PROJECT PROPOSAL: LEVEE FAILURE IN THE WEST SACRAMENTO-SAN JOAQUIN DELTA – GIS ANALYSIS OF LAND USE CHANGES

Mathew Rogers
Department of Civil and Environmental Engineering, University of California, Berkeley

LA 221: Quantitative Methods in Environmental Planning

Submitted March 10, 2005

PROBLEM STATEMENT

California's Sacramento-San Joaquin Delta conducts 50 percent of California's freshwater and provides drinking water to 20 million people. The Delta's contemporary configuration is a series of islands protected by 1100 miles of levees, used largely for agriculture, which have subsided up to 26 feet below sea level. Delta levees are prone to failure and subsequent island flooding would cause saltwater intrusion into the Delta, posing a serious threat to drinking water quality. In its current state, the integrity of the Delta levee system is not sustainable and will ultimately result in one of two steady states: *i*) permanent deep water flooding of one or many islands or *ii*) the managed rebuilding of Delta islands to above sea level. The CALFED Bay-Delta Authority is charged with managing the Delta for improved water quality and supply and ecosystem health. CALFED requires the development of tools to assess the impact of Delta island flooding. Tools developed should clearly communicate the effects of Delta island flooding on land uses for use in CALFED planning. A GIS analysis would address the following problems from Delta island flooding:

1. Identify habitat for threatened or endangered species currently found in the Delta that would be adversely affected by flooding
2. Calculation of the area of new wetland and deep water habitat formed
3. Determination of the loss in agricultural land area and economic value
4. Determination of the loss of public resources (e.g. natural gas wells, power line, highways)
5. Calculation of the volume of water needed to fill island accommodation space
6. Modeling of water quality changes resulting from flooding events at one or more islands.

Accommodation space (volume of islands below sea level) has been previously calculated (Mount and Twiss 2004). A spatially correlated model of Delta hydraulic mixing is beyond the scope of this project. Thus the thrust of this project will be items ones through four above.

BACKGROUND

The Sacramento-San Joaquin Delta at the time of American settlement of California was a tidal freshwater marsh system. Between 1880 and 1930 the Delta marshes were reclaimed, largely for agricultural use, with a system of more than 1100 miles of levees (Mount and Twiss 2004). The Delta levee system created the island and channel network of today (Fig 1). Levees were constructed using readily available materials and

construction methods of the day (Twiss 2005). Construction on wetland sediments with improper shoring materials created structurally inadequate levees prone to failure. Failure mechanisms include seepage, boils, and rodent damage. Boat-generated waves also erode the fine grain mud-silt bottom materials on the channel side of Delta levees (Bauer et al. 2002).

The integrity of Delta levees was made more perilous by subsidence of the Delta islands the levees surround. Microbial oxidation of organic wetland sediments, dewatering and compression of wetland sediments, burning of peat, and poor agricultural practices contributed to land subsidence. Gaseous CO_2 fluxes from microbial oxidation accounted for the majority of subsidence in recent years, with subsidence rates of 0.46 to 1.06 cm/yr (Deverel and Rojstaczer 1996). Some Delta islands are now more than 26 feet below mean sea level (Mount and Twiss 2004).

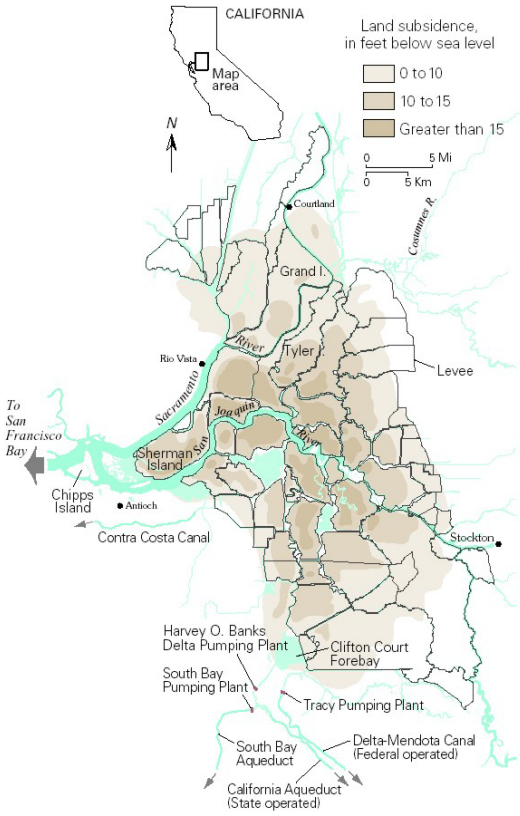

FIGURE 1 – Sacramento-San Joaquin Delta, California. The Delta is comprised of islands or tracts protected by an extensive levee system. Shading indicates the elevation of subsided islands. (Adapted from Ingebritson et al. 2000).

In addition to threats from structural deficiencies, Delta levees could be ruptured by earthquakes. The Sacramento-San Joaquin Delta is in close proximity to a number of major faults, including the San Andreas, Hayward, and Concord-Green Valley Faults. There is a 62% probability of at least one magnitude 6.7 or greater earthquake in the San Francisco Bay Region by 2032 (US Geological Survey 2005). Uncompacted sands, silts, clays, and peat soils forming Delta levees and levee foundations would likely liquefy

during a seismic event (Boulanger et al. 1998). Subsequent levee failure and island flooding would have profound impacts on island agriculture, wetland habitats, and Delta water quality.

The Sacramento-San Joaquin Delta is the center of water resources in California. The Delta drains 40 percent of California's land area and 50 percent of freshwater flows. Federal and State water projects, the California Aqueduct and Delta-Mendota Canal, export up to 7.5 million acre-feet of water from the Delta for agricultural and drinking water use south of the Delta. Two-thirds of California's population gets part of its drinking water from the Delta (Ingebritson et al. 2000). Hydrology of the Delta is complex; freshwater flows from the Sacramento and San Joaquin Rivers, movement of salt water through tidal action, and Delta island configuration effect hydraulic mixing processes. Saline and freshwater are kept in carefully managed balance to protect water quality. Levee breaching would alter hydraulic mixing and saltwater movement into the delta, possibly halting the export of water from the Delta, causing major disruption to the state of California.

The CALFED Bay-Delta Authority is a consortium of state and federal agencies and stakeholder groups with legal power and mission to solve water supply and quality issues in the Sacramento-San Joaquin Delta. Our clients for this project represent the CALFED groups:

- Bob Twiss, Co-chair CALFED Ecosystem Restoration Science Board
- Curt Schmutte, Director Department of Water Resources Levee Integrity System
- Ken DeVore, California Department of Fish and Game

The results of this project would represent CALFED stakeholders and serve as communication tools for Delta levee planning. Products of GIS analysis should clearly communicate changes in agriculture, public resources, and potential wetland habitat as defined in the problem statement above without requiring viewers to be GIS savvy.

A thorough review of literature yielded no studies that used GIS as a tool to show changes in land use due to levee failures. GIS analysis has been conducted to describe flooding scenarios on the McCormack Williamson Tract, a Delta island (Hammersmark et al. 2002). Levee failure risk assessment and land subsidence processes have been modeled with GIS (Pistocchi et al. 2002; Zhou et al. 2003). Changes in wetland habitats due to levee building has also been modeled in GIS (Liu et al. 2004).

Beyond GIS analysis, plans for Delta levee and island management include those drafted by CALFED (CALFED 2004; CALFED 2003) and alternate plans drafter by non-government organizations (NGOs). The Delta management plan developed by the NGO Natural Heritage Institute (NHI) includes ambitious recommendations to avoid construction of another water supply canal bypassing the Delta. Among other actions, the plan calls for the decommissioning Friant Dam to restore flows to the San Joaquin River and rebuilding Delta islands with Tule ponds and additions of dredge spoils and rice straw (NHI 1998; 2002). Drastic measures such as these should be considered in GIS

analysis to create a steady state solution to stopgap measures currently employed in the Delta to protect water quality.

PROPOSED SOLUTION

A GIS analysis of available data will be implemented to satisfy the requirements of the above problem statement. Data layers required will include:

1. Digital Terrain Model (DTM) for California land surface
2. California Cities
3. California Roads
4. California Water Bodies
5. Delta Levees
6. Land use data for Contra Costa, Solano, Sacramento, and San Joaquin Counties (for agriculture land area)
7. National Wetlands Index (NWI) data for the Delta (for current wetland analysis)
8. Aquatic and terrestrial species distribution in California
9. Gas and oil production fields
10. Power lines
11. Water supply infrastructure.
12. DWR Delta Island Flood Simulation Model

The above data has been provided by the clients in a NAD 27 projection. Additional information must be gathered on the types of wetland habitats that exist in areas of specific salinity and water depth. This data is available in common wetlands textbooks (Horne and Goldman 1994). The economic value of agricultural activities in the Delta must also be determined and this will be obtained from County Agriculture Commissioner's reports (California Agriculture Statistics Service 2003).

ArcGIS 3D Analyst and Spatial Analyst tools will be used to identify areas of habitat loss, the loss of public infrastructure, impacts on agriculture, and new habitat created on an island-by-island basis. Other possible analyses include miles of Delta levees and the cost to repair them, and the timescale and volume of fill required for subsidence remediation plans.

EXPECTED RESULTS

The GIS analysis described above will produce new data layers for threatened Delta habitat, threatened species, agricultural land lost, public infrastructure destroyed, and new habitats created by Delta flooding. Our clients intend to use the results of this project for communicating information within CALFED and for public outreach. A variety of map products will be created using newly created data layers. 3D images and cross sections would also improve viewer comprehension. Our clients have requested that we investigate presenting our results through 3D fly-throughs and internet web server technologies.

CONCLUSION

The Delta is at the center of California water resources and exists today in a state of peril. Tools are needed to communicate to CALFED stakeholders and the public the dire results of Delta levee failure. A GIS analysis of the results of levee failure will help our clients to protect ecosystem health and water resources.

REFERENCES

Bauer, B. O., Lorang, M. S. and Sherman, D. J. (2002). Estimating boat-wake-induced levee erosion using sediment suspension measurements. Journal Of Waterway Port Coastal And Ocean Engineering-Asce **128**(4): 152-162.

Boulanger, R. W., Arulnathan, R., Harder, L. F., Torres, R. A. and Driller, M. W. (1998). Dynamic properties of Sherman Island peat. Journal Of Geotechnical And Geoenvironmental Engineering **124**(1): 12-20.

CALFED (California Bay-Delta Authority) (2003). Levee System Integrity Program, Multi-year Program Plan (years 4-7). Sacramento, CA**:** 13.

CALFED (California Bay-Delta Authority) (2004). Ecosystem Restoration Multi-Year Program Plan (year 4-7). Sacramento, CA**:** 29.

California Agricultural Statistics Service. (2003). *Summary of County Agricultural Commissioners' Reports: Gross Values by Commodity Groups – California 2001-02.* Sacramento: California Agricultural Statistics Service.

Deverel, S. J. and Rojstaczer, S. (1996). Subsidence of agricultural lands in the Sacramento San Joaquin Delta, California: Role of aqueous and gaseous carbon fluxes. Water Resources Research **32**(8): 2359-2367.

Hammersmark, C. T., Schladow, S. G. and Fleenor, W. E. (2002). Habitat Enhancement on the McCormack Williamson Tract: and Evaluation of Proposed Scenarios with a Hydraulic Model and GIS. American Geophysical Union, Fall Meeting 2002.

Ingebritson, S. E., Ikehara, M. E., Galloway, D. L. and Jones, D. R. (2000). Delta Subsidence in California:The Sinking Heart of the State. U.S. Geological Survey. **FS-005-00**

Liu, H. Y., Zhang, S. K., Li, Z. F., Lu, X. G. and Yang, Q. (2004). Impacts on wetlands of large-scale land-use changes by agricultural development: The Small Sanjiang Plain, China. Ambio **33**(6): 306-310.

Mount, J. and Twiss, R. (2004). Subsidence, Sea Level Rise, Seismicity in the Sacramento-San Joaquin Delta: Report to the Levee Integrity Subcommittee of the California Bay-Delta Authority Independent Science Board.

NHI (Natural Heritage Institute) (1998). An Environmentally Optimal Alternative for the Bay-Delta: A Response to the CALFED Program, Natural Heritage Institute, San Francisco, CA.

NHI (Natural Heritage Institute) (2002). Subsided Island Restoration Design in the Sacramento-San Joaquin Delta: A Solution for Levee Fragility and Water Supply Vulnerability in the Delta, Natural Heritage Instutute, Berkeley, CA.

Pistocchi, A., Zani, O. and Gottardi, G. (2002). GIS-Based Predictive Modelling for Levee Failure Risk Assessment in the Romagna River Basins. EGS XXVII General Assembly, Nice.

Twiss, R. (2005). Personal Communication.

US Geological Survey (2005). Major Quake Likely to Strike San Francisco Bay Region Between 2003 and 2032. Accessed March 10, 2005 from http://quake.wr.usgs.gov/research/seismology/wg02/

Zhou, G. Y., Esaki, T. and Mori, J. (2003). GIS-based spatial and temporal prediction system development for regional land subsidence hazard mitigation. Environmental Geology **44**(6): 665-678.