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In the Delta Risk Management Strategy (DRMS) analysis, risk is defined as the likelihood (frequency) of adverse consequences that could occur as a result of levee failures in the Sacramento–San Joaquin River Delta (Delta). Quantitatively, risk is defined in terms of three components: loss or consequence, frequency of occurrence, and probability as a measure of uncertainty (Kaplan and Garrick 1981). Although the focus of DRMS is on analysis of risk as defined above, it is worth noting that the events that are modeled may involve benefits (rather than only losses), such as potential changes for the ecosystem (e.g., from stopping the water export pumps and their associated damage to fish).

This section defines the scope and the limits of the DRMS risk analysis, especially what is included in the analysis and what is not included. The DRMS project is not a planning study; rather, it is a quantitative analysis of risk and alternative risk-informed strategies for managing the Delta. This work, when incorporated with other studies and information, will provide planning-type information to guide design activities. The risk analysis results and the identification of risk-informed management strategies will be available to (and hopefully helpful to) other initiatives, including the Delta Vision initiative, the Bay-Delta Conservation Plan, the assessment of the California Bay-Delta Authority Program (CALFED) End of Stage 1, CALFED planning for Stage 2, and to others performing planning studies.

The most important contributions the DRMS makes are the methodology and submodels developed and integrated for the purpose of quantifying Delta levee risks. Those comprehensive tools can be used again in future planning studies to explicitly quantify the risks associated with alternatives that are of special interest in the planning process. Thus, if the tools are carefully used, planners and decision makers can obtain specific information for comparing risks of competing alternatives. Such information has not been available previously. In the past, such comparisons have usually been made only on a qualitative or intuitive basis, if risks were considered at all.

3.1 OVERVIEW

The focus of the DRMS study is the assessment of risk to the Delta area and California associated with Delta levee failures. The risk analysis addresses events (e.g., earthquakes, floods, climate change) that impact the performance of Delta levees and the consequences that may ensue due to levee damage or failures.

Earthquakes (or floods) that cause levee damage may, of course, also cause other infrastructural damage not involving Delta levees. The other damage could be in or out of the Delta area. For example, water aqueducts may breach, bridges may fail, or water distribution systems may be affected. Such damage that is not caused by Delta levee failure is not addressed within the present DRMS analysis. Aspects of such damage may warrant consideration in future risk analysis updates. Non-levee or out-of-Delta damage could make overall event consequences worse by delaying Delta repairs or by their own causative effects on infrastructure and economic activity. Similarly, other damage (by itself) could cause some of the same consequences that would stem from levee damage. The synergistic/antagonistic effects and the double mechanisms for impact are not addressed here. Consequences are attributed to levee damage as if that were the only mechanism of causation.

3.2 GEOGRAPHIC AND EVALUATION SCOPE

With respect to the evaluation of levee systems, the geographic scope of the DRMS risk analysis includes the area of the Delta and Suisun Marsh:

- Suisun Marsh east of the Benicia-Martinez Bridge on Interstate 680
- Legally defined Sacramento–San Joaquin Delta, as defined in Section 12220 of the Water Code

This area, which is identified on Figure 2-3, is the area within which the damage to and failure of levees and island or tract flooding, including levee/flooding impacts on infrastructure, is evaluated.

However, the consequences of levee failure within this area may be more widespread; they can extend well beyond the defined boundary to other regions and the entire state. For example, although outside the Legal Delta, parts of Sacramento could be flooded as a result of levee failure in the Delta. These consequences are within the DRMS scope. Therefore, the economic impacts of levee failures within the Delta and Suisun Marsh are evaluated for the entire area that could be flooded or otherwise affected. However, only the direct impacts to the in-Delta ecosystem resulting from levee failure are addressed in this work. The potential indirect impacts to ecosystems outside the Delta caused by levee failures within the Delta and Suisun Marsh are complex and difficult to model and are therefore outside the scope of this project.

An assessment of risks and the evaluation of risk management strategies must be made on the basis of the current state-of-knowledge. To the extent the present knowledge is incomplete, an assessment of risk is uncertain (and may specifically recognize uncertainty). That uncertainty will be assessed and characterized as part of the overall DRMS analysis results.

This analysis of risks associated with Delta levee failures is a complex and challenging undertaking, especially in light of the incomplete information available and other constraints imposed. The following precepts guide the Delta risk analysis:

- The DRMS project must be carried out, for the most part, using existing information (data and analyses). The project schedule does not afford the opportunity to conduct field studies, laboratory tests, research investigations, or complex new modeling efforts.
- The analysis must include an assessment of the epistemic (lack of knowledge) uncertainty (i.e., an assessment reflecting the uncertainty associated with the current state of knowledge [data, information, cause-effect relationships, and engineering and scientific understanding] regarding the events and consequences that are modeled).
- Measures of risk (e.g., risk metrics) and risk reduction strategies must address the impacts (e.g., economic and environmental) outlined in Assembly Bill 1200. Life safety was subsequently added to consequences that must be addressed.
- A “business-as-usual” (BAU) approach is taken to guide the analysis with respect to modeling the current risks as well as evaluating risks for future years. This approach assumes that existing regulatory and management practices are carried forward into the future and serves as a base case. More discussion about BAU and its influence on the risk analysis can be found in Section 3.4.

3.3 DELTA DYNAMIC AND FUTURE

Several factors, or drivers of change, will affect future levee risks in the Delta and Suisun Marsh. These factors include forces of nature over which little human control exists (e.g., earthquakes), and factors like urbanization for which no single oversight is in place, given existing regulatory and management practices. The Delta and Suisun Marsh are facing changes that may be gradual or sudden, as summarized in the Delta Vision “Status and Trends” document (URS 2007). The respective DRMS Technical Memorandums (TMs) provide additional detail (URS/JBA 2007a–2007f, 2008a–2008f).

- **Subsidence** – Land subsidence has placed most of the Delta land surface below sea level. Subsidence varies with location, but rates of 0.5 to 1.5 inches of soil loss per year are common in the Delta. This historical subsidence has left multiple islands with average land surface elevations as much as 15 feet or more below mean sea level. Several islands have areas as much as 25 feet below sea level. The dramatic reduction of land surface elevation on Delta islands has increased the differential head between the landside and water surface elevations in the channels. Although the areal extent and rate of subsidence of Delta islands and tracts have reduced in recent years, subsidence is still continuing in many areas. Continued subsidence will increase levee vulnerability and add to both the chances and consequences of levee failure.
- **Global Climate Change and Sea-Level Rise** – Sea levels have been rising for approximately the past 20,000 years. They rose rapidly after the last ice age and then at a modest rate for about the last 5,000 years (Gornitz 2007). But the rate appears to have increased during the past century. Current estimates by the Intergovernmental Panel on Climate Change indicate that sea level will rise by about 0.3 foot to 2.9 feet over the next 100 years, with a possible added 0.5 foot if the rate of Greenland ice melt increases. Other estimates predict more rise (Climate Change TM [URS/JBA 2008b]). For example, Rahmstorf (2006) estimates a sea-level increase of 1.3 to 4.8 feet by 2100. If levees are to be maintained, a continuing effort to repair, raise, strengthen, and expand the levee system is required. Even if the effort keeps up with the rate of sea-level rise, both the chances and consequences of levee failure are likely to increase.
- **Regional Climate Change and More Winter Flooding** – By the end of the century, depending on future heat-trapping emissions, statewide average temperatures are expected to rise between 3 and 10.5 degrees Fahrenheit. The estimates show more winter precipitation occurring as rain and less as snow, leading to more winter flooding. Higher flood stages in the Delta would increase the chances and consequences of levee failure.
- **Seismic Activity** – From research conducted since the 1989 Loma Prieta earthquake, the U.S. Geological Survey (USGS) and other scientists presently assign a 62 percent probability to the likelihood of at least one magnitude 6.7 or greater quake, capable of causing widespread damage, striking the San Francisco Bay region before 2032 (USGS Open-File Report 03-214). This shaking has the potential to cause multiple levees in the Delta to fail. Furthermore, the probability of such an earthquake (within a given number of years) is increasing as time passes, assuming no major earthquake occurs in the interim (Seismology TM [URS/JBA 2007a]).

- **Delta-Suisun Land Use** – Although agricultural and conservation uses are encouraged for the Delta and Suisun Primary Zones, further urbanization is expected in the Secondary Zones. There is uncertainty on when full development of the Secondary Zones will have occurred, but consensus seems to point toward mid-century rather than later (URS 2007).
- **Delta-Suisun Population** – Projections of study area population increases indicate the present (year 2000) population of 470,000 will increase by 600,000 to 900,000 people by 2050 for a total population of between 1,070,000 and 1,370,000 (URS 2007).
- **State Population** – Similarly, but less dramatically, the state population is expected to increase from 33.8 million in 2000 (DOF 2007a) to 59.5 million in 2050 (DOF 2007b).

In assessing risks for the future as contrasted with the present, these progressive changes and the evolving probabilities of sudden changes must be explicitly recognized and factored into the analysis. Quantification of the various changes can be complex and challenging and will be accompanied by increasing uncertainty as projections extend further into the future.

3.4 BUSINESS AS USUAL

During the Phase 1 analysis, various models of stressing events and their consequences are used to characterize Delta levee damage events now and in the future. The events resulting from uncontrollable natural and physical processes are estimated using engineering and scientific tools that are readily available or on the basis of a broad consensus among the practicing community. Such events include the likely occurrence of future earthquakes of varying magnitude in the region, future rates of subsidence given continued farming practices, the likely magnitude and frequency of storm events, the potential effects of global warming (sea-level rise, climate change, temperature change) and their effects on the environment.

The evaluation of risk to the Delta and the state will be made for the present and for 50, 100, and 200 years in the future. It becomes apparent that projections and/or assumptions defining the future “look” of the Delta need to be established. The Delta will change in the next 50, 100, and 200 years. The question facing the DRMS project is, What type of Delta should one assume in these future year projections?

Again recognizing that risk-informed decisions will be made to shape the Delta of the future, one must establish the BAU scenario for the Phase 1 risk analysis as a base case. Defining a BAU Delta is required, because one of the objectives of this work is to assess whether continuation of existing management practices provides for a sustainable Delta for the foreseeable future. Furthermore, setting a BAU scenario helps to establish an unbiased measure of risk for the Delta and remove potential speculations.

The BAU scenario can only be defined as far as the limited duration of existing agreements, policies, and practices. Hence, longer time spans may not be covered by such policies or be well represented by current practices. The study assumes that current policies and practices are maintained to the extent possible for the longer periods of time (50, 100, and 200 years). Exceptions to this assumption may potentially arise in conditions where the changes in the Delta overwhelm the financial and human resources normally devoted to maintaining the Delta. The bullet points listed below present examples to illustrate these potential conditions.

Also, certain water transfers would likely occur during a catastrophic event, so it was assumed that the state would not allow the pumps to south-of-Delta areas to be out of service for more than 2 years. However, it would be speculative to identify the specific water transfers and exchanges that might occur in this situation, so the BAU analysis does not attempt to do so.

Furthermore, instances will occur where procedures and policies may not exist to define standard emergency response procedures during a major (unprecedented) stressing event in the Delta or the restoration guidelines after such a major event. In such conditions, prioritization of action will be based on: (1) existing and expected future response resources, and (2) the highest value recovery/restoration given available resources.

Below are some examples illustrating the development of the BAU scenario:

- **Flood Protection** – Flood protection levees will be maintained in urban areas to provide the same level of protection (e.g., 100-year flood) for the period of study considered (e.g., 50, 100, 200 years from now).
- **Delta Levees** – Levees in the Delta will be maintained in accordance with current maintenance practices as defined by the recent record of available resources. That is, it will be assumed that appropriations of subvention and special projects funding will continue at the 2005 rate. Note that this does not include recent bond funding, which is not viewed as a BAU mechanism.

Present state appropriations are not adequate to keep up with current maintenance and repair needs, even without sea-level rise. Thus, should sea level rise by several feet in the next 100 years, raising the levees to keep up with sea-level rise cannot be considered BAU. The resources and funding required to build and maintain levees several feet higher than they are now would clearly exceed BAU resources. This has been viewed as a severe restriction. To facilitate understanding, a modified version of the base case is to be developed – one in which levee improvement funding is assumed to increase to keep up with sea-level rise by raising, but not structurally strengthening (or weakening) Delta levees.

- **Emergency Response (Levee Repair)** – Human and financial resources available at the time of a major disruption to the Delta (as a result of an earthquake, flood, or other hazard), will limit the emergency response as it relates to the repair of levees (breaches and nonbreach damage). As an example, if tens of levees breach during a major event in the near future, the state, federal, and local entities may not have enough resources to reclaim them all quickly. The islands will be stabilized to prevent future deterioration, if possible.

Prioritization of certain islands for early recovery efforts will be based on the highest benefit for the available resources (e.g., public health and safety, infrastructure, water supply and water quality, and habitat). Furthermore, during a flood fight, prioritization will have to be considered, depending on available resources, to protect those islands with highest opportunities first, considering both the value of the threatened resources and the prospect for success in preventing flooding of the island.

- **Delta Improvements** – Delta improvements in the planning stage were considered if those projects were funded and approved in the 2006 calendar year. Planning studies under consideration for future years will not be considered in the Phase 1 risk analysis. Such examples include the planned upgrades of the levees to bring them to a Public Law (PL) 84-

99 status and other south Delta improvement planning studies. Although, these potential projects will not be considered in the BAU scenario for Phase 1, they will be included in the risk reduction evaluations in Phase 2. They may turn out to be prime candidates for improvements.

- **Land Use** – Urbanization and land use for the Phase 1 BAU scenario will be based on the assumption that the Delta’s Primary Zone will continue to be free from new urban development as is now required by the Delta Protection Act. However, development in the Secondary Zone will continue at the current trend, based on current and projected urban development plans. These Delta zones are defined in Figure 2-3.
- **Habitat Restoration** – Habitat restoration has been underway for at least 5 years. The Phase 1 analysis assumed an ecosystem with no additional restored areas.
- **Water Operations** – Operations following an event in the Delta will be based on current project operating procedures (including reservoir operation guidelines, any formalized standing orders and emergency procedures, and pre-action consultation procedures with fisheries agencies or others) and stated priorities as expressed to the DRMS project team by the State Water Resources Control Board staff. These water allocation priorities are first for human health, and second for endangered species to the extent mechanisms exist to implement them, and then other uses according to water rights.

Major levee failures are difficult and expensive to repair. The 2004 failure of the Upper Jones Tract levee caused damages that cost about \$100 million to repair. Multiple levee failures caused by a single earthquake or flood could have a devastating effect on the Delta and the entire state economy. All Delta and Suisun Marsh services would be impacted.

3.5 HAZARDS AND ENVIRONMENTAL FACTORS

The risk analysis focuses on natural hazards that have the potential to cause the failure of levees and subsequent flooding of islands. The specific hazards considered in the analysis include:

- Floods
- Earthquakes
- Sunny-day failures (nonflood flows)
- Winds/waves

The analysis is to consider appropriate combinations of these hazards. Time-dependent processes (such as subsidence and climate change) that impact the frequency or severity of hazards in future years, or change the vulnerability of Delta levees, are analyzed as characteristics of the Delta environment in each analysis for a given future year.

For floods and winds/waves, the analysis considers both normal (i.e., usual) conditions that occur each year and transient events; that is, events having a low estimated frequency of occurrence in any given year. The impacts of these hazards are combined with subsidence and climate conditions as projected for each specified future analysis year.

The risk analysis does not consider hazards that could cause failure of a Delta asset, but poses no threat or relationship to the Delta levees. Thus, for example, the failure of a gas pipeline within

the Delta due to corrosion is not considered, unless such an event would put a Delta levee at risk. If such a pipeline failure occurred at a levee and resulted in a levee breach, it would be considered an example of a sunny-day failure. Furthermore, man-made hazard events (such as vandalism or a terrorist act) also are not considered in this analysis.

3.6 CONSEQUENCES OF LEVEE FAILURES

The potential consequences of levee failures are many:

- Death and injuries to humans
- Damage to residences
- Damage to businesses
- Damage to public buildings and disruption of public services
- Damage to contents of structures
- Damage to utilities
- Damage to transportation corridors
- Change in Delta salinity
- Changes in ecosystem conditions that can have a wide variety of impacts
- Disruption or cessation of in-Delta and export water supplies
- Loss of crops and future agricultural production
- Loss of use for residences, businesses, utility infrastructure, and recreation
- Repair and recovery costs including debris removal
- Additional loss to the economy through economic linkages
- Potential permanent flooding of some island and tracts or portions of islands and tracts.

These are discussed in more detail in Chapter 12.

3.7 ASSESSING RISK FOR FUTURE YEARS

Assembly Bill 1200 called for DWR to assess potential impacts on water supplies derived from the Sacramento–San Joaquin Delta based on 50-, 100-, and 200-year projections. Assessing conditions even 10 years into the future is difficult for some aspects of risk, especially as these evaluations are based only on readily available information. For some key variables (e.g., Delta smelt species viability), the uncertainties are simply too great.

However, after evaluating risk under the 2005 Base Case (Section 13), the report assesses risks for future years (Section 14) based on best available information. Like any projections of this type, they should be relied on only until better information becomes available to make improved assessments.