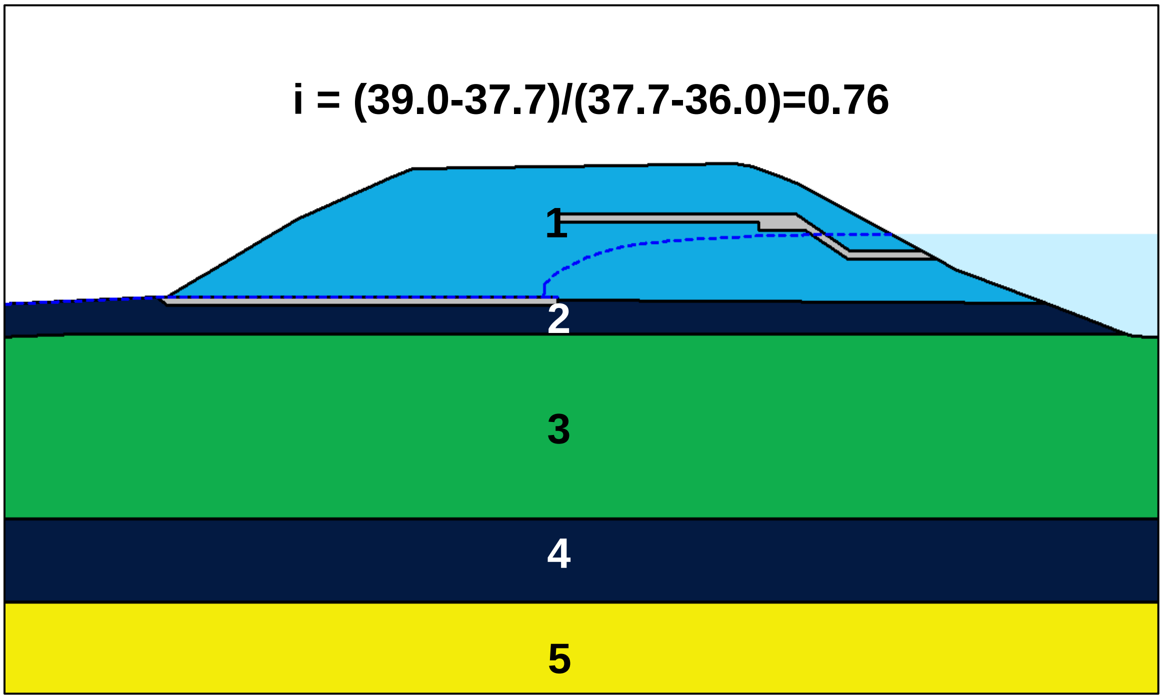


**Figure 18. Seepage Analysis Model - Waterside Burrow Hole and Landside Burrow Hole at Toe (Case 3)**

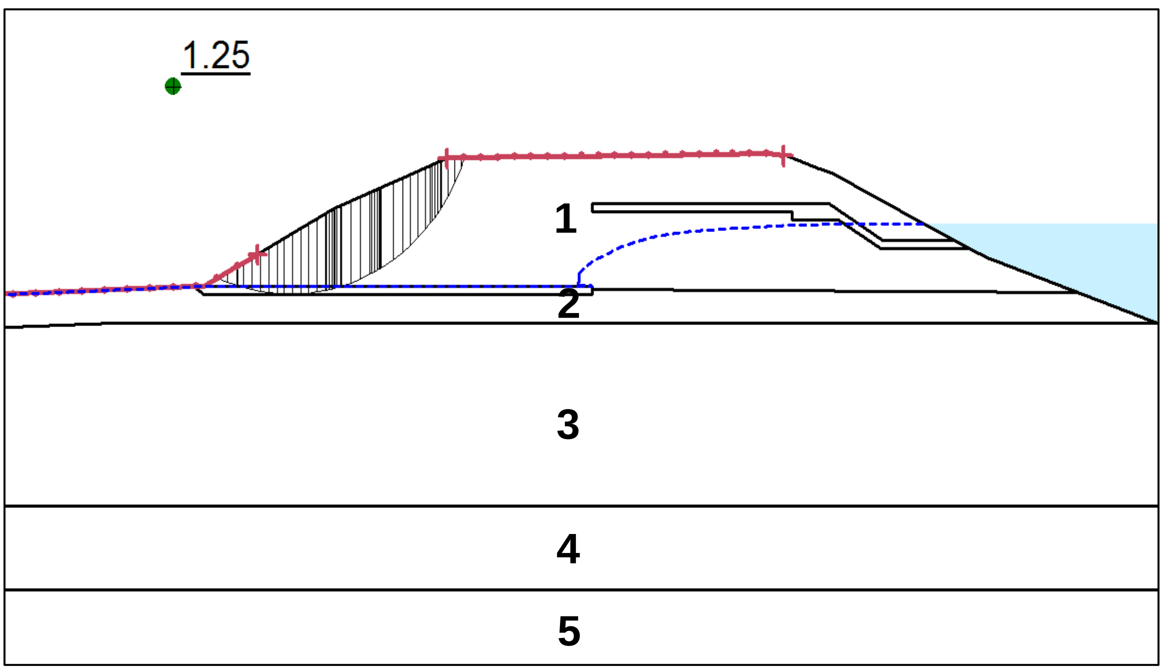


**Figure 19. Stability Analysis Model - Waterside Burrow Hole and Landside Burrow Hole at Toe (Case 3)**

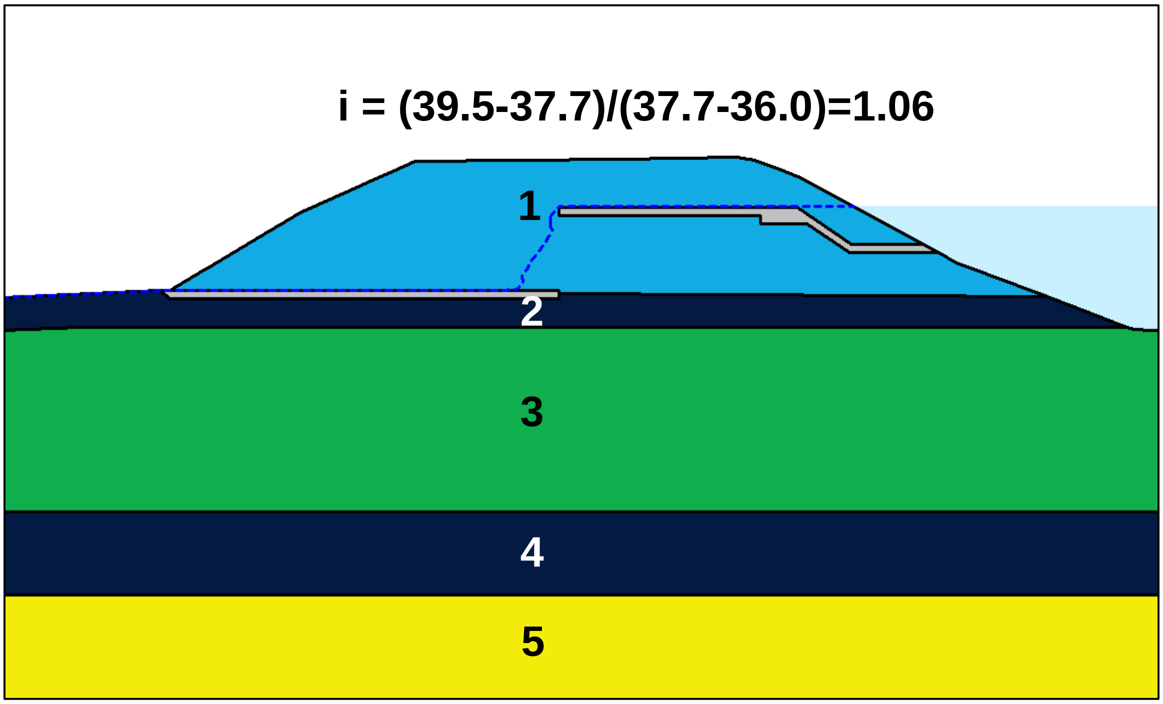


**Figure 20. Seepage Analysis Model - Waterside Burrow Hole and Landside Burrow Hole at Toe with Water Surface Elevation to Top of Waterside Burrow Hole (Case 4)**

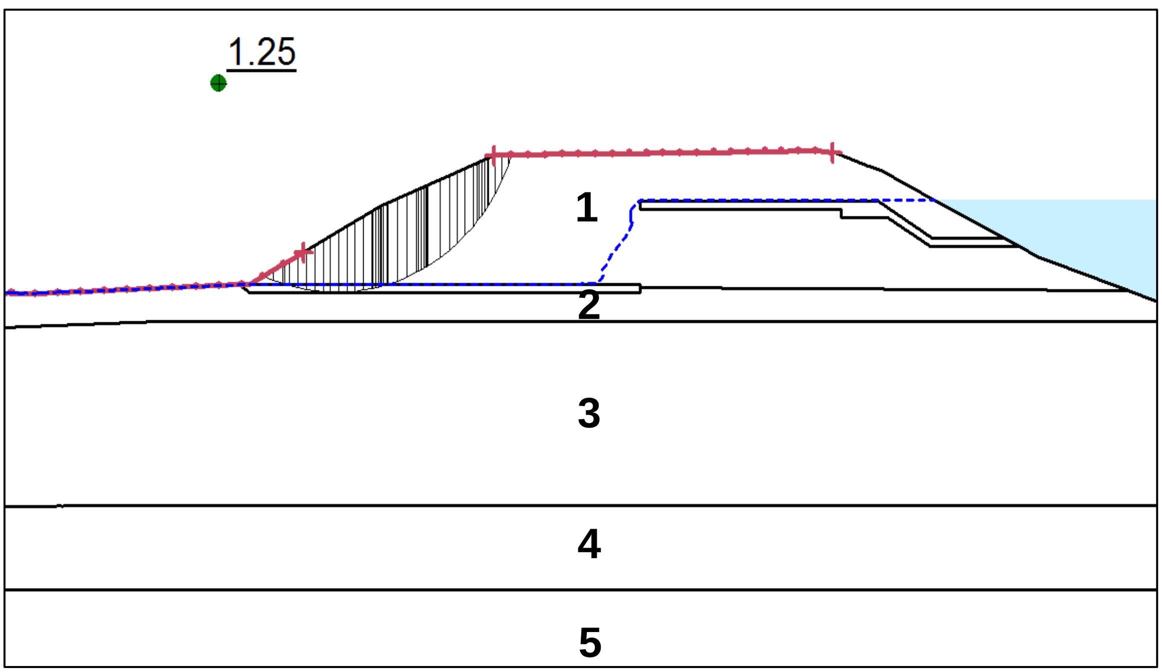


**Figure 21. Stability Analysis Model - Waterside Burrow Hole and Landside Burrow Hole at Toe with Water Surface Elevation to Top of Waterside Burrow Hole (Case 4)**

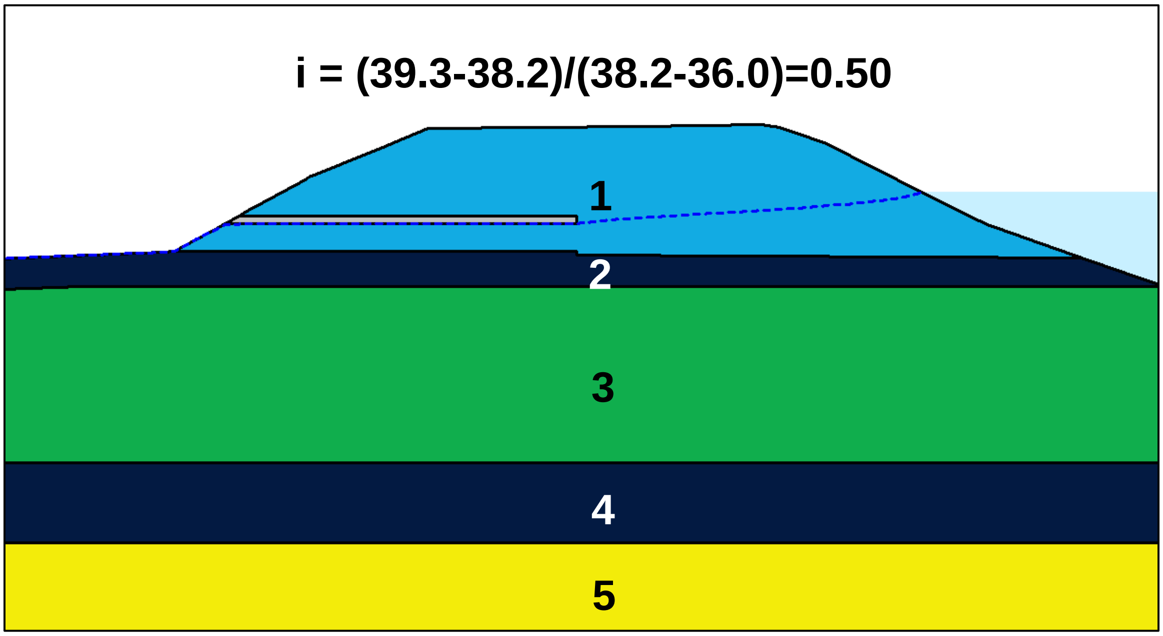


**Figure 22. Seepage Analysis Model - Burrow Hole on Landside Slope Located 1.5 ft. Below the Water Surface Elevation (Case 5)**

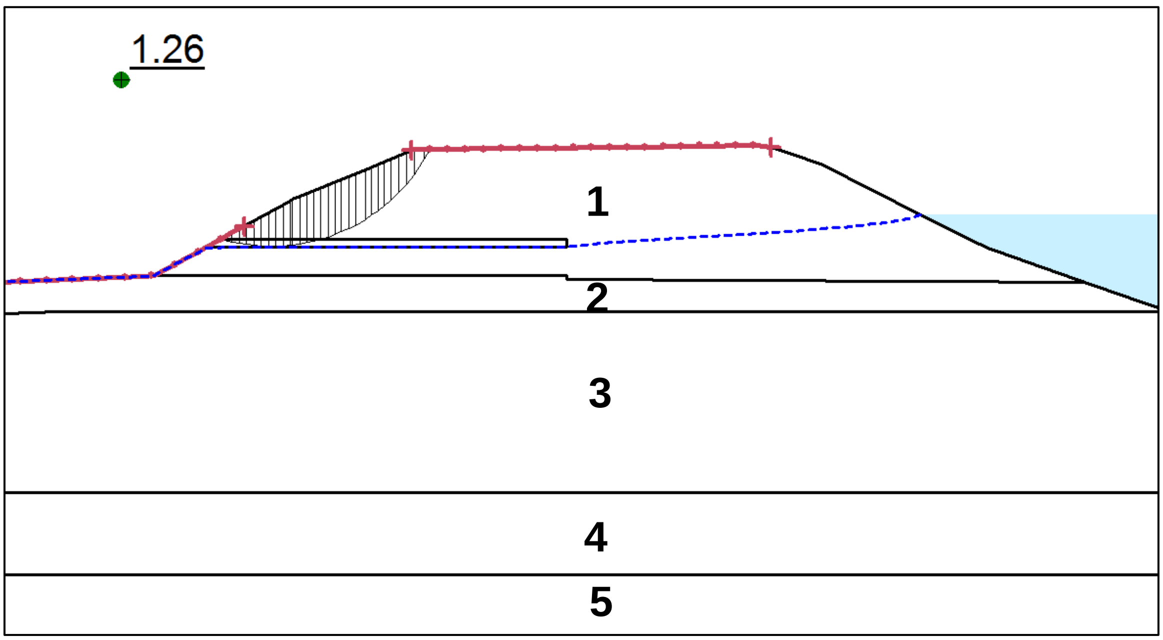


**Figure 23. Stability Analysis Model - Burrow Hole on Landside Slope Located 1.5 ft. Below the Water Surface Elevation (Case 5)**

## CONCEPTUAL MODEL SUMMARY

Analyses were performed on the conceptual model with and without animal burrows in the levee for seepage and stability failure modes. The results of the analyses were summarized in Table 2 and presented in Figures 14 and 23. The results are discussed below:

### Conceptual Model with No Burrows (Case 1)

- Underseepage analysis performed on the conceptual model resulted in an average vertical exit gradient of 0.5 at the levee toe. The calculated gradient meets criteria of 0.5 for underseepage (Figure 14). Potential seepage conditions along landside toe would initiate at gradient of above 0.5 and potential piping at a gradient of 0.8.
- Landside stability analysis resulted in a factor of safety (FOS) of 1.74. The calculated FOS meets criteria of 1.4 for stability (Figure 15).
- Analysis results indicate the through seepage phreatic surface breakout point approximately 0.6 feet above the levee toe. Since the embankment material at and below the breakout elevation is erodible, the result does not meet criteria for through seepage.

### Conceptual Model with Waterside Burrow (Case 2)

- Underseepage analysis performed on the conceptual model with animal burrow on the waterside slope, resulted in slight increase in the average vertical exit gradient from 0.5 (for no burrow condition) to 0.55 at the landside levee toe (for the waterside burrow condition). The calculated gradient does not meet criteria of 0.5 for underseepage (Figure 16).
- The factor of safety from the landside stability analysis decreased from 1.74 (for no burrow condition) to 1.70 (for waterside burrow condition). The calculated FOS meets criteria of 1.4 for stability (Figure 17).
- The phreatic surface break out point is approximately 0.6 feet above the levee toe in erodible material. The result does not meet criteria for through seepage.

### Conceptual Model with Waterside and Landside Burrows (Case 3 and Case 4)

- The animal burrow modeled at the landside toe resulted in reduced blanket thickness, increasing the underseepage gradient from 0.5 (for no-burrow condition) to 0.76 at the levee toe (for combined landside and waterside burrow conditions). The calculated gradient does not meet criteria of 0.5 for underseepage (Figure 18).

- The factor of safety calculated from steady-state stability analysis was reduced from 1.74 (under a no-burrow condition) to as low as 1.25 (under a waterside and landside burrow condition) (Figure 19).

### Case 4 (Case 3 Sensitivity)

- Additional underseepage sensitivity performed on the Case 3 model increasing the WSE by 1.3 feet (so that waterside burrow is submerged under water) resulted in increase of average vertical exit gradient from 0.76 to 1.06 (Figure 20).

- The landside stability analysis on the Case 4 resulted in a factor of safety of 1.25 (Figure 21).
- The presence of animal burrowing activity on a levee (both landside and waterside) results in significant reduction of the seepage path (as observed from phreatic surface), and could result in a piping failure of the levee (i.e., piping potential increases if the levee embankment material is erodible in nature).

### Conceptual Model with Burrows on the Landside Levee Slope (Case 5)

- Underseepage analysis performed on the conceptual model resulted in an average vertical exit gradient of 0.5 at the levee toe. The calculated gradient meets criteria of 0.5 for underseepage (Figure 22).
- The factor of safety calculated from steady-state stability analysis was reduced from 1.74 (under a no-burrow condition) to as low as 1.26 (under a burrow on the landside slope at 1.5 feet below the water surface elevation condition) (Figure 23).
- Additional analysis was performed considering a burrow on the landside slope, located 1.5 feet below the water surface elevation. Seepage analysis performed resulted in increase in the break out point above the landside toe from 0.6 (under a no-burrow condition) to 1.7 feet (under a burrow on the landside slope at 1.5 feet below the water surface elevation condition) due significant reduction in the seepage path(Figure 22).

## CONCLUSIONS

The following conclusions were made based on review of the data collection and analysis results.

- Solid physical evidence is available to indicate that animal burrowing has had a contributory role in the examined levee breach case histories.
- Mathematically modeling the effects of animal burrowing demonstrates a significant increase in the likelihood distress of levee embankment (increased exit gradients and lowered factors of safety for landside stability).
  - Potential for seepage and stability failures with animal burrow on either landside or waterside of the levee is dependent on the flood stage on the levee, and location of the animal burrow.
  - Presence of burrows on the both sides of the levee (landside and waterside) presents an increased failure potential condition when compared to burrow on one side (either landside or waterside) of the levee.
  - Presence of burrows on both sides of levee significantly reduces the seepage path and increases the potential for piping failure of the levee or seepage induced stability failure of the levee.
  - Presence of burrows at or below the levee embankment toe could reduce the blanket thickness and result in potential underseepage failure.
- Continued observations and maintenance in areas of identified animal burrow activities and backfilling and sealing of burrows in the levee embankments is recommended to minimize the risk of sudden levee failures.

## Additional Factors

Based on a review of case studies and analysis results, the following factors were identified as additional potential risk factors in cases of animal burrowing. These factors can significantly impact levee performance:

- Location of animal burrow (i.e., embankment slopes, beyond levee toe, landside, waterside)
- Hydraulic loading (i.e., from river/waterway) on the levee embankment (i.e., magnitude and duration)
- Levee geometry (primarily width)
- Proximity to animal habitat (such as canal, orchard, grasslands, etc.)
- Embankment and foundation material (clayey soils allow burrows to stay open)

## LIMITATIONS

The discussions presented in this memorandum are based on review of readily-available information obtained from levee evaluations database and documents gathered from local experts working on levee-related research projects. An attempt was made to collect relevant data, however, the data may not have encompassed all information related to the cited case histories or identified all relevant case histories. URS has relied on third-party information included the documents referenced. URS is not responsible for, and has not independently verified the accuracy of this information. Models developed for performing analyses as part of this memorandum are conceptual in nature and could vary from actual field conditions. Limited geotechnical analyses were performed primarily to provide an assessment of the impact of burrows on levee performance and do not necessarily reflect all factors that can influence levee performance.

## ACKNOWLEDGEMENTS

The information presented in this Technical Memorandum is based on the efforts of the URS and experts working on levee-related research projects. Team members who helped develop this Technical memorandum included:

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**Attachment A. Summary of Case Histories.**

| Item | Case History Title | Date of Incident | Water Course | Embankment Geometry Prior to the Breach Event | | | | Levee Characteristics | | Identified Cause (As noted) | Distress Type | Burrow Hole Diameter (inch) | Description | Land Use Condition | | Prior Animal Activity (as Noted) | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Crest Width (feet) | Embankment Height (Above Landside Toe) (feet) | Landside Slope (xH:1V) | Waterside Slope (xH:1V) | Embankment Material | Foundation Material | | | | | Waterside | Landside | | |
| 1 | Pin Oak Levee, Missouri | 6/27/2008 | Mississippi River backwater | Unknown | Unknown | Unknown | Unknown | Sample was recovered, after the breach, from about mid-height of the exposed levee. Laboratory results indicated it was a lean clay with the following characteristics liquid limit (LL) = 34, PL=18, PI=16, 1.2 % organic content, 11.3 % sand content. | Unknown | Muskrat burrowing | Through seepage and stability (LS)/breach | 2 to 3 | Levee failed in 1993 due to overtopping. The failure in 2008 occurred when the peak river stage was comparatively 2 feet lower than the 1993 peak river stage. Landside slides and heavy through seepage emerging near the levee toe were observed at two locations. Observers noted that muskrats were seen diving in the area where the flood fight was occurring. | Water filled ditch/canal | Water filled ditch/canal | Unknown | Appealing habitats to muskrats on both sides of the levee. |
| 2 | Truckee Canal at Fernley, Nevada | 2/1/2008 | Truckee Canal | 20 | 8 | Unknown | 1.5 | Homogenous mixture of silt and clay (minor amounts of sand and gravel) with a landside slope blanket of sand and vegetative material from years of cleaning out the canal. | Elastic silt and lean and fat clay | Muskrat burrowing | Unknown | 6 to 7 | A t-structured muskrat burrow was exposed about 9 feet in from the canal. Several cracks parallel the embankment. | Unknown | Unknown | Rodents are highly active in the canal in the breach vicinity (Truckee-Carson Irrigation District Personnel). Also, rodents were observed in the residual water upon arriving at the breach site. | |
| 3 | Pleasant Grove Creek Canal Levee, Natomas | 2008 | Pleasant Grove Creek Canal | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Beaver Den | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | |
| 4 | Soil-Cement-Bentonite Cutoff Wall, Pocket Area | Unknown | Sacramento River | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | |

**Attachment A. Summary of Case Histories.**

| Item | Case History Title | Date of Incident | Water Course | Embankment Geometry Prior to the Breach Event | | | | Levee Characteristics | | Identified Cause (As noted) | Distress Type | Burrow Hole Diameter (inch) | Description | Land Use Condition | | Prior Animal Activity (as Noted) | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Crest Width (feet) | Embankment Height (Above Landside Toe) (feet) | Landside Slope (xH:1V) | Waterside Slope (xH:1V) | Embankment Material | Foundation Material | | | | | Waterside | Landside | | |
| 5 | Wright Elmwood Tract, Northern Levee | 12/1/2005 | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Beaver den on the waterside and squirrel holes on landside. | Stability (sinkhole) | Unknown | There was only 1 foot of freeboard when the sinkhole/collapse of the levee crown occurred. It is suspected that the sinkhole was caused by the collapsing void of the beaver den, and seepage occurred in concentrated flows out of connecting squirrel holes from the landside. | Unknown | Unknown | Unknown | Reports state the breach was likely prevented by collapsing the burrow hole and filling the void. |
| 6 | Upper Jones Tract | 6/3/2004 | Middle River | 36 | 24 | 4 | 2.5 | Silty sand/sand | Approximately 13 feet of silty sand and sandy silt on top of black silty peat and black sandy silt with peat | Beaver den on the waterside and squirrel holes on landside. | Through seepage or underseepage/breach | Unknown | Breach occurred during summer. There is a large population of beavers on the island adjacent to the waterside and it was common to see beavers on the landside in the canal nearby. Prior to the breach (between May and June) a landside slope repair related to burrowing mammals was performed. | Beaver Island | Row crop and irrigation canal | It was well known that a large population of beavers lived in Middle River near the levee failure. The small tule center island immediately to the west of the breach location was known as "Beaver Island." Mr. Dennis Lass testified, in his work as a levee maintenance worker on Upper Jones Tract, he commonly saw beavers in the vicinity of the failure site. Beavers were also common in the large drainage canals in Upper Jones Tract. | In a follow up inspection in 2011 several squirrel burrows were observed on the landside levee near the breach site. |

**Attachment A. Summary of Case Histories.**

| Item | Case History Title | Date of Incident | Water Course | Embankment Geometry Prior to the Breach Event | | | | Levee Characteristics | | Identified Cause (As noted) | Distress Type | Burrow Hole Diameter (inch) | Description | Land Use Condition | | Prior Animal Activity (as Noted) | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Crest Width (feet) | Embankment Height (Above Landside Toe) (feet) | Landside Slope (xH:1V) | Waterside Slope (xH:1V) | Embankment Material | Foundation Material | | | | | Waterside | Landside | | |
| 7 | Glenn-Colusa Canal Break near Ord Bend | 10/22/2013 | Glenn-Colusa Canal | Unknown | 12 | Unknown | Unknown | Unknown | Unknown | Gopher hole | Unknown | Unknown | 25-foot-wide breach. | Water filled canal | Orchards | Unknown | Recent breach, cause was suspected to be gopher burrowing but no new information available. |
| 8 | Medford Island | 1/24/2009 | Columbia Cut | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Beaver den | Through seepage/stability (sinkhole) | 5 feet height x 9 feet wide x 12 feet across the levee | The beaver den void was approximately 5 feet high by 9 feet wide by 12 feet across the top of the levee. The thickness of the crown was only about 2 feet above the beaver den. The den ranged from the landside of the levee to within 2 feet of the waterside slope. Water entered the den from two tunnels and was exiting halfway down the levee slope. | Small island adjacent to waterside slope | Unknown | There were several beaver dens nearby that were exposed at time of construction and repaired. Also, Arundo vegetation was removed, exposing more beaver dens. | |
| 9 | Staten Island | 6/1/2007 | South or North Mokelumne River | Unknown | Unknown | Unknown | Unknown | Unknown | Unknown | Beaver den | Through seepage | Unknown | Believed collapse of beaver den led to large boil on landside slope near toe. Occurred in the summer. | Unknown | Unknown | Unknown | |

**Attachment A. Summary of Case Histories.**

| Item | Case History Title | Date of Incident | Water Course | Embankment Geometry Prior to the Breach Event | | | | Levee Characteristics | | Identified Cause (As noted) | Distress Type | Burrow Hole Diameter (inch) | Description | Land Use Condition | | Prior Animal Activity (as Noted) | Additional Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Crest Width (feet) | Embankment Height (Above Landside Toe) (feet) | Landside Slope (xH:1V) | Waterside Slope (xH:1V) | Embankment Material | Foundation Material | | | | | Waterside | Landside | | |
| 10 | Hat Creek No. 1 – Forebay Embankment | 3/14/2012 | Hat Creek No. 1 Forebay | 10 | 14 | 1.5 | Unknown | Silty Sand | Bedrock | Muskrat burrowing | Through seepage/stability (sinkhole) | 4 | Several years of seepage were observed in the area. As a result of raising the water surface, 1 foot of seepage began to occur. Several attempts to repair were made and failed to stop the seepage. A seepage berm was one of the attempts to repair the site. In 2012 a sinkhole was observed on the landside of the crown near the interface of the original embankment and repair berm. | Water filled forebay | Unknown | Animal burrows were observed on the landside slope. No notes on prior animal burrowing activity. | |
| 11 | Dry Creek | 1997 | Dry Creek | Narrow | 8 | Unknown | Unknown | Clay | Clay | LMA states that it was rodent activity | Unknown | Unknown | Reclamation District (RD) 2103 insists that the breach was due to rodent activity. This theory is supported by the fact the levees are constructed of clay, the flash type flows experienced (in this case the water had receded to below the levee toe within 2 to 3 hours), and the local maintaining agency (LMA) stated that this reach had rodent activity prior to the event. | Unknown | Orchard | Rodent activity in the area prior to breach. | |