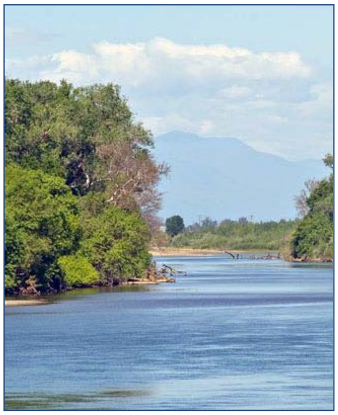
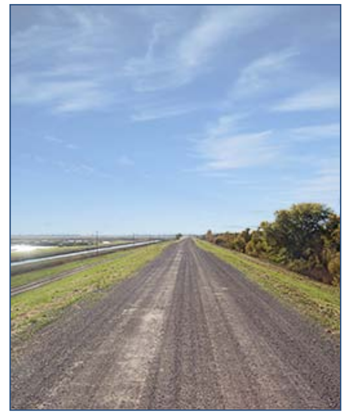
California Levee Vegetation Research Program (CLVRP)

Informational Circular No. 2: Summary of Research Completed to Date

December 12, 2011

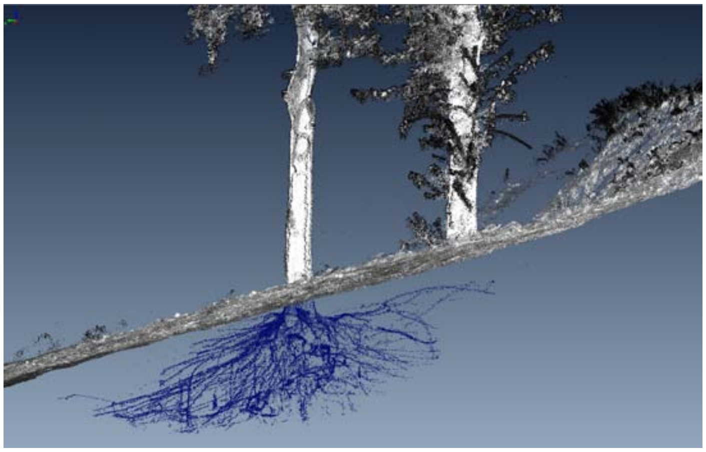




The partner agencies of the California Levee Vegetation Research Program (CLVRP) have sponsored several research studies to better understand how woody vegetation affects levee performance. This Informational Circular No. 2 summarizes progress on CLVRP studies that began in 2009.

Tree Root Architecture – *How and where do tree roots grow on and near levees?*

A team from University of California (UC) Davis led by Dr. Alison Berry is studying the physical parameters of tree roots that grow on or near levees which may affect levee integrity and stability. Root systems of cottonwoods (*Populus fremontii*) and valley oaks (*Quercus lobata*) at three levee sites have been excavated with a pneumatic 'air knife'. In collaboration with Dr. Gerald Bawden of the US Geological Survey (USGS), tripod-mounted light detection and ranging (T-LiDAR) equipment has been used to scan the soil surface, trees, and tree root systems as excavation progresses. Using virtual cross-sections and a 3D vector model, scientists have measured root characteristics such as biomass, geometry and directionality. At the tree scale, Dr Berry and team are analyzing spatial distribution and branching arrangement of roots in different directions – towards the levee, towards the river, parallel to the levee, vertically and radially. Preliminary findings indicate that the roots of trees on the levee slope grow along the slope at a fairly uniform depth parallel to the slope surface, rather than penetrating deep into the levee; and that the total root biomass is significantly lower toward the levee, compared to other directions. Tree root systems on the levee slopes show a pronounced directional asymmetry, comparing parallel and perpendicular directions to the levee, which is likely a biomechanical growth response to levee structures and slope. Using a parametric approach, the biomass distribution and spatial configuration data will be incorporated into geotechnical models of levee slope erosion, stability, piping, and levee seepage, in collaboration with the team from UC Berkeley, led by Dr. Nicholas Sitar and Dr. Jonathan Bray. Parameters such as root cross-sectional area, root area ratio, root-soil surface contact, rooting depth, horizontal spread, radius of gyration, root azimuth and zenith angle are being computed since they are critical to levee and bank stability and failure mechanisms. These field methods and quantitative analyses can help to answer questions about tree root systems in relation to slopes and other physical features of levees, and can inform related geotechnical and ecological studies. Manuscripts are in preparation and will be submitted for publication in 2012.



Valley oak root system superimposed in levee slope. 3D LiDAR image.

<u>Levee Slurry Wall Investigations – *Do tree roots penetrate slurry walls? What are their effects?*</u>

Dr. Les Harder, a levee geotechnical engineer and researcher with HDR, Inc., has excavated trenches in a Sacramento-area levee to study tree root penetration into an 18-year-old soil-cement-bentonite (SCB) wall designed to cut off water seeping through the levee. Excavations in 2009 revealed that roots from a large black walnut tree growing at the top of levee had been encountered during the original construction of the wall and were cut or broken at the edge of the wall by construction equipment in 1991. However, over time, many of the cut roots had regenerated new branch roots which were observed to grow laterally along the outside edge and within the outer few inches of the SCB wall – sometimes for distances of up to 10 feet. The 18-inch-thick SCB wall was also observed to have small, vertical cracks. In some cases cracks were exploited by small roots growing along the outside portion of the wall, at times penetrating through the SCB wall. In 2010, Dr. Harder undertook a follow-up slurry wall trenching investigation along the same SCB wall opposite valley oak and cottonwood trees. The trenches opposite valley oak trees showed no significant root penetration into the levee at a distance of 15 feet or more. A separate excavation in this area, however, revealed that cottonwood roots had penetrated the levee (both perpendicular and parallel to the levee) from trees as far away as 50 to 100 feet. Similar to observations in 2009, several cottonwood roots penetrated the wall through small vertical cracks. In 2010 ground squirrel burrows were also observed in the levee and in the SCB wall. The burrows were found approximately 4 to 5.5 feet below the levee crown, and approximately 15 - 20 feet horizontally into the levee slope.

Exposed slurry wall (Pocket area levee)

Preliminary findings from both SCB wall investigations:

1. Root growth (diameter & distance) and root interactions with a SCB wall vary by tree species.

2. The old, relatively thin SCB cutoff wall in Sacramento's Pocket Area provided a partial barrier against root penetration. Roots will grow through small vertical cracks in the SCB wall to depths of 5 to 6 feet from the top of the wall.

3. Further study is required to examine cracking, root penetration and presence of mammal burrows in more modern cutoff walls with greater widths and higher strength properties.

4. Ground squirrel burrows from 2 to 10 inches in diameter/width were observed within the central part of the levee. These observations suggest that further research should evaluate whether burrowing mammals pose a greater risk to levees than vegetation.

A link to full manuscripts for the 2009 & 2010 field studies can be found at http://www.safca.org/Levee%20Veg%20Int.%20Symposium%20.htm

How Trees affect Seepage and Stability of Levees – *Do tree roots become preferential seepage pathways through a levee and do trees contribute to levee slope instability?*

Between August and November of 2010, UC Berkeley researchers in the Department of Civil and Environmental Engineering conducted a field test to examine the effects of live and decaying root systems on seepage and slope stability on a levee bordering the American River near the California Exposition and State Fair (Cal Expo) grounds in Sacramento. The test consisted of constructing 45-foot-long parallel trenches on the landside slope above and below a decomposing eucalyptus stump. The trenches extended into a control area away from the stump and decomposing root system. The upper trench (2 feet wide by 3 feet deep) was filled with water and held at constant head to simulate and induce a slope-parallel wetting front through the levee. The lower trench was left open to view the effect on the progression of seepage caused by tree roots and other anomalies found in the trench walls. Piezometers and tensiometers installed across the test section of levee were used to describe the wetting and flow patterns as they evolved within the levee during the test. Based on observations made during the flow test, wetting front and water flow patterns appeared to be dominated by flow through a network of shallow small mammal burrows. Though intermittent gaps associated with decomposing roots were observed, the gaps did not result in preferential water flow between the upper and lower trenches. Advancement of the wetting front appeared to be delayed in the area of the stump. Instrument data and preliminary computer simulations support the basic patterns observed in the field test.

Decomposing stump field test site at Cal Expo

USGS employed T-LiDAR to map roots and other features in the levee following the field test. Instrumentation data and T-LiDAR results will be utilized to enhance ongoing seepage and stability modeling efforts.

To further understand the contribution of trees to the seepage and stability of levees additional field efforts are ongoing, including two complementary efforts at field test sites in the Sacramento-San Joaquin River Delta. UC Berkeley researchers have placed instruments on Staten Island along the Mokelumne River levee to measure the effects of roots on soil saturation and seepage due to river stage variations, and are currently undertaking a second field test at Twitchell Island along Sevenmile Slough. In the Sevenmile Slough study, an existing water table will be monitored and then raised by filling a trench on the levee crown with water held at a constant head. The test will focus on the effects of living trees on levee seepage as compared with an adjacent control section with no trees. A summary of methods and preliminary results for the Cal Expo field test can be obtained at the following link: http://www.safca.org/Levee%20Veg%20Int.%20Symposium%20.htm.

Tree Windthrow – ***What are the forces necessary to topple trees on California Levees?***

On a river levee, a falling tree leaving a large root pit could alter levee surface morphology, affecting erosion and seepage paths through the levee. To estimate variation in relative risk of treefall among trees of different sizes and species, Dr Chris Peterson and his team from the University of Georgia instrumented and winched trees until they broke or fell. Valley oak and Fremont cottonwood were selected at four locations in the Central Valley. Trees from 6 to over 39 inches in trunk diameter at breast height were winched down using a strap and winch system, augmented by heavy machinery for the largest trees. Tree strength increased with tree diameter, as expected. The forces required to winch the trees ranged from 1 to nearly 22 tons of pull. Surprisingly, despite stronger wood and presumably deeper root systems, valley oak trees were only slightly stronger than cottonwoods, for a given tree size. Trees on riparian flats (rather than on levee slopes) were much more likely to uproot than similar trees on engineered, sloping substrates. Both cottonwoods and valley oaks exhibited uprooting as well as trunk breakage. Winching downhill resulted in no significant difference in tree strength compared to winching across slopes of the levees. Pulling force necessary to topple trees allowed formulation of estimates of critical wind speeds that would have blown down the study trees. Among the 69 trees for which such estimates are possible, only two had estimated critical wind speeds < 75 mph, and those trees were small. The largest trees were the most windfirm: among the study trees > 16 inches in trunk diameter (at 4 ft. above ground), most had estimated critical wind speeds above 100 mph. Given recorded history of high winds in California's Central Valley, the researchers estimated the likelihood of high winds that might topple similar trees to those chosen for this experiment. They concluded that there is an extremely low probability that healthy oaks and cottonwoods would fall due to high winds in this region. A manuscript is in the final stages of preparation. It will be submitted to the journal *'Forestry'* published by Oxford University in the UK by the end of December 2011 with publication anticipated in mid to late 2012.

Burrowing Mammal Habitat Associations – *How is burrowing mammal abundance related to the presence or absence of trees on levees?*

A team from UC Davis, under the leadership of Dr. Dirk Van Vuren, evaluated the likely effects of tree removal on habitat quality for burrowing mammals, whose activities threaten levee integrity. California ground squirrels in particular are considered a primary threat; their burrows average 25 feet in length and have the potential to perforate a levee. Botta's pocket gophers also may be threats because of their soil-excavating activities (an estimated 12 cubic yards per acre annually), which can cause soil erosion that weakens the levee. Levees were surveyed for mammal burrows in order to determine associations between burrowing mammals and particular habitats. Surveys of levees at 12 locations within the Central Valley revealed 5,705 burrows of California ground squirrels and 33,678 burrows of Botta's pocket gophers in a total of 5.2 miles of levee. The distribution and abundance of ground squirrels and gophers were related to habitat. Trees had a strongly negative effect on the occurrence and abundance of ground squirrels (i.e. habitats with more trees had fewer ground squirrel burrows), probably because more open habitats, especially grasslands, provide the visibility that ground squirrels need to detect predators. Trees had a similar negative effect on the abundance of gophers, probably because of scarcity of food (grasses and forbs) in woodlands compared with grasslands. Study findings suggest that conversion of woodland habitats on levees to more open habitats, especially grasslands, will probably increase habitat quality for both ground squirrels and gophers. This could in turn increase the potential threat that their burrowing activities pose to levee integrity. A link to the full manuscripts can be found at http://www.safca.org/Levee%20Veg%20Int.%20Symposium%20.htm.

California Ground Squirrel

Levee Mammal Burrow Characterization and Grouting Efficacy – *What are the seepage and stability implications? Do standard grouting methods seal burrows in a levee?*

UC Berkeley recently completed field work for a burrow grouting study to ascertain the extent of mammal burrows on a Sacramento River levee segment near Kirkville, CA with no woody vegetation. The objectives of the test were twofold: to assess the extent and architecture of the mammal burrow networks in a previously un-grouted sandy levee; and to study the efficacy of current California Department of Water Resources (DWR) grouting techniques. Two methods of grouting were used: first, DWR performed their regular grouting procedure by injecting a standard gray cement-bentonite grout into the largest burrows that were visible on the levee surface. Subsequently, a urethane-based chemical grout, colored with pink dye, was injected in perforated stand pipes arranged in a 1.2 m x 1.2 m grid pattern to fill burrows potentially not fully grouted in the first round and other holes with no visible surface expression. As the levee was excavated burrows grouted with standard grout were painted green to distinguish them prior to T-LiDAR imagery taken by USGS. The data collected will be used to estimate the volume of voids created by burrowing mammals within the embankment, differentiating between the two types of grout (pictures next page).

Preliminary observations of the test exposed a complex system of burrows that seemed to be highly dependent on soil stratigraphy. The excavations on the waterside slope exposed a single large burrow near the toe, and the excavations on the landside slope exposed a series of interconnected squirrel burrows that extended both horizontally and vertically for several tens of feet in the direction parallel to the levee alignment. No tunnels were found that extended through the levee from landside to waterside.

Levee site pre excavation

Post excavation - site with grouted excavated burrows

A similar field test will be performed next year on a clayey levee that has been routinely grouted on an annual basis, with the goal of documenting the effects of repeated periodic grouting in levees and comparing the magnitude of animal intrusion in different embankment materials.

Forensics – ***Has woody vegetation affected historic levee performance?***

As part of DWR's Levee Evaluations Program, URS Corporation and Kleinfelder engineers conducted a systematic effort to collect available documents about levee performance in the Central Valley. The project team cataloged the documents into a searchable database with links to electronic copies of the documents. Each document was reviewed to identify and describe points of interest related to levee performance. The number of performance records that discuss vegetation influence on levee performance is small (95 records or 1.4% of 6,970 records). Of these, a small number of records (11 records or 12% of the 95 vegetation-related records) indicated that vegetation played a role in the levee performance. Most of these discussed the influence of vegetation on levee operation and maintenance. Typically they described the inability to visually determine levee performance during high water events. None of the 348 records of levee breaches identified vegetation as influencing the breach.

As this study is based on currently available data collected as part of the levee evaluations program, it is not a comprehensive assessment of all recorded performance data. However, it does provide an indication of the relative magnitude and nature of vegetation influence on levee performance in California. Future research may include analysis of interviews with local maintenance personnel about vegetation related factors influencing levee performance and operations and maintenance.

A link to the full manuscript can be found at:
http://www.safca.org/Levee%20Veg%20Int.%20Symposium%20.htm.

About the CLVRP

The California Levee Vegetation Research Program (CLVRP) is a partnership of federal, state, and local agencies formed to conduct original scientific research to address vegetation policy issues affecting the state and federal levee system in the California Central Valley.

The CLVRP began in 2009 and is funded by the California Department of Water Resources and the Sacramento Area Flood Control Agency.

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