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California Levee Risk, Now and in the Future: Identifying Research and Tool Development Needs

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Disclaimer

Auspices Statement

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California Levee Risk, Now and in the Future:
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Sacramento, CA

Workshop Report

Robin L. Newmark, Michael Hanemann, Daniel Farber, editors

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Executive Summary

California depends on a complex system of engineering structures – dams, aqueducts, and levees – for both its water supply and flood protection. The Sacramento-San Joaquin Delta system is the hub for California's water supply as well, providing water for twenty-three million Californians and three million acres of agricultural land, and sustaining a $400 billion economy; it is also a unique environmental asset. Because of an aging and deteriorating levee system, the city of Sacramento itself faces a greater risk of flooding than any other major city in the United States, including New Orleans. In addition, substantial seismic risks in Northern California threaten both the water supply infrastructure in the Delta and the levees that protect valuable agricultural and, increasingly, urban property throughout the Central Valley. Simulations show that a large-scale levee failure would pull salt water into the Delta, requiring a shut-down of water exports to southern California for one to three years (Benjamin Associates, 2005).

The Jones tract levee failure in 2004, combined with the impact of Hurricane Katrina on New Orleans, have raised public consciousness about this flood risk. California voters have recently approved massive bonds to address the threat. Yet, much of the critical scientific information needed to design a solution does not yet exist. Without this information, we have no way of knowing whether the billions of dollars to be spent on the levees will really fix the problem.

To begin to address these urgent informational needs, three University of California Research Centers – the Center for Catastrophic Risk Management, the Center for Environmental Law and Policy, and Lawrence Livermore National Laboratory – sponsored a two-day workshop. Roughly sixty research scientists, engineers, policymakers and agency representatives gathered at the University of California Center in Sacramento to map out a research agenda for flood control issues in the Delta.

This report distills the discussion at the workshop. Workshop participants identified a broad range of research needs. The following four issues were identified as particularly critical:

1. *Climate Change*. Extreme flood episodes escalate quite sharply along with sea level change, which is expected as part of global climate change. High tides and large winter storms, combined with sea level change, pose grave risks. Improved hydrological modeling of the Delta system, along with flood characteristic modeling and probabilistic climate models, are needed. At present there is no comprehensive hydrological model

suitable for assessing the overall flooding and water supply risks in California's water system.

2. *Seismic Risks*. Modeling shows that soil conditions in the Delta will magnify earthquake ground movements. A major quake on the Hayward fault would cause as much shaking in the Delta as near the fault itself. Faulting underneath the Delta is poorly understood. We need probabilistic seismic hazard prediction and scenario prediction to model these risks.

3. *Current conditions*. We do not have an accurate inventory of levee conditions in the Delta, nor do we have accurate subsidence data. (Peat soils inside the levees tend to subside, as in New Orleans, greatly increasing potential flood risks.) We need a complete data base of levee inspection reports, along with comprehensive information about the ownership and control of specific levees (which are often in private hands), the terrain protected by the levee, and the potential economic impact of breach or overtopping in specific locations. We also need improved information about channel geometry and bathymetry; flow rates, water densities, and improved computer modeling. On-going Lidar coverage of Delta levees is needed.

4. Dynamic change. Delta conditions are expected to change because of climate change, the impact of environmental policies, land use changes that strongly influence flood risk, and projected weather changes. All of these matters require careful attention. In particular, we need to have better methods of evaluating the environmental, social, and economic harms associated with Delta risks. We also need improved decision-making techniques for dealing with infrastructure planning under conditions of dynamic change. Decisions made today about land use or infrastructure repair could greatly limit future options for the Delta, making it hard to react to developing scientific knowledge of the risks.

The goal is not merely to develop improved scientific knowledge for its own sake, but to deliver usable and timely information to the officials who are charged with making critical decisions about the Delta. Fulfilling this goal requires the development of a new institutional structure in which policymakers and scientists can interact, so as to ensure that the scientists are asking the right questions and the policymakers are getting the most reliable and objective research findings. The Workshop participants strongly suggested that a consortium approach is needed to engage, provide products to and get feedback from policy and decision makers. What is required is an umbrella that supports the broad set of technical and policy-relevant disciplines that need to be applied. We strongly urge the creation of such an institutional structure by the State of California.

References

Jack R. Benjamin & Associates, *Preliminary Seismic Risk Analysis Associated with Levee Failures in the Sacramento-San Joaquin Delta*. June 2005.

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Workshop Description

Overview: The Center for Catastrophic Risk Management (CCRM) and the California Center for Environmental Law & Policy (CCELP) at UC Berkeley and the Lawrence Livermore National Laboratory (LLNL) joined together to cosponsor a workshop to define research requirements to mitigate the hazards facing the Sacramento-San Joaquin Delta Levee system. The Workshop was intended to provide a forum to

- Report assessments of current vulnerabilities facing the levees, such as structural failure, seismic loading, flooding, terrorism;
- Consider longer term challenges such as climate change, sea level rise; and
- Define research requirements to fill gaps in knowledge and reduce uncertainties in hazard assessments.

Background: The Sacramento-San Joaquin Delta Levee system has received considerable attention since the Jones Tract levee failure in June 2004, the Hurricane Katrina disaster in New Orleans and the centenary of the 1906 San Francisco earthquake. The fragility of the levees in the Sacramento-San Joaquin Delta, and the threat of a tremor on the faults running nearby, have long been a concern for water managers in California. The Delta region faces societal and economic pressures related to land-use issues for agriculture, water resources, navigation and urbanization. Addressing levee issues requires dealing with uncertainty regarding how risks will evolve in the coming decades due to expected changes: natural ones such as climate change, then social ones such as population growth and urbanization.

It is timely to assess the current status of Delta Levee hazards and define the research requirements to reduce uncertainties to move toward mitigation of these hazards. The Katrina disaster has demonstrated the importance of the levee systems. Substantial resources will be mobilized in the coming years to address aspects of the problem. Certainly California is poised to undertake an extensive effort in analysis and implementation. Hopefully, some of that effort will support research and technology development.

A key workshop objective is to begin to describe the R&D required to provide specific solutions or new approaches in a few years' time to address key issues, along with justification for prioritization. The intent is to identify the work that needs to be done over the next few years to provide the solutions for the next round of infrastructure investments, for input to the policy makers and those responsible for the levee infrastructure. This includes research priorities for problem definition, prediction, management tools, policy approaches, technology development and data collection. The workshop report should ideally lay out a strategic plan for research and development.

Many disasters we experience result more from organizational or social/policy problems than purely technical ones. For example, the Shuttle disaster was not due to an O-ring problem so much as the socio-organizational structure that prevented appropriate decision making to take place. However, the problem is much more than "structure" of the organization - and the failure of the New Orleans flood defense system clearly illustrated this. It is due, in part, to a lack of understanding of how very complex systems work, considering that the decision-making process is an integral part of the system as well as the physical part of the levees. It is also due to problems in accounting for non-quantifiable effects, such as a certain perception of the risk, and the effects of operating within a certain mind-set. Although this workshop targeted technical issues to improve on the quality of technical information provided to the decision-makers, the need for revisiting issues of decision-making as an integral part of the system was also recognized.

Participants were a representative sample of experts, researchers and practitioners addressing multiple dimensions of the complex Delta and levee system. Their responsibilities range from defining the required functional system needs for the future of the State and the nation; to evaluating the integrity of the present system; to making recommendations for modifications and upgrades of the system (including engineering solutions, analyses and tools); to implementing those recommendations. A list of participants is included. The environmental perspective was somewhat underrepresented, as the focus of this effort was more on the structural issues. This was not to underplay the importance of environmental issues; in fact, they may be the dominant driver in the decision-making process. However, we needed to start with a workable scope, recognizing that environmental issues might require an expanded discussion at a later date.

Details: The Workshop was conducted over a day and a half, consisting of talks, posters and breakout discussions. The agenda is included here. Participants were encouraged to bring a poster and/or a 1-viewgraph summary of their work as it relates to levee issues. The final general discussion addressed cross-cutting issues, interfaces and broader recommendations than those developed in the individual discussion sessions.

Workshop Participants

James Agnew	California Department of Water Resources
Rodger Aines	Lawrence Livermore National Laboratory
Carol Baker	Office of Assembly Speaker Fabian Nunez
Joshua Bernardo	Solano County Department of Resource Management
Cheryl Bly-Chester	Rosewood Environmental Engineering
John Boatwright	United States Geological Survey
Scott Brandenberg	University of California, Los Angeles
Alt. Brandt	California State Assembly
Thomas Brocher	United States Geological Survey
Robert Budnitz	Lawrence Livermore National Laboratory
Nicholas Burton	Solano County Department of Resource Management
Dan Cayan	Scripps Institution of Oceanography, and United States Geological Survey
Michael Dettinger	United States Geological Survey
Larry Dale	Lawrence Berkeley National Laboratory
Yun Duan	Lawrence Livermore National Laboratory
Tim Duane	University of California, Berkeley
Stephen Durrett	United States Army Corps of Engineers
Daniel Farber	University of California, Berkeley
John Fletcher	United States Geological Survey
Guido Franco	California Energy Commission
Richard Frank	University of California, Berkeley
Justin Fredrickson	California Farm Bureau Federation

Catherine Freeman	California State Legislative Analyst’s Office
Ceci Giacoma	Delta Fire Protection District
Michael Hanemann	University of California, Berkeley
Rodger Henderson	United States Army Corps of Engineers
Thomas Holzer	United States Geological Survey
Nina Kapoor	University of California Center, Sacramento
Tadahiro Kishida	University of California, Davis
Jane Long	Lawrence Livermore National Laboratory
Ladd Lougee	CALFED Science Program
Cathie Magowan	University of California, Office of the President
Dick McCarthy	California Seismic Safety Commission
Norm Miller	University of California, Berkeley and Lawrence Berkeley National Laboratory
Toby Minear	University of California, Berkeley
Jeff Mount	University of California Davis
David Mraz	California Department of Water Resources
Robin Newmark	Lawrence Livermore National Laboratory
Ron Ott	CALFED Bay-Delta Program
Elizabeth Patterson	California Department of Water Resources
Jessica Pearson	California Department of Water Resources
Henry Reyes	California Seismic Safety Commission
Arthur Rodgers	Lawrence Livermore National Laboratory
Doug Rotman	Lawrence Livermore National Laboratory

Badie Rowshandel	California Geological Survey
John Rundle	University of California Davis
Said Salah-Mars	URS Corporation
Jean Savy	Lawrence Livermore National Laboratory
Curtis Schmutte	California Department of Water Resources
David P. Schwartz	United States Geological Survey
Ray Seed	University of California, Berkeley
Larry Smith	United States Geological Survey
Rune Storesund	University of California, Berkeley
Ralph Svetich	California Department of Water Resources
Ken Trott	California Department of Food and Agriculture
Fred Turner	California Seismic Safety Commission
Matt Vander Sluis	Planning 7 Conservation League
Geoffrey Wandisford-smith	University of California, Center, Sacramento
Frank Webb	Jet Propulsion Laboratory
John Ziagos	Lawrence Livermore National Laboratory

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1130 K Street, Suite LL22
Sacramento, CA 95814 (916)-445-5100

AGENDA

Thursday September 28

8:00 am Morning Hospitality, Poster set-up

9:00 Welcome/Logistics **UCCS host**

9:15 Opening Remarks & Introduction to Workshop Goals **CCRM/CCELP/LLNL**

9:30 Keynote Lecture **David Mraz (DWR)**
Overview of Delta Levee System

10:10 The Role of Science in the Delta Visioning Process **Jeffrey Mount (UCD)**

10:45 Break

11:00 Levee Engineering Issues: Katrina lessons for California **Ray Seed (UCB)**

11:35 Needs of Existing Flood Damage Reduction Infrastructure
Stephen Durrett (USACE)

11:55 California Flood Control Levees Response to Recent Flood Events, and
DRMS - Overview of Delta Levee Vulnerabilities **Said Salah-Mars (URS)**

12:15 pm Lunch and poster intros **ALL**

1:30 Climate change and the Threat of Greater Sea Level Rise and Flooding in the Bay Delta **Daniel Cayan (SIO)**

2:00 Translating Risks into Economic and Social Impacts
Michael Hanemann (CCRM - UCB)

2:30 Break

2:45 Working groups: Creative thinking discussion groups

5:00 Poster viewing

6:30 No-host Workshop Dinner

Friday September 29

8:00 Morning Hospitality

9:00 Welcome/Logistics **UCCS host**

9:10 Making Sensible Choices in an Uncertain World **Dan Farber (CCELP - UCB)**

9:30 Plenary session:
Presentation of the groups' suggestions, and discussion.
9:30 Group 1
10:00 Group 2
10:30 Group 3
11:00 Group 4

11:30 Identify common themes

12:00 Lunch

1:00 General discussion
Brainstorming: system performance criteria, problem definition, constraints
Cross-cutting issues, interfaces
Approaches, new tools, gaps, research and development priorities
Summary

3:00 Report out
Drafting of Workshop Report

4:00 Adjourn

Summaries of Presentations

1. Keynote Lecture: Overview of Delta Levee System

David Mraz, Acting Branch Chief, Delta Suisun March Office, California Department of Water Resources

The Sacramento-San Joaquin River Delta drains the flow of five major rivers and carries 47% of California's run-off. Water for 23 million Californians, 3 million acres of agricultural lands and $400 billion of the State's economy are supplied through the Delta. The Delta has numerous functions beyond serving as the hub of California's water supply, including navigation, motor and rail transportation, power transmission, natural gas extraction, recreation and natural habitat. A key component of the Delta are the 1,100 miles of levees that hold back the flow of rivers and tidal surges enabling residential and agricultural uses of reclaimed land, called "islands". These islands are often below sea level and rely critically on the integrity of levees to prevent flooding. These levees are vulnerable to erosion, overtopping, underseepage and animal activities. Sea level raise from global climate change must be considered to increase the load on levees into the future. Seismic loading from the numerous active faults in the greater Bay Area present another expected failure mechanism. A study of impacts from a large scenario earthquake indicates that numerous levee sections could fail and flood large areas. A rush of salt water from the San Francisco Bay would exacerbate flooding. Water export to southern California would cease until repairs enable fresh water to flow to the Mendota and California Aqueducts. The repair of levees would require a huge mobilization of construction and material resources. However, repairs could be expected to take an extended period of time (1-3 years) leading to the depletion of available water resources. All activities that rely on the Delta and its water, such as industry, agriculture and transportation, could be expected to be impacted for years and result in economic losses.

The DWR is taking steps to mitigate threats to the Delta and its levees. The Delta Risk Management Strategy (DRMS) is currently defining hazards and environmental consequences that must be considered to reduce vulnerabilities. The Delta Vision Project will attempt to take more concrete steps to improve levee systems. The November 2006 election included 2 bond measures that would provide funding to improve and protect water delivery systems. So the potential exists to take proactive steps to reduce the hazards facing the Delta Levee System and improve the margin of safety for the critical functions provided by the Delta.

2. Guiding Delta Visions: First-order Drivers of Change

Jeffrey Mount, Roy Shlemon Chair in Applied Geosciences, Department of Geology and Director, Center for Watershed Sciences University of California Davis

Traditionally, CALFED member agencies have approached Delta management based on a desire to maintain current conditions or to restore historic attributes. Until recently, consideration of future conditions has rarely appeared within agency planning documents in CALFED beyond acknowledgement of changes in water use demand. Yet, the scope and pace of landscape and ecosystem change in the Delta are likely to dictate the success and sustainability of all future management options.

The dynamic nature of the Delta forms an important constraint on planning for the future of the Delta. Scenarios that are dependent on maintaining existing or historic conditions are less likely to be viable than those that anticipate or are adaptable to current trajectories of change. Based principally on CALFED science's current understanding of the nature of change in the Delta, there are six first-order drivers of change in the Delta. These drivers are likely to significantly alter the Delta over the near- and long-term and are independent of or unaffected by day-to-day management activities. These drivers include: subsidence, sea level rise, regional climate change, seismicity, exotic species and population growth/urbanization. Each of these drivers will have, or has had, a significant impact on the Delta at variable length and time scales. All will require some form of management response, regardless of which vision is eventually adopted for the Delta. All are a product of anthropogenic activities that have altered, and will continue to alter, landforms, hydrologic conditions, and the environmental services of the Delta.

In setting goals for a science agenda that addresses the needs of on-going planning efforts, it is important to incorporate the need for high-quality modeling tools that can be used to address the six first-order drivers of change.

3. From New Orleans and Hurricane Katrina, to California's Levee Situation Timely Lessons for a State at Risk

Ray Seed, Professor of Civil and Environmental Engineering, University of California, Berkeley

Hurricane Katrina was a tragic disaster that led to the deaths of 1492 people, displacement of over 400,000 people and $150 to $300 billion in losses. Even more tragic is the fact that these losses could have been largely prevented with proper planning and diligence. Findings from the NSF-funded "Independent Levee Investigation Team Final Report" indicate that hubris and denial lead to the tragic losses of Hurricane Katrina. These findings are a sobering warning for the Sacramento-San Joaquin Delta Levee System and strongly suggest that measures be taken in the present to mitigate potential losses from levee failures in the future. Levees are unnatural structures meant to hold back water where it would natural flow. As such government officials and planners must expect to have to choose their battles to defend what can be defended and be willing to concede to nature what is too costly to protect. Numerous examples from New Orleans can be cited where either levees were either poorly designed or not built to withstand the expected loading. This indicates that more diligence is required in the planning and design stages for levee construction and that the plans are executed to the design goals. Geologic structure must be considered when designing a levee for a specific area and analysis of planned structures must be performed by competent independent reviewers. Other examples were shown where the connections of levees systems failed, jeopardizing public safety. Often these connections were at the boundaries of different bureaucratic jurisdictions, suggesting failures of organizational responsibilities. Finally, the lessons of Hurricane Katrina must be considered here in northern California. Many of the observed levee failure mechanisms (overtopping, under seepage, rapid erosion) in New Orleans can be expected to impact the Sacramento-San Joaquin Delta Levee System. Seismic loading presents another expected failure mechanism. The way to prevent a Katrina-like disaster in northern California is to be proactive and plan for expected environmental consequences. This can be accomplished political and public will to spend the money to plan and build effective levee structures and diligently follow these plans.

4. Needs of Existing Flood Damage Reduction Infrastructure

Stephen Durrett, P.E., Levee Safety Program Manager, HQ Engineering & Construction CoP, U.S. Army Corps of Engineers

The Corps has moved to a more risk based approach to looking at infrastructure. Corps Dams have moved into this methodology 2 years ago and the Corps inspection of Levees is moving to catch up. There are bills in front of Congress to establish a National Levee Safety Program and the Corps has been funded to start the development of a National Levee Inventory and Risk assessment methodology. The Corps is working with FEMA, ASFPM, and NAFSMA to better communicate flood risk to communities. The goal of the Risk assessments will be to prioritize projects for Congress and to identify areas of a levee system that require additional study. Areas in Levee safety that need to be improved are techniques to better monitor levees during flood events and methods for performing risk assessments.

5. California Flood Control Levees Response to Recent Flood Events, and Delta Risk Management Strategy (DRMS) - Overview of Delta Levee Vulnerabilities

Said Salah-Mars, URS Corporation

California flood control levees have a history of failures or distress during regular flood events. All failure mechanisms associated with embankment levees have been observed. Back calculation of historic levee damage during past storm events indicates that the California flood control levees are generally performing poorly even during storm events associated with flood intervals of less than 100-years. The need to conduct a thorough and comprehensive evaluation of the flood control system is urgent.

The current risk evaluation of the Delta and Suisun Marsh Levees is an example of initiating a comprehensive assessment of the levee system. This effort includes the evaluation of various stressing events, such as: seismicity, flooding, climate change, subsidence, impact from invasive species, and their combined effects on the: levees, life safety, environment and ecosystem, water quality, water reliability, infrastructure, the economy, etc.

6. Climate change and the Threat of Greater Sea Level Rise and Flooding in the Bay Delta

Daniel Cayan, Climate Research Division, Scripps Institution of Oceanography, UCSD and Water Resources Division, US Geological Survey

During the next several decades, climate model simulations indicate that global warming could amplify sea level rise along the California coast at rates substantially higher than the ~2mm/yr rise that has been observed during recent history. We employ a plausible range of sea level rise, combined with predicted astronomical tides, projected weather forcing, and El Nino related variability to explore possible water level extremes during the next century in the San Francisco Bay region. Extreme event occurrences, relative to current levels, escalate quite sharply as the magnitude of future sea level rise increases. Impacts in the Delta are exacerbated during periods when high tides and large winter storms coincide, producing wind waves and freshwater floods from Sierra and coastal mountain catchments.

7. Translating (Engineering) Risks into Economic and Social Impacts

Michael Hanemann, Center for Catastrophic Risk Management (CCRM) and Chancellor's Professor, Department of Agricultural & Resource Economics, University of California, Berkeley

We argue against an “engineering” mindset which assumes that the unknowns have all been identified and quantified. This is not true, and one needs to allow an additional risk factor for unquantified elements of uncertainty. Moreover, the risk of damage is likely to be changing over time due to (i) the geriatric aging of the flood control system, and (ii) ongoing economic and social change, including land use. Therefore, the estimate of risk needs monitored and updated over time. At present, there is no mechanism to make this happen.

Building an “event tree” analysis of the human, as opposed to engineering, components of risk is hard, yet it needs to be done. The event tree will depend heavily on institutional factors because those create incentives for individuals and groups to take action, both advance preparation (adaptation) and response. Hence the need for a behavioral component to the risk analysis.

The recent assessment of potential climate change impacts in California shows that spatial downscaling is important because it more clearly reveals threshold effects that can generate significant non-linearities in the economic damages. Another issue is the significance of risk aversion, which has largely been overlooked. With perfect foresight, the cost of adaptation can be minimized; for example, water can in theory be purchased in the exact amount of a prospective shortfall. In reality, however, there is uncertainty (imperfect foresight) and also risk aversion, Because of the latter, water users will rationally want to buy protection (in effect, insurance). With insurance, some costs are incurred that turn out ex post not be have been needed – but they are worth it because, ex ante, one does not know what will happen during the coming year. This additional cost has not been factored into existing analyses of climate change impacts. For water infrastructure these costs are likely to be especially significant.

8. Making Sensible Choices in an Uncertain World

Dan Farber, California Center for Environmental Law & Policy (CCELP) and Sho Sato Professor of Law, Boalt Hall School of Law, University of California Berkeley

Economists distinguish between risk, which involves events whose probability can be quantified with reasonable precision, and uncertainty, which involves events with poorly characterized probabilities. Sometimes we are aware of these gaps in knowledge, but we also may simply have failed to conceptualize a potential hazard. The design of the New Orleans flood control system several decades ago provides apt illustrations. For examples, designers of the New Orleans flood control system assumed that weather patterns changed only over a period of centuries, failing to account either for climate change or cyclical storm patterns. Acknowledging these uncertainties has several implications. First, we should favor strategies that are sufficiently flexible to adapt to unexpected new information, rather than favoring the kind of brittle infrastructure now characteristic of the Sacramento-San Joaquin Delta region. Adaptive management techniques should also be integrated with environmental assessments.

Second, we also need to develop new decision techniques to identify robust strategies in view of plausible hazards. Third, researchers need to give policy makers a firm understanding of known areas of uncertainty, rather than limiting themselves to discussing hazards that can be readily quantified. Model uncertainty should be clearly discussed. Where potential hazards cannot be reliable quantified, researchers should aim to bracket the range of probabilities or at least qualitatively characterize the seriousness of the hazard. Fourth, planning should never be based solely on point estimates of hazard probabilities when these estimates are subject to significant doubt, because doing so may result in adoption of unduly brittle solutions.

Research Summaries

During Thursday's lunch, several of the participants presented brief summaries of research related to the delta and levee system:

Lynn Wilder (LLNL) pointed out that, given the inherently spatial nature of the Delta system, GIS can be a unifying technology for delta levee system research.

Tom Brocher (USGS) presented a summary of the probabilities of large (M>6.7) earthquakes on major Bay Area faults. He also showed shear-velocity depth profiles for several basins in the Bay Area and pointed out that the Delta is composed of low-velocity shallow materials that are likely to amplify ground shaking during an earthquake.

Jack Boatwright and Joe Fletcher (USGS) presented a summary of a planned seismic deployment for the Delta. These data will provide site response observations where no previous data are available.

John Rundle (UC Davis) described the California Hazard Institute, recently formed as a UC Multicampus Research Program.

Tom Holzer (USGS) described a USGS program to determine liquefaction potential in the San Joaquin Delta.

Scott Brandenberg (UCLA) described a destructive field testing approach and examples of levee issues that this approach could be used to investigate.

Rune Storesund, P.E. University of California, Berkeley described measurements made with an Erosion Function Apparatus (EFA) in collaboration with Dr. J.L. Briaud (TAMU), demonstrating a measure of erodibility.

J. Toby Minear (UC Berkeley) described ground-based LiDAR for surveying levees and erosional sites

Artie Rodgers (LLNL) presented results of a recent study of in which earthquake ground motion was predicted for a M_W 7.0 Hayward Fault Earthquake, showing that predicted delta ground motions are almost as high as along the Fault itself.

Larry Smith (USGS) described a project designed to sequester carbon and reverse land subsidence by managing freshwater march to accumulate carbon as plant biomass – a potential new use for delta islands.

Discussion Groups

Discussion Groups: The participants broke into discussion groups, each focusing on one of four broad questions with the assistance of a facilitator and a note-taker:

(1) **How to characterize the levee system infrastructure?**
Including characterization of the levee system, its structural behavior, flow dynamics, geology, etc, and the dynamics of the decision-making process for design, updates, and evaluation.

(2) **What could disturb the levee system?**
Including possible natural and environmental hazards, man-made hazards, malevolent actions, and non-natural hazards such as socio-political elements in the organization

(3) **What can go wrong in the system?**
Including all possible failure scenarios which could lead to damage, loss of functionality, or catastrophe, decision-making break-down, and

(4) **What is at risk and what are the consequences of damaging events?**
Including physical damage, economic loss, social disruption, and political ramifications, etc.

Each of the discussion groups were asked to (1) identify existing gaps in knowledge or in the existing technology and (2) determine what tool development, data collection and monitoring strategies might be undertaken to address these four questions. Each group prepared a presentation of the material summarizing their discussion and their recommendations. It was acknowledged that, while many issues can be addressed by technical options, some issues are best addressed through policy. While policy was not the focus of this workshop, the participants were asked to keep track of those non-technical issues and options that were raised in their discussions, especially those dealing with societal choice, economic drivers and the role of policy. Similarly, they were asked to note cross-cutting issues and interfaces that might cause artificial boundaries (such as organizational responsibilities). Finally, each group was provided with key questions and elements to consider, partly to spark discussion.

GROUP 1: How to characterize the levee system infrastructure:

Group (1) Participants: Jean Savy (Facilitator), Roger Aines (Note-Taker), Michael Dettinger, David Mraz, Said Salah-Mars, Jean Savy[1], Larry Smith

Key questions:

What functions do the levees perform? How are these likely to change in coming decades?
What is the state of the integrated system by which the levees are designed, constructed and maintained?
What are the important attributes of the Delta levee design, construction and maintenance system for which we need improved or new methods of analysis and/or tools?
What are the promising new methods or tools that would be appropriate to handle these attributes?
What are the important knowledge gaps for which we need new creative thinking?
What factors or conditions must be monitored to evaluate levee performance and integrity?

Elements to consider for answering these questions:

1) Network characterization and function of the integrated system, physical characterization
   - Functionality of the levee system, including dependent and functions, industries
   - Network characterization, complexity
   - Geographic distribution of levees
   - Geometry and material properties of levee sections
   - Age of construction, probability of failure
   - Risk factor for land protected by section
   - Lifeline coupling (transportation, water, power, gas, etc…)
2) Monitoring and Data Requirements

- Levee structural integrity
- Free board water level (sea level rise)
- Saturation of levee materials
- Lifeline integrity
- Subsidence

Group 1 Discussion Summary

The levee system has physical, biological, and political/organizational elements. No single issue stands out as the primary characterization concern. The ability to access and use information in a timely and effective fashion is the primary concern. The DRMS process is focused on relatively short-term needs for improvements in the physical system, but may not address the needs for emergency information in the event of earthquake-caused failure of levees. The effects of climate change may go beyond simple water level rise. Earthquake hazard is not well understood. Climate change and ecosystem hazards are moving targets in the delta, requiring integrated analysis to prioritize the important problems before adequate characterization can be identified.

These issues call for delineation of problems at a system level. For instance, the effects of population change in the delta are as important an element as the condition of the levees; both can have dramatic effects on the consequences of an earthquake. There is also a need for a mechanism to accumulate and distribute the various social, scientific, and engineering data associated with the delta. This should focus on making data available for both planning and emergency response. This is specifically not a call for an agency to take over such a role, but perhaps a joint agency working group to coordinate data activities. The roles of various agencies in an emergency should be well known, and pathways to obtain vital information clearly established. Several specific data needs were identified: better standardization of levee construction methods, better real-time monitoring particularly after storms and earthquakes, and better models and material data bases specific to the behavior of the delta.

<u>GROUP 2: What could disturb the levees? Damaging Hazards</u>

Group (2) Participants: Jane Long (Facilitator), Artie Rodgers (Note-taker), Jim Agnew, Jack Boatwright, Tom Brocher, Dan Cayan, Yun Duan, Jon Fletcher, Roger Henderson, Tom Holzer, Tadahiro Kishida, Badie Rowshandel, Henry Reyes, John Rundle, David Schwartz, Ralph Svetich

Note: Group 2 was composed primarily of technical experts, including 12 seismologists, earthquake engineers, and 2 climate/hydrology scientists.

Key questions:

What are the hazard phenomena that put the levees at risk?
Are the methods of assessment of each of these hazards appropriate for this task?

What are the promising methods or tools that would be appropriate to improve on existing methods and tools?
What are the important knowledge gaps for which we need new creative thinking?

<u>Seismic Hazard</u>

How will the levee system behave under earthquake loading?
What is required to predict this behavior? For design/modification guidance?

<u>Elements to consider for answering these questions:</u>
1) Probabilistic Seismic Hazard prediction
   - Long-term characterization, for design
   - Scenario prediction, for design and response preparation
   - Real-time updating for response management
2) Monitoring and data Requirements
   - Seismicity
   - Tectonic dynamics, geodetic data, stress data

<u>Hydrologic Hazard</u>

Is the levee system adequate to support the multiple hydrologic demands anticipated in the future (flood protection, water supply, navigation, etc)?
Is current flood forecasting adequate for protecting the levee system?
What factors require monitoring?

<u>Elements to consider for answering these questions:</u>
1) Probabilistic River flow prediction
   - Precipitation (rainfall/snowpack)
   - Flood forecasting
2) Monitoring and data Requirements
   - Flow (volume and speed)
   - Sediment properties
   - Rainfall/snowpack data for watershed(s)
   - Incoming storm potential

<u>Climate Change Hazard</u>

Given the uncertainties in climate change projections, how can we determine how climate change will impact the levees?
What factors require monitoring?

<u>Elements to consider for answering these questions:</u>
1) Probabilistic climate behavior models
   - Climate change modeling
   - Temperature and precipitation models
   - Flood characteristics modeling

2) Monitoring and data Requirements
   - Sea temperature
   - Sea level rise

<u>Other Hazards</u>
   - Navigation
   - Commerce and recreation
   - Non-natural hazards such as terrorism, malevolent actions
   - Non-natural hazard such as organization and decision process flaws

Group 2 Discussion Summary

This group was tasked with defining the hazards that could disturb the Delta Levees and lead a potential loss of function. The group focused mainly on natural hazards, although human-caused disturbances were briefly discussed. The main natural hazards that threaten the Delta Levees are: seismic ground motions from earthquakes, hydrologic loading and response, climate change and subsidence. The human-caused hazards are development and terrorism. In the following sections the discussions and conclusions on the each of these issues are presented with attention to the questions listed above. A detailed list of issues raised and discussed by Group 2 is included in the Outbrief.

Seismic Hazards

Earthquakes and the ground motions they cause pose a very credible threat to the Delta Levee system. The USGS has estimated the probability of a magnitude 6.7 or greater earthquake in the greater San Francisco Bay Area between now and 2032 to be 62%. While the methods for seismic hazard assessment are well established, the required inputs for assessing hazard in the Delta are poorly known. These involve the presence of and likelihood of earthquakes beneath and adjacent to the Delta. Faults cannot be mapped under the Delta with conventional means because of the presence of water and development. Earthquake repeat times are typically longer than the ~100 years of recorded earthquake history, making it difficult to assess the threats posed by known faults adjacent to the Delta. Another major issue is the nature ground motion amplification in the Delta. The sedimentary geology of the Delta is expected to amplify seismic ground shaking, but little empirical data is available on this. Other issues are more poorly known, such as the structural response of levee sections to ground motion (with and without the presence of water) and the accuracy of ground motion estimates from 1D and 3D simulations. All of these factors suffer from the general lack of detailed geologic and geophysical information about the Delta. It was recommended that a concerted effort be undertaken to collect data that will improve understanding of seismic hazard in the Delta.

Hydrologic Hazards

The Delta Levee system channels water for many users. The amount of water and how it flows through the Delta varies with season, weather and use demands. Of particular concern is the response of the Delta and its levees to high precipitation and flood events. These can damage, overtop and possibly lead to catastrophic failure of the levees. Because most of the water flowing through the Delta originates far away the flow has a complex dependence on upstream factors such as precipitation, snowmelt, reservoir management and water export. No model exists for this entire water system and this was noted as a major gap in the understanding and management of water passing through the Delta. Such a model should also include the ability to investigate the hydrologic consequences of levee failures, which could arise from natural (e.g. spontaneous, flooding, earthquake failure). Finally, any model of hydrology is only as good as the input data, so an effort to acquire detailed hydrologic (e.g. flow rates and dam controls), precipitation, wind, and other data for modeling flow in the water system is also needed. These data should be made available to a broad user community.

Climate Change Hazards

It is expected that sea level will rise as the earth's atmosphere and hydrosphere warm. Because much of the Delta islands are at or below sea level there will be an increased load on levees protecting these islands. Sea level rise must be accounted for in the hydrologic model proposed in the last section. Climate change will impact the amount and nature of precipitation falling in California. For example precipitation that currently falls as snow at high elevations in California's mountains may fall as rain in the future. This will result in hydrologic surges and the loss of water for consumption by humans and agriculture. Finally, we need to better understand the consequences of climate change in California for extreme weather events such as drought and storms.

Subsidence Hazards

Subsidence is a secular trend whereby compaction and erosion of the Delta soils leads to the gradual lower of Delta islands and levees. Subsidence increases the load on levee systems by decreasing the freeboard height of the levees and making it easier for water to seep into the islands. This phenomenon can be monitored with geophysical methods. However, no known continuous surveys have been or are being performed on the Delta. There is a need for the application of proven methods to monitor subsidence.

Development Hazards

Human development for recreational, residential, commercial and agricultural uses in or near the Delta exposes people and economic interests to the many hazards facing the Delta. Development in turn alters the landscape in ways that can make the levees more susceptible to failure. Impacts of ground water pumping, gas extraction and building should be evaluated for their impacts on levee stability.

Terrorism Hazards

The shear expanse of the Delta Levee system, its fragility and the grave consequences of losing functionality in a levee section make the Delta a target for terrorism. There is an acute need to survey the Delta for particular levee sections whose loss would result in failure of systems to deliver water to residential, commercial and agricultural users. These sections could then be hardened and protected to reduce terrorist threats.

Synergistic Hazards

It was mentioned that all the hazards discussed can happen independently or together and there is a need to consider the consequences of simultaneous events that could be even more catastrophic than any single event. Examples could be a high tide during an intense winter storm in the presence of global warming-induced higher sea level, or an earthquake during a flood. The modeling capabilities described above could be used for evaluating the consequences of simultaneous events.

GROUP 3: What can go wrong in the system?

Group (3) Participants: Cheryl Bly-Chester (Facilitator), Robert Budnitz (Note-taker), Scott Branderberg, Roger Henderson, Ron Ott, Ray Seed.

Key questions:

How can levee system behavior be predicted?
How can levee structural integrity be predicted? Modeled? Measured? Enhanced? What is required?

Elements to consider for answering these questions:
1) Behavior of the levee system
- Response, geotechnical properties

- Levee structural properties
- Operating requirements
- Real-time behavior of system

2) Monitoring and data requirements
   - Update of the topology of the system
   - Update of the functional demands
   - Environmental parameters (animal and fish life, marshland, air and water quality, etc..)

Group 3 Discussion Summary

Group 3 first developed a list of specific causes that address "What can go wrong?". Some of these are technical factors, but many are non-technical or institutional factors. Among the latter, the most important are inadequate investments in maintenance; overlapping jurisdiction problems that impede such investments; the problem of dual-use levees, where the other function (for example, if the levee is also a road) causes the problem; and most importantly, continuing adjacent development (housing, commerce, light industry).

The Group then moved on to identify knowledge gaps, or gaps in analysis capabilities. Again, a long list was developed. One very important gap is the lack of comprehensive levee-specific information about who owns and manages each levee, who could make a quick decision about it, what assets each levee protects, which dual uses does it support, and the inspection history. Another gap is the need for a complete data base of levee inspection reports, available on a "no-fault" basis vis-à-vis liability. Still another one is the need for a training and certification program for levee inspectors Technical needs include an improved hydrodynamic modeling capability, an improved wind model for the Delta, and the fact that hydrology information is outdated and the topography is dynamically changing, making modeling of the system uncertain if not sometimes erroneous. Finally, a systematic inspection protocol for the levees must be developed and implemented across-the-board by the owners/managers of every levee.

GROUP 4: What is at risk and what are the consequences of damaging events? Physical, Societal/Economic Vulnerabilities/Organizational, etc.

Group (4) Participants: Michael Hanemann (Facilitator), John Ziagos (Note-taker), Carol Baker, Dan Farber, Catherine Freeman, Nina Kapoor, Ladd Lougee, Doug Rotman, Matt Vader Sluis

Key questions:

What kind of information is needed to help in the decision-making process?
What are our expectations for the levee system?
What mechanisms are available for protection of vulnerable elements?
What is required for improved mechanisms?

Elements to consider for answering these questions:
1) Characterization of elements at risk, and how they will evolve
- Residential population census (where do people live)
- Commercial/Industrial census
- Agricultural land use
- Traffic patterns (commute, escape routes)
2) Model the consequence of all possible hazard scenarios
- Economic models
- Land use models
- Social migration, health, … models
3) Monitoring and data Requirements
- Building permits
- Land development
- Water absorption (runoff potential)

Group 4 Discussion Summary

The over-arching theme of the discussion was how might scientists and technologists best support the natural disaster legislative decision-making process? Detailed physical, societal, and economic vulnerabilities, decision-making, and organizational issues were considered with detailed examples permeating the entire discourse. Discussion highlights include: the understanding and brain-storming of solutions to current and relevant natural disaster-related legislative actions/inactions and contentious issues such as resolving floodplain mapping particulars and the sharing of liability for flood protection between state and local governments and developers in the context of significant built-in funding impediments and multi-agency cross-responsibility chaos.

Summary of key recommendation topics include: 1) creation of a mandate for official State planning for hazards to develop a state-wide, long-range, adaptive flood and climate change risk assessment management approach, 2) development of scenario contingency planning to encourage focused investigation of adaptation policy *including* unthinkable policies focusing attention on modifications to building codes and examination of *unthinkable* alternative land use management strategies under the climate change scenario considering, for example, buying up farmland/restricting urban development while utilizing financing/liability options for flood control that incorporate land use modeling and disaggregate current information to match jurisdictional boundaries and finally, 3) development of tools to assist legislators and agencies in policy formation and decision-making, that might include: post-breach decision support systems to assist in setting levee repair priority, development of state-wide multi-year levee repair standard, and creation of an official State climate change scenario(s).

General Discussion

The final session was a general discussion, intended to address cross-cutting issues and interfaces, to brainstorm system performance criteria and constraints as well as highlighting points not made in the earlier sessions. A few topics emerged as main discussion points. What follows is a summary of the main points, with specific notes grouped under the discussion topics:

What is needed?

A consortium approach is needed to engage, provide products to and get feedback from policy and decision makers. This is broader than the research community alone. We need an umbrella that supports the broad set of (technical and policy-relevant) disciplines that need to be applied.

On the scientific side, it is critical for seismology and geotechnical experts to get together with hydrology and climate researchers. A key question to address is "what are the conditions that set the stage for a catastrophe?" (i.e., an earthquake during wet season). Need a working dialogue.

There is a missing piece in the current forum dealing with policy and our ability to assess the potential impacts of different policy options. DWR staff may see their role as doing science, not policy. CalFed has been a forum. There may be a need for neutral ground to float policies and ask scientists for analysis related to the policies their research relates to or can contribute toward.

The Katrina example highlighted the need to invest DOLLARS and DILIGENCE. California should consider the benefits of PROACTIVE and PREVENTATIVE. We are acutely aware of our vulnerabilities and the threats posed. An ounce of prevention is worth 10 pounds of cure.

Unfolding events/opportunities:

Bond Issues: The upcoming bond issues (1E and 84) have specific tie-ins to levee improvements. There is potential for some targeted R&D to enhance the efforts these bonds may finance.

Legislative actions and Executive Order: The Governor recently signed several delta bills, including Executive Order S-17-06 that establishes a blue-ribbon task force to address the Delta – the Delta Vision process.

Information on the legislative actions:

- Executive Order S-17-06 initiates the Delta Vision and establishes an independent Blue Ribbon Task Force to develop a durable vision for sustainable management of the Delta. Making the Delta more sustainable will require a concerted, coordinated and creative response from leaders at all levels of government, stakeholders, academia and affected communities, and will require significant private and public partnerships and investments. The Delta Vision is designed to accomplish these goals:
- SB 1574 will create a cabinet-level committee chaired by the Secretary of the Resources Agency and include the Secretary of the Business, Transportation, and Housing Agency, the Secretary for Environmental Protection, the Secretary of Food and Agriculture, the President of the Public Utilities Commission, the Director of

the Department of Finance and the Director of the Office of Planning and Research to develop a plan for a sustainable delta.

The Delta Vision is already underway. There are two potentially bad end-member options about this:

(1) there is no money to affect changes, or

(2) these is money provided, but without a plan. The bond issues may provide on the order of $6B for the levees, and a strategic plan is needed to ensure these investments provide the expected protection and reliability. We are likely to have significant funds available soon (through the bond measures). We want these funds to be spent wisely.

Urgent: a short range view needs to be developed ASAP, but work will go on for some time. There is an opportunity to incorporate R&D along the way to improve overall results. We need to lay out an R&D strategy for three timescales:

- Urgent, short-range
- Medium timeframe
- Long-term

Other points:

A lot of construction and other work will be outsourced – controlled by DWR. They need a good strategic conceptual framework to ensure satisfactory results.

There may be sufficient funding and sense of urgency that there will be a need to get a lot of work done quickly.

Typically, the funding is distributed through the organization and the staff approves projects according to guidelines. There is not now a research component specified. With respect to a science program, DWR would look to CalFed to do it.

Need a long term view with adequate science to guide the implementation of the policies that are developed by Delta Vision, policy makers, legislature using DRMS.

Vision goals: As some of the workshop speakers pointed out, the decision may be to create a hydrologic bypass (peripheral canal), or to armor a part of the levees through which the water supply would run. There are multiple options, and the technical options, potential consequences and ultimate costs must be investigated.

In the meantime: Legislative bodies need to sustain the existing Delta system while the deliberation progresses on what to do in the long-run.

Systems approach:

A systems approach is important for considering the multiple dimensions. Tools are needed.

Coordination between policymakers and the technical community:

The system model you build has a lot to do with the question you think are important. Challenge is to find those policy makers that can help you determine the right questions. The model is only a thinking tool to focus other research. We need to get guidance from policy-makers in framing the question a model needs to address.

We must short-cut the cycle by meeting with dedicated legislative staffers – liaisons as way to do this, on a regular basis.

An advisory committee (including legislative staff) might serve this purpose.

Similarly, multiple agencies need to coordinate better. The state needs to encourage a high reliability organization.

Leverage existing roles and capabilities in all technical fields. For example, the California Geologic Survey has made its resources and data available.

Ongoing activities/opportunities:

CalFed started the Bay Delta Science Consortium, that could be focused on these issues. It provided financial support to encourage collaboration, something much needed in this arena. NOTE: CalFed hasn't done much on levees to date and has recently reconstituted the science board without any engineers on the board, and important gap.

The USGS seismic work (i.e., NEHRP) – a seismic safety communication – could be incorporated to advantage.

The CA Seismic Safety Commission has some relevant initiatives listed in their strategic plans:

- California Earthquake Loss Reduction Plan CSSC 02-02, 22002-2006.
- A Safer, More Resilient California: The Alfred E. Alquist State Plan for Earthquake Research CSSC Publication 2004-03, June 2004

The DRMS Phase 1 draft will be due 3/07; Initial Technical Frameworks (ITF) white papers (14 of them) are now available on the DWR website

Additional inputs were given regarding the prioritization of recommendations and next steps:

Which are the highest priority actions or most important areas to focus on (short-term to long-term)?

1. Improve our ability to predict high-water stands (height, duration, frequency) spatially within the Delta channel system.

This will require better characterization of the levee configurations, channel geometry and bathymetry (at lidar resolution or better?); more complete observations of the network of Delta water levels, flow rates, and water densities (both from salinity and turbidity); and development of more practical/complete hydrodynamics models of the Delta flows brought to as realtime as possible,

2. Improve the mapping of probabilities of seismic episodes that are AT LEAST large enough to threaten major levee disruptions.

This is NOT to say improved mapping of the largest seismic episodes, or greater ability to resolve among various levels of seismic activity, but rather a focus on mapping of the odds of EXCEEDING some reasonable seismic-impact threshold.

3. Improve our knowledge of the development of lands in and around the Delta.

Too much of our knowledge of plans and built developments in and around the Delta seem to arrive as anecdotes and hearsay...some central monitor/repository of Delta land uses and land-use plans needs to be developed and maintained.

- **Rationalize current projections of sea-level rise as apply off San Francisco and as translated into the Delta.**
  Current projections have a serious disconnect between short-term sea-level fluctuations and the long-term trends as derive from ice-cap melting...even if we can't be sure yet what the ice caps will do, a considered and rationalized approach to incorporating these uncertain trends into sea-level projections is largely lacking.

<u>What are the key next steps to be taken?</u>

1. The State needs to acquire and maintain its own capacity for VERY regular surveys of the Delta and levees at high resolution (i.e., lidar). Lidar coverage of all the Delta levees could be obtained (from a small plane) in a day, and with in-house capability, this could become a standard action on a periodic basis and after most large storms or earthquakes.

2. Develop a 21st Century plan for monitoring in the Delta, taking advantage of new daisy-chained sensor-network capabilities and new sensor types

3. Land-use, water-use and economic information must be made available from the many stakeholders in the Delta for strategic planning. Legislation should be introduced to facilitate and guide this process.

- **A long-term community plan for a practical but highly resolved Delta hydrodynamics model (and supporting data streams) must be developed and implemented**. The goal would be a community effort to develop the best technical product that meets the practical needs of the next decade or so. It will likely require a broader participation amongst public and private institutions than has been achieved in the past.

Appendix I

Group Discussion Outbrief Presentations

GROUP 1: How to characterize the levee system infrastructure:

Components of the Levee "System":
Physical element
Operation, management, and decision-making process
Funding process
Science community
Regulatory element
Political component
Public input/support
Interagency interface cooperation
We need to have a holistic view of a "complex" system (organic), where stakeholders may have diverse and diverging interests

Current Delta Levee Functions
Water Supply
Current agriculture
Flood control
Maintain ecosystem/bio-diversity
Transportation/Infrastructure
Recreation
Human life and property
Run-off disposal

Functions of the future:
All the current functions
Changing in time
Regional and area specific
Possible function to consider is CO_2 sequestration
Others…?

Tightening Web:
Sea Level rise (climate change)
Seismicity
Urban development
Subsidence
Ecosystem
Increasing funding need in business-as-usual for upgrade funding needs for maintenance and emergency response

Some issues, constraints:
Need to look at solutions for:
- Short term, immediate update and improvements (i.e., the DRMS effort)
- Emergency response
- Long term maintenance, and updating for a changing world (Long-term = > 10years)

Are present decisions made with long-term view?
Present approaches are incremental (Time, resources and funding). Limits ability to make major changes and experiment with new approaches.
Political Constraints/Expediency and rush studies could be counter productive
Consensus, political and scientific. Need to fold-in experts'diversity

Different degrees of maturation in sciences and engineering:
Climate change need more characterization – Needs a sound risk model
More work in fault studies and characterization
Ecosystem is least understood – More research and observation is needed

Factors for monitoring levees
Crest elevation, width, slopes
Seeps and boils
Deformation
Cracking
Settlement
Erosion
Water flow
GWT
Subsidence
Ecosystem monitoring
Population
Delta smelt
Water quality – Salinity change, turbidity, etc.
Flood stage, run-off, temperature, etc..

General Recommendations:
Understanding the critical needs
Preparing for emergency response
Pre-event readiness-Inter-agency protocol
Social engineering
Commit to higher funding for maintenance
Establish partnership between the government and industry
Characterization data should be coordinated and organized for immediate (real-time) access.
- Where should it reside? Central? Distributed?
- Coordinate the various activities (i.e. GIS work)
- Need for Delta data center ?
- Need for a unified source of information (during an emergency response)
- Define agency roles for the Delta

Know where to go

Both during and emergency and normal time

- Need to collect the existing data and update

Remote sensing and non-destructive testing (GPR, MR, Geophysical survey)

Instrumentation – Real-time input

A few specific recommendations:

Develop Standard for design and construction of Delta Levees

Need for specialized material properties, testing to augment the geotechnical database

Better LiDAR survey and more frequent flights particularly after each storm

Need to identify potential borrow material

Large scale testing

Need for a 3-D hydrodynamic model real time mode

GROUP 2: What could disturb the levees? Damaging Hazards

What could disturb the levee system? (defining scope)

Including possible natural and environmental hazards, man-made hazards, malevolent actions, and non-natural hazards such as socio-political elements in the organization

What could disturb the levee system?

Seismic Events and Consequences

Hydrologic Events and Conditions

Climate Change Consequences

Development

Subsidence

Terrorism

Seismic Hazard

How will the levee system behave to seismic loading?

What is the expected loading?

- Seismic Hazard Analysis
- Ground motion observation and modeling
- Geotechnical observations
- Ultimately, need input ground motion for levee design

Time-series or response spectrum

Will levees fail under seismic loading?

- Detailed characterization of levees
- Modeling of levees

Expected Seismic Loading

Requires:

- Seismic Sources

Earthquake Faults (geometry)

Slip rates (repeat times, max magnitude)

- Regional-Scale Geologic/Seismic Velocity Model
  - Attenuation relationship
  - Basin Effects
  - Scenario earthquake modeling
- Site Response and Geotechnical Constraints
  - Empirical Observations
  - Boreholes, Sampling, Lab Measurements
  - Must include dynamic response

Requires observations of ground motions

- Weak motion recordings from
  - Smaller local/regional events
  - Large teleseismic events
- Can be used to identify amplification of seismic waves in the Delta (basin structure
- Can be used to validate geologic/seismic velocity model

Seismic Sources (see Figure 1)

Green Valley & Greenville Faults are poorly characterized

- These are very close to Delta
- Can trench these strike-slip faults

Blind Thrust Faults

- Coast Range Great Valley Fault

Runs under Delta

- Mount Diablo Fault
- Must rely on seismic reflection

Geodetic techniques may improve slip rates

- InSAR, GPS, LIDAR
- Will also constrain subsidence

Geologic/Seismic Model (see Figure 2)

Inherently 3D

Require deep boreholes to map sub-surface

Seismic imaging difficult due to logistics and near-surface materials

Must scale lithology to

- seismic velocity
- attenuation

Must be validated with various observations

- Local/Regional/Teleseismic earthquake waveforms
- Gravity

Site Response/Geotechnical

Characterize near surface geology

- Site response (amplification)
- Liquefaction potential
- Can one identify the “failure” layer

Collect samples throughout the Delta

- Increase spatial coverage

- Characterize dynamic properties of samples

Ground Motion Prediction Methods

Standard Probabilistic Seismic Hazard Analysis (PSHA)

- With improved input
- Only provides PGA, PGV, Spectral response

Ground Motion Time-Series and/or Response Spectra

- Joint empirical and simulation-based method
- Compute ground motions, use HPC

3D simulations of large earthquakes for low frequencies

Empirical or simplified model-based motions for high frequencies, stochastic ruptures

Merge low-frequency with high-frequency motions

Levee Failure Under Seismic Loading

Requires detail models of levees

- Geometry, materials, effect of water
- Sub-surface geology

Improved analysis methods

- Current practice

2D, equivalent linear, simplified non-linear

- More sophisticated analysis could be done

3D, fully non-linear, includes liquefaction

More Challenging:

Validate levee performance by mechanically driving motion

- Find analog structure w/o water

Search for deformed geologic surface at depth

- What density of boreholes?

Monitor deformation with geodetic techniques

- Identifies slip on faults and subsidence

Hydrologic issues

Can we predict precipitation in sufficient detail?

When will events occur? Dry or wet season? How will this correspond to how much water is stored in reservoirs?

Need a study of how well large and long duration flood events are handled by the model. How well did models handle floods of record such 97 and 86.

Time based forecasting. Can we release water when we know something is coming in three days even though we haven't hit the 75% level when they are supposed to release it. More specific understanding of the effect of where the rain fall. See project INFORM to get more flexible operating procedures. CALSim is a component (Jay Lund) but he isn't looking at these time scales. Optimize the short term management of the system. Need to do this comprehensively for the state.

We need a model of the managed hydrologic system coupled with models of the hydrologic and atmospheric input.

Flood advisory and diagnostic system – like LLNL's National Atmospheric Release Advisory Center (NARAC)
Can this help to work with conservative decision makers?

What is the impact to the delta from a breach under various conditions?
There have been failures that resulted in gulps – but models of this are slow – need a quicker faster model – in order to know whether to release model from Shasta etc.
- Jones track episode gave some information, but not generalize-able

Need to study which levee breach puts the system in danger the most – we don't know now.
Need a model to understand how the delta flushes out – hydrodynamic model of the delta.
There is need for a parallelized version of these models
A better model – 3d that could be run quickly.

Climate change
Needs to be an updated survey of sea level rise projections
We need a better characterization and exploration of flooding under climate change that accounts for the managed system (reservoirs etc)
Need more thorough exploration of winter storminess and ppt systems in climate change model projections – where is the snow line? Changing runoff regime while climate is changing.
Need to understand extreme events better – like in 1997 when a storm track was stuck for 10 days – do our models replicate this behavior and how does this go forward. Number of intense, persistent events and under what temp they occur.
Water temperature is a variable that has not been studied or monitored in the bay and delta – need for better models– effects species.

Look at the simultaneous effects of
- High tide
- Sea level rise
- Floods
- High winds
- And a large earthquake

Climate Monitoring:
Mountain rain/snow transition zone needs to be monitored – as this dictates runoff
Water temperatures in the tributaries and delta need to be monitored
Do we have enough water gages in the system? Say between Antioch and the delta?

Subsidence
Need permanent geodetic monitoring
- InSAR, GPS, LIDAR

Subsidence of the levees themselves? Can we predict this? Is it monitored effectively?
- Permanent scatterer methodology

Are the elevations of the levees known?

Development
Changes geologic conditions near levees
At what distance and how does development change stability conditions for the levees?

Terrorism
Are there particularly soft targets?
Do we know where they are and do we know how to protect them? Or harden them?
- A hydrodynamic system model could answer this

<u>GROUP 3: What can go wrong in the system?</u>

What can go wrong? (technical factors)
Overtopping
Through-levee seepage
Under-seepage
Bank erosion
Channel erosion
Wind erosion
Levee slope instability
Seismic-liquefaction
Seismic lurching
Dredging that undermines the levees
Close-in dredging damage vs. broader dredging damage
Penetrations (local)
Un-maintained growth (trees, bushes, etc.)
Beaver damage
Sea-water penetration due to sea level rise
Terrorist acts

What can go wrong? (Institutional/non-technical factors)
Cancellation of state programs or funding
Emergency response failures (planning, OR implementation)
Dual use levees --- failure of another function (<u>e.g.</u>, levee also a road)
Inadequate investment in maintenance (causes a lot of above issues)
- Obstacles to maintenance:
  Physical and policy obstacles
  Resources---follow-through

Overlapping jurisdiction problems impeding investment or response
Problems with the levee SYSTEM vs. individual levee problems
The needs of the RIVER AND ITS USERS vs. the levees
The needs of other utilities (electricity, gas, rail)

What can go wrong? (Land use management)
<u>DEVELOPMENT (the largest single issue today)</u>
Property rights impediments

Agricultural practices causing subsidence
Ecosystem restoration

KNOWLEDGE GAPS & TOOLS GAPS
(data, knowledge, tools/methods, implementation)

- **<u>Information about each levee:</u>**

Who owns it, manages it, who could make a quick decision, what assets does it protect, which dual-uses does it support, inspection history
Improved topographic data, kept up to date
Improved cross-section topography
Improved subsurface geotechnical knowledge
Several fully-characterized levee sections (a few dozen)
- Study a subset of the above with full seismic response, stability, and SSI analyses

<u>2. General (broader) information needs</u>
Enlist geophysics community to brainstorm how they can help us understand levee structure (Get the geophysicists to focus on under-seepage and through-seepage issues)
Data base on endangered species and all other species
Outdated hydrology
- Even without climate change

Delta topography is dynamically changing
Improved hydrodynamic modeling tools
- Including real-time hydrodynamic tools in an emergency

Seismic instrumentation -- including full suite of seismic data

<u>3. Need for a complete data base of inspection reports</u>
<u>Legal issue:</u> The reports need to be on a "no-fault" basis vis-à-vis liability
Reports on all levee works, and why
Reports on repetitive repairs in the same spot
Data base of annual flood-fight observations by location

CROSS CUTTING ISSUES

Develop a systematic inspection protocol for levees
Need a training program to develop a cadre of levee inspectors
- Graduate students, junior engineers, internship programs

Need a wind model for the Delta (statistical compilation of velocity,
- direction, hazard, annual variation across the Delta)
- data to validate models

IN GENERAL:
We need technical information and insights to inform the political and decision-making process

GROUP 4: What is at risk and what are the consequences of damaging events? Physical, Societal/Economic Vulnerabilities/Organizational, etc.

Background: As it happens, there was a legislative battle in the last session on (i) floodplain mapping, (ii) "show me the flood protection", and (iii) sharing liability for flood protection between local governments & developers. Plan to require proof of 200 yr flood protection was lowered to 100 yr (and only > 25 units) before the bill was killed.

Maintenance of levees is a "hodge-podge" of agencies, they say "not enough funds" and run into a prop 218, need a 2/3 vote to get new funds – THIS IS A BIG ISSUE

Risk Assessment – the problem
We need to develop a plan ahead of time for which islands we should let go. The geotech assessment will take 10 yrs for DWR. But, can't wait that long. Therefore, need multi-year, long-range plan. But, what exactly would that look like? In effect, how would one structure an adaptive management approach to risk assessment?
Also, not just which levees should be repaired in the event of a breach, but also to what standard should they be repaired (100 yr, 200 yr, 1,000 yr)
Again: how to answer this in the spirit of adaptive management?

How to move forward?
To make headway in face of bargaining impasse on flood control, broaden the agenda: include climate change along with flood risk.
Recognize crucial need to work through contentious issues ahead of time – contingency plan, which can be based on a *scenario* rather than a forecast.
Create a mandate for official State planning for flood and climate change hazards.

Floodplain/Preparedness Planning for California
Develop an official State climate change scenario(s) like those used by Climate Action team, but with some additional modifications; perhaps focus on 2005-2035.
Assess risk of damages under this scenario for flooding, fire, for local governments etc.
Also, encourage focused investigation of adaptation policy and unthinkable policies.

Adaptation Policy
Focus attention on what modifications are needed for building codes under the climate change scenario. We normally do this ex post. Here we do it ex ante.
Examine (presently unthinkable) alternative land use management strategies under the climate change scenario: buying up farmland/restricting urban development.
Examine (presently unthinkable) financing/liability options for flood control.

Additional modifications for scenarios
Spatial disaggregation/downscaling to more local regions and to upper elevations.
Refine from monthly to daily/hourly time step to investigate flooding, and environmental quality (temperature, flow), at certain locations.
On hydrology, include Colorado River basin.

Incorporate land use modeling.
Disaggregate to match jurisdictional boundaries

Challenges
Shift focus from optimization to robustness and bargaining.
How to implement adaptive management in an institutional and political setting?
How to incorporate (1) periodic review, and (2) compensation to permit modifications to be made

Technical Tools
To deal with climate change, need new hydrology (streamflow/reservoir management) models that are NOT tied to past hydrology.
Need to link hydrology model to land use model, economic model.
Focus should be linking distinct models probably on different temporal & spatial scales, rather than a single, galactic, integrated, hydrologic-economic model.

Figure 1. Seismic Sources

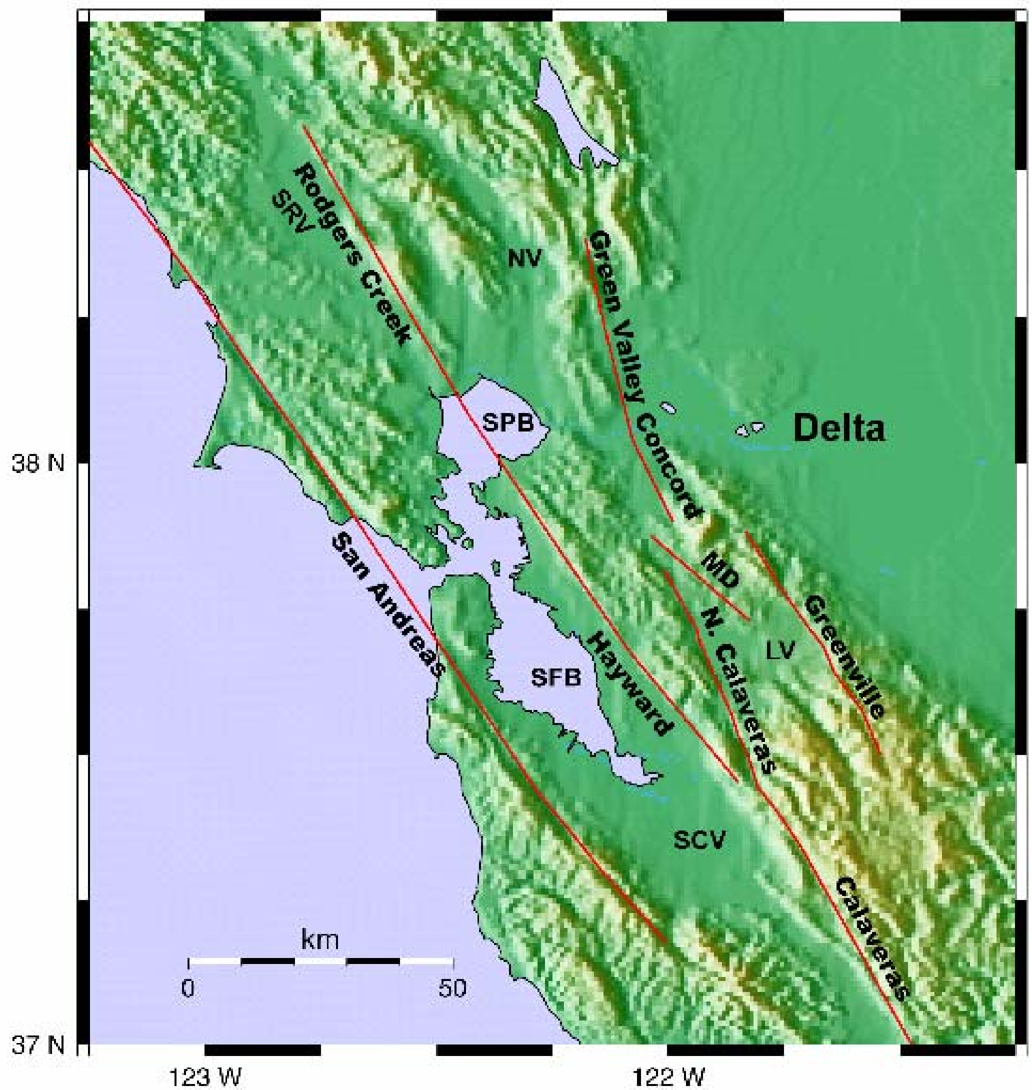
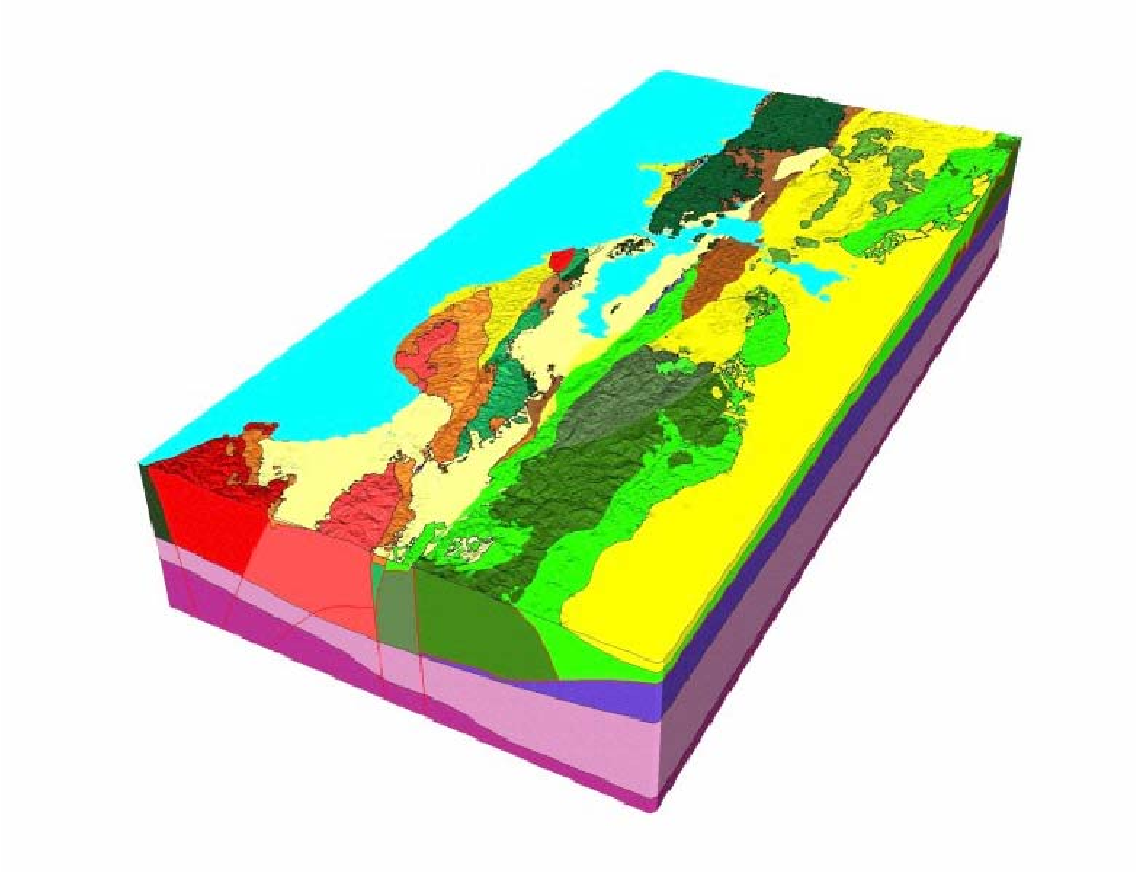


Figure 2. Geologic/Seismic Model



Appendix II
<u>Press Release</u>

The workshop was highlighted in a news statement released on October 4, 2006, shown below (it can be found at http://www.llnl.gov/pao/news/news_releases/2006/NR-06-10-01.html.)

Workshop identifies research needs to protect levees

Approximately 60 research scientists, engineers, policy makers and agency representatives from around California gathered recently for a two-day workshop to define research needs in order to manage the flood risks facing California's levees.

The workshop, held at the University of California Center in Sacramento, covered a wide range of risks facing levees in the Sacramento-San Joaquin Delta and the Central Valley – from seismic risks and infrastructure frailty risks to climate change and risks associated with urbanization and inappropriate land development.
California Department of Water Resources
Concerns over flood risks from California's levees range from earthquakes to climate change and urban growth.

"The Sacramento-San Joaquin Delta and levees are complex and extremely vulnerable. This workshop delineated a critical need to understand how all the parts and aspects of the Delta interact as a system, so that society can make wise choices about investing in the future of this vital resource," said Jane C.S. Long, associate director for Energy and Environment at Lawrence Livermore National Laboratory.

Concern over the viability of the Sacramento-San Joaquin Delta and levee system has increased in recent years, due in part to the Jones Tract levee failure in 2004, the Hurricane Katrina disaster in New Orleans and the recent centenary of the 1906 earthquake. The Delta is crucial to California's agricultural economy.

With several groups now investigating the wide variety of hazards facing the Delta, the Center for Catastrophic Risk Management and the California Center for Environmental Law & Policy at UC Berkeley and Lawrence Livermore co-sponsored the workshop.

"The session brought together California policymakers with some of the nation's leading technical experts," summarized Dan Farber, professor of law at UC Berkeley and director of the Environmental Law Program. "The group identified critical gaps in our knowledge about the enormously complex Delta system, including the impact of climate change on flood risks."

"This workshop generated a new paradigm for viewing the Delta system that promises to bring together many competing interests to work on a common sustainable solution to delta concerns," added Dave Mraz, program manager for the California Department of Water Resources' Delta Levees Program.

Over the two days the forum:

* Identified current vulnerabilities facing the levees, such as structural failure, seismic loading, flooding, terrorism;
* Considered longer-term challenges such as climate change, sea level rise and water supply implications; and
* Defined research requirements to fill gaps in knowledge and reduce uncertainties in hazard assessments.

“One of the key goals was to broaden the focus from seismic risk to the flood risks associated with climate change and rapid urban growth, and from engineering issues to the economic, legal and institutional factors that can have a crucial influence on the success of efforts at disaster prevention, response and recovery and, hence, determine California’s flood damage exposure” said Michael Hanemann, professor of environmental economics and policy at UC Berkeley, and director of the California Climate Change Center there.

The workshop then turned to development of a detailed list of short-term and long-term research and tool development needs, including research priorities for problem definition, prediction, management tools, policy approaches, technology development, data collection and more. A report will be prepared summarizing the workshop’s findings.

Raymond Seed, a professor of civil engineering at UC Berkeley, summarized the workshop by noting, “In the wake of the recent disaster in New Orleans, there is now an increased awareness of California’s own levee fragility and flood risk exposure. These are complex issues, requiring levels of teamwork and collaboration among numerous technical disciplines, and this workshop has been a valuable step in that regard.”

Founded in 1952, Lawrence Livermore National Laboratory has a mission to ensure national security and to apply science and technology to the important issues of our time. Lawrence Livermore National Laboratory is managed by the University of California for the U.S. Department of Energy’s National Nuclear Security Administration.

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