Comments on Delta Risk Management Strategy (DRMS) Draft 2.0

Astronomical influence on levee performance

Not surprisingly several of the dozen or so Delta levee failures and many of the episodes of levee distress that have occurred in the past fifty years have occurred during periods of periodic flooding of the Sacramento and San Joaquin rivers and their tributaries (storms, snowmelt) in the Delta. These failures tend to be observed by local residents and "flood fighting" crews who are assigned during times of general flood to patrols which attempt to find and treat areas exhibiting distress signs such as erosion, slope distress, or sand boils, suspected harbingers of failure. The actual mechanics of these failures have rarely if ever been investigated in detail *post mortem* but they are frequently attributed to seepage and "piping" (erosion of tunnels beneath the levee perhaps aggravated by animal borrows.)

Failures of another distinct class happen in what the DMRS calls normal "sunny weather" conditions. These failures are less often observed and likewise not investigated and are typically ascribed either to "mysterious" causes or speculatively to the actions of squirrels or beavers. The failure of the Upper Jones Tract levee on the Middle River in June 3, 2004 falls into this latter category and I will discuss that failure further here.

In fact the Jones tract failure occurred under the most predictable of astronomical conditions: a time of full moon in the month of June, i.e. a spring tide. Moreover the expected and observed tidal behavior on the day of failure, for which there are plenty of detailed records available, was compounded by a secondary orbital effect arising from the eccentricity of the lunar orbit, the so-called perigean effect.

High waters accompanying abnormal tides may be a significant factor in triggering levee failures as at Jones Tract. The higher the water, the greater the seepage forces. However other aspects of tidal behavior could

be of equal or greater destructive effect. Abnormal tidal range produces high flow velocities which cause resuspension of sediment which has accumulated in the bottom of the river channel. Extensive field observations in the delta thirty years ago led to the conclusion that "the greatest resuspension was observed when tidal height differences and maximum velocities were highest scour of the channel". Although the DRMS study proposes to consider erosion as a destabilizing factor it is clear that what is meant is erosion of the levee slopes. This is consistent with the levee maintenance practices over the years which focus on armoring levee slopes with rock to prevent slope erosion. However though levees are often seen to be damaged by floodwater or boat wake erosion, I am not familiar with any actual failures of levees that resulted erosion of the levees themselves.

On the other hand I believe that channel erosion, i.e. scouring of the silty sediments on the bottom of the river, has a strong impact, probably exceeding in most instances the effect of high water, on levee stability. This can be readily demonstrated at least in theory. The delta is a hydrogeological system involving recharge of groundwater via river and slough channels combined with extraction of water from lower farm lands via heavy pumping operations. If, as records show was the case for much of the early to mid twentieth century in the Middle River (the site of the Jones Tract failure), silt tended to accumulate in the river channels, and groundwater recharge was impeded, which translates into a stabilizing influence. (Other contemporaneous factors such as subsidence leading to greater head differentials may have had an opposing effect.) But if seepage is encouraged by removal of protective silt accumulation in the channel the hazard will increase.

This is no new theory. The adverse impact of disturbing natural seepage barriers on the water side of dams and levees has been long known. The danger was understood by Army engineers working on both the Mississippi Sacramento levees fifty years ago. For various reasons this knowledge was not applied in levee engineering and maintenance

in California after about 1955. Nonetheless the adverse impact of man-induced disturbance of the natural protective blanket on the river side of levees can be seen retrospectively in several recent and disastrous levee failures: the 1955 Marysville failure (construction of Englebright Dam and consequent scouring of the Feather river channel by sand-starved floodwaters), the 1986 Linda failure (excavation of a gravel and gold mining pit next to the failure point), and the 1997 failure at Arboga (excavation of an environmental mitigation pond next to the levee, in advance of fixing a known weak spot.) Interestingly the latter two problems were recognized by local farmers and even state inspectors who complained for months before the failures to Corps and state authorities about the attendant dangers.

In the case of the Jones Tract failure the importance of protective silting and the adverse impact of channel erosion was also repeatedly recognized and documented by local farmers well before the failure in 2004.

Other Contributions to Scour

I conclude on the basis above that scour of the river channels, whether from flood, tide, or human intervention (usually some combination) will remain a probable factor in many levee failures of the "sunny weather" type. Scour, being a result of increased flows and velocities, is a predictable factor: a few elementary astronomical calculations remove much of the mystery from those failures that happen on those "sunny day" failures. The tidal behavior is confirmed by review of tidal and flow records maintained by the state showing river velocities reaching an abnormal high just the day before the June 3 2004 failure. Abnormal, but not unprecedented. This raises a question: if the levee was subjected to abnormal tides from time to time in the past, what then was different the first week of June, 2004 that tipped the balance to failure?

I suggest that the reviewers direct their attention to the operation of the State water project, which involves large withdrawals of water at Clifton Court upstream of the reach

of the Middle River at the failure site. The Middle and other rivers and channels have over the past decades been used to draw water backwards, against the natural flow of the river, so that under normal conditions the daily velocities upstream on rising tide are much greater than natural, by a factor of as much as 300 percent. Further, as a result of a program of experimentation involving gating of the Middle and other rivers, along with temporary reduction of water exports (the VAMP program), the conditions in the Middle River underwent changes just two days before the tidal event of June 3, 2004, with a resulting threefold increase in upstream flow.

Issues of Failure Mechanics

Levee failures in California have never been subject to much technical review or study. Perhaps as a result of Paterno there has been an increased attention to this subject and a rediscovery of much of the excellent work done by the Corps of Engineers in the 1940s and 1950s, including the role of underseepage which had been in California locally forgotten and even denied in the tumult of litigation that followed the Feather River failures. However the reassertion of failure theories based on the idea of underseepage and piping needs updating and further development. For example, current local guidance developed by some engineers suggests certain “seepage gradient” safety guidelines drawn on an interpretation of the 1950s Corps data for the Mississippi River. However there is no broad acceptance of these criteria (which the DMS proposes to incorporate into its risk analysis). But these same guidelines applied retrospectively to the case of the failure of the Linda levee would indicate a safe condition even though the levee failed. There are both empirical and theoretical reasons to question these tentative suggested gradients and associated factors of safety. They are also based on the idea that many or most levee failures come about as a result of “piping”, i.e. erosive tunneling beneath the levee. This is a very old idea, based on scant observation, and very difficult to model in any way to provide predictive value. On the other hand more recent work in the Netherlands and re-evaluation of the Linda and Arboga failures does not support this

traditional notion, rather suggesting a more predictable stability mechanism.

All of these rather technical issue will have to be worked out in future research (which in my view needs a significantly improved geological and observational database) and will not be available in the course of the DMS. However, I suggest that with regard to the failure mechanics “epistemic” uncertainties (to use a term favored by the current reviewers) may be much greater than suggested in the current effort on “levee fragility”. Uncertainty on this point may go to the heart of the overall reliability of the analysis.

Seismicity

Finally, I suggest that the seismic hazard should be considered in the light of the lunar and solar periodicity discussed above. Earthquakes of the type which are likely under or just to the west of the Delta are of a class which may be subject to their own astronomical periodicity, and it seems possible that heightened seismic risk could be associated with heightened tidal effects. In other words, the same astronomical effects that weaken the levees may also raise the probability of earthquakes.

Concluding Comments

Incorporating the foregoing additional considerations into the proposed DRMS may or may not have a substantial effect on the overall risk of failures in the Delta. However the study aims to review preventive measures including planning, design research, maintenance, and emergency operations, and these factors may be significantly impacted by the foregoing considerations.

Certainly there would be a significant impact if in the future court decisions shifted the financial burden of Delta levee failures from local landowners and small impecunious agencies to the state or federal government. Additionally I understand that some consideration is being given to increase water exports to state and federal projects. This would increase flows and velocities in the south Delta beyond their present levels.

I suggest that this risk factor could be much more significant than some others such as global warming.

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I've been investigating levee and dam failures in California since the 1960s. I was expert for the plaintiffs in the Paterno case (Google: paterno california meehan). A nice summary of the Linda (Marysville) failure and the subsequent Arboga failure, which touch on some of the subjects discussed here, was written by Chronicle reporter Lance Williams in 1997, seven years before the final supreme court adjudication of the Paterno case. It can be found at

http://www.stanford.edu/~meehan/sfexam.pdf