Draft Vegetation Variance Request Natomas Levee Improvement Program Supplemental Appendix H – Preliminary Data and Analysis of Tree Fall in the California Central Valley

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Part I: Review of Kleinfelder Report

The March 9, 1989 addendum by Kleinfelder, Inc. contained some sections that I could not evaluate, given my limited familiarity with technical levee drawings, and also because an important photo (R2-6) was not included in my version of the document. That said, based on what material I had, I find that I am in general agreement with the conclusions of the Kleinfelder document. Nevertheless, this document has a number of shortcomings from a research science point of view. The two major shortcomings 1) its reliance on unreplicated or poorly replicated examples; and 2) lack of solid evidence to support its conclusions. I will speak to each in turn, but I should first remark that their attached figures are poorly labeled and it is impossible for the reader to understand what all the lines are for.

1. Kleinfelder indicates that trees pose little threat to levee integrity because their roots don't penetrate very deeply. Their letter of March 9, 1989 contains the results of their safety factor calculations for potential treefall of trees on levees. The verbal description of their analyses is unclear in several respects. For example, their use of the terms "top and bottom" does not make sense since a tree cannot be at both the top and bottom of a levee slope. Their table presents factors of safety for 6 scenarios -- treefall of trees in the three positions having 2-ft deep roots, and treefall of trees in the three positions having 3-ft deep roots. However, they base their calculations on measurement of a single fallen oak tree, 24" in diameter. Thus while I think their findings are more or less correct, they have built their conclusions on a narrow foundation of data from one tree. That said, my own experience after observing literally thousands of uprooted trees in eastern U.S. forests, is that a majority of root pits are indeed less than 2 feet deep, and probably 95% or more of roots pits are less than 3 ft deep. I don't think I have seen a single root pit more than 4 feet deep. Thus I think their approximation of root pit depths is in the right range. More specific to trees on California levees, initial findings from the California Levee Vegetation Research Program's "windthrow" study, of which I am the lead investigator, support the above conclusions. In this study, over 50 trees, most on levee slopes, were winched down to document their wind-firmness and the size of root pits for the ones that uprooted. Of those that uprooted, none created root pits > 3 ft deep, and most were < 2 ft deep. A related observation was measurements our team took from a naturally-uprooted large (40" trunk diameter at 1.3 meters) cottonwood that fell next to the river in Discovery Park, Sacramento. Despite this tree's large size, the root pit created was only slightly more than 1 ft deep.

2. Kleinfelder cites the expert opinion of Mr. Aksland, whose expertise is that he has owned up to 280 acres of almond trees. This doesn't give Mr. Aksland any particular insight into root depth distribution or the size of root pits if a tree uproots. It is unclear how many of Mr. Aksland's almond trees have ever been uprooted or whether he has ever excavated the root system of any of his almond trees. Thus citing Mr. Aksland as an expert to support this document's findings is not convincing. Similarly, Kleinfelder's deduction that the Corps must

consider that trees to pose little threat because the Corps was requiring revegetation, while probably true, does not add weight to the technical argument .

The follow-up letter dated April 14, 1989 by Mr. Robert Dixon has some of the same weaknesses as the March 9, 1989 letter. Again, though, I find myself in full agreement with Mr. Dixon's conclusions; it is just that the evidence that he presents is not very robust. Like the Kleinfelder March 9 letter, Mr. Dixon relies on sampling with limited replication. For example, Mr. Dixon had root borings done near four trees. The subject trees were described as "four of the largest and most representative"; but it is not clear that “largest” are the most “representative”. Because of understandable logistical constraints, Mr. Dixon drilled 1-3 holes with an auger at varying distances from the four focal trees. However, a single 6" diameter hole tells us very little about the root distribution of a tree. Even 2 or 3 holes are such a tiny sample of the volume of soil occupied by a tree's root system, that the findings from the borings are very uncertain. In a number of locations, Mr. Dixon makes observations that reflect his opinion; however his expertise in this area is unclear. His resume reflects a lot of practical experience but little of it seems to be really relevant to this particular topic.

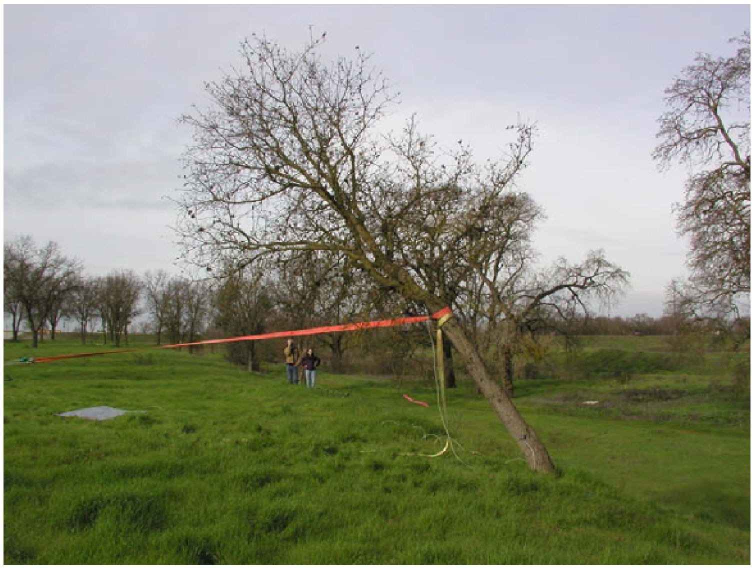
Despite the above weaknesses, I think that both letters reach conclusions that are consistent with current knowledge. In particular, Mr. Dixon writes a very good brief summary of root penetration into soil. Taken together, I think these two letters make statements that are broadly consistent with what we know about root penetration into soil, and about root pit formation when a tree uproots. However, anyone eager to find flaws in their evidence and the approaches presented herein, would not have to look very hard. I think that if anything, this pair of letters argues for just the suite of field investigations that are now underway as part of the Levee Vegetation Science Team's efforts to provide empirical data to guide levee vegetation decisions.

Part II: Relevant observations from experimental treefall studies

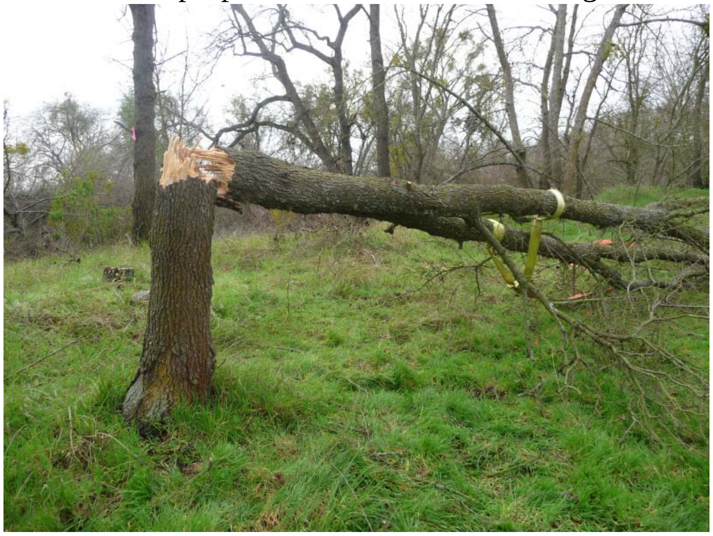
In January and February 2010, a tree-windthrow-vulnerability experiment was initiated, led by Dr. Chris Peterson of University of Georgia, and underwritten by California Department of Water Resources and Sacramento Area Flood Control Agency, with support and cooperation from several other state and federal agencies. The goal of this study (it will be continued in January and February 2011) is to determine the relative stability of levee trees to windthrow. The approach taken is called ‘static winching’ and consists of attaching a winch and steel cable to a tree, pulling until the tree breaks or uproots, and in the process measuring the force generated by the winch. Photos in this section show this research in

progress. The first photo shows winching, cable attachment to the anchor tree, and Peterson seated by the field computer that recorded the cable strain and tree tilt from electronic instruments.

Results of this research confirm the general impressions presented in Part I above. In this study, 54 trees were attempted, and 49 reached the point of breakage or uprooting. The study species were primarily *Quercus lobata* (valley oak) and *Populus fremontii* (Fremont cottonwood). A few *Acer negundo* (boxelder) were also included. Winched trees ranged in size from 4 inches to 20 inches in trunk diameter. The majority of trees were located on levee slopes, but for the purposes of comparison, some trees located on floodplains next to levee slopes were also winched. Photo at left shows a valley oak at the Bear River study site, part-way through the winching process. For all trees considered together, the average size was 11.0 inches diameter; trees on the flooplains were slightly larger (levee slope trees had average sizes of 10.2 inches diameter). Each tree was fitted with two inclinometers ("tilt meters") that measured the tilt simultaneously with the measurement of cable strain by a load cell inline with the steel cable. Both of these instruments fed their output directly into a laptop computer at the study site.

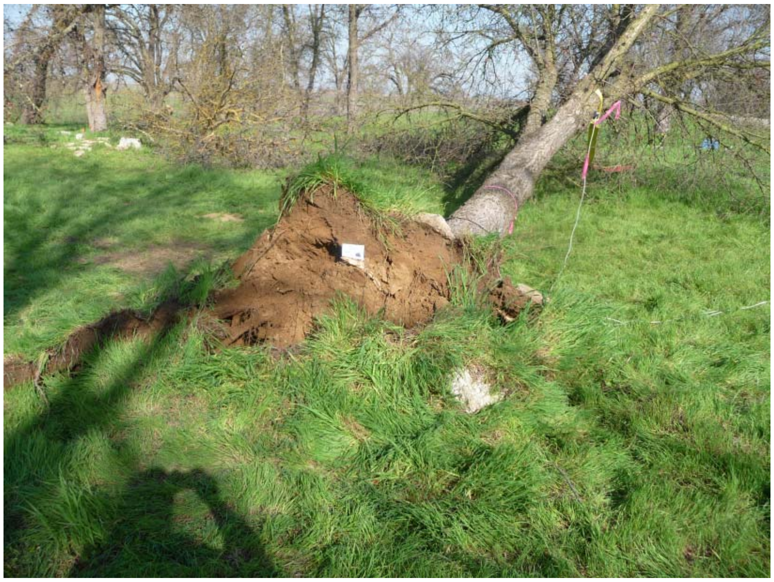


Findings included 26 trees that experienced trunk breakage, and 23 that uprooted. Almost all of the trees on the floodplains uprooted. If the nine uproots from floodplains are removed, the proportions are 26 trunk breakage and 14 uprooted of the trees on the levee slopes proper. The breakage and uprooting data yield several preliminary conclusions: on levee slopes, winched trees were almost twice as likely to break rather than uproot, so for a given probability that a levee tree might be toppled by high winds, it appears that perhaps 2/3 may break off rather than uproot. Oaks on levee slopes were roughly evenly distributed between trunk breakage and uprooting; cottonwoods on levee slopes almost always had trunk breakage; while boxelders almost always uprooted. These patterns suggest that when



concern is with the potential impacts of tree uprooting on levee integrity, oaks and cottonwoods are of less concern because they are less likely to uproot, compared to boxelders. Future research will examine other species, such as willows. The photo at left shows the result of trunk breakage.

Uprooting occurred in a total of 23 trees, 14 of which were on levee slopes. Of these levee slope trees, the root pit created by uprooting was on average 4.1 feet x 2.9 feet, for an average area of 10.6 square feet. The trees on floodplains created larger root pits (data not shown here), probably because they were slightly larger. Root pit areas were significantly positively correlated with tree size (diameter; p = 0.035, r = 0.56). Root pits for levee slope trees had mean depths of 1.62 feet; maximum recorded depth was 3.5 feet for levee slope trees that uprooted. Root pit depth was significantly positively correlated with tree diameter.



Finally, the force required to cause trees to break or uproot was measured in this study. The critical force ranged from less than 1 ton of lateral force for small trees, to more than 9 tons for the largest trees studied. Thus while larger trees create larger root pits, the force necessary to break or uproot a large tree (9 tons in this study) would likely require wind speeds that are quite rare in the Central Valley area. The graph below shows the cable force necessary to bring down trees of differing sizes, as a function of trunk diameter.