Delta Infrastructure –
Drivers of Change, Strategies, and Policy Options

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Prepared by

Will B. Betchart, P.E.
Consulting Water Resources Engineer
17050 Montebello Road
Cupertino, CA 95014
(408) 741-5762
Betchart@earthlink.net

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1. Introduction

This document supports Delta Vision discussions about infrastructure in the Delta. It analyzes Delta infrastructure systems in order to identify issues and policy options relative to risk and the long-term sustainability of Delta infrastructure and services (Delta Vision, 2007). It is responsive to five distinct subtasks:

- Analyze long-term drivers of change (sea level rise and other climate change effects, subsidence, seismicity, floods, urbanization, and population growth) relative to pertinent infrastructure systems.
- Review ***Potential Impacts of Climate Change on US Transportation*** by the National Research Council (NRC, 2008) in order to highlight its pertinence to risks, consequences, and policy options for Delta infrastructure.
- Review ***Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study Phase I*** by the US Climate Change Science Program (USCCSP, 2008) in order to highlight its pertinence to the Delta.
- Analyze the prospective use of infrastructure corridors in the Delta.
- Explore incentives and liabilities relative to state participation in protection or upgrades to infrastructure systems owned or controlled by others in the Delta.

More information about each of these subtasks is in the appendices to this report. The following serves as a summary that highlights the most pertinent and useful results.

2. Long-Term Drivers of Change

The long-term drivers of change for the Delta that were identified in the Delta Vision document, ***"Status and Trends of Delta-Suisun Services"*** (URS, 2007) are:

- Subsidence
- Global Climate Change (Sea Level Rise)
- Regional Climate Change (More Winter Floods)
- Seismic Activity
- Introduced Species
- Population Growth and Urbanization

These can be expected to affect Delta infrastructure in a variety of ways. A broad concept of infrastructure has been adopted here, including the Delta levee system, the conveyance capability of Delta channels for flood and fresh water, and the urban area utilities that exist or may be added in the Delta. Applying this broad perspective, the major relevancies of each driver have been discussed in Appendix A. Highlights are:

***Subsidence* –** Subsidence acts in two ways. First, it can adversely impact the capability of the levee system through 1) localized loss of soil and buttressing support immediately adjacent to the levee on the land side or 2) through settling of the levee and lowering its crest or otherwise compromising its stability. These problems are generally localized. An adequately funded, effective maintenance program can overcome these effects on levee capabilities.

The second result of subsidence is widespread loss of surface elevation in the fields protected by the levees, primarily due to peat oxidation. This soil loss increases accommodation space – the volume of water required to flood the island if there is a levee breach. One effect of this on infrastructure is greater potential intrusion of salinity in event of a levee breach, resulting in a requirement for more fresh water and time to restore Delta water quality. Another is more scour in the vicinity of the levee breach because of the larger difference in water level (and resultant flow velocity) as the breach occurs and the greater volume of flooding inflow. This will increase damage to nearby infrastructure and will also increase repair costs and time. Field subsidence may be lessened by improved farming practices or modification of cropping.

***Global Climate Change (Sea Level Rise)* –** There is agreement that sea level rise is occurring and must be expected to continue as a result of global warming. A moderate amount (perhaps as much as 16 inches) may occur by 2050. There is much debate and uncertainty on how much sea level rise might occur in the latter half of the current century. This depends on the reaction of Greenland and Antarctica ice sheets to warming and also on whether greenhouse gas emissions are effectively curtailed. The Delta Risk Management Strategy (DRMS) Climate Change Team has recommended use of a year 2100 range of 8 inches to 4.6 feet for sea level rise (URS/JBA, 2007a). Although the 4.6 feet appears reasonable for the upper end of the range (given current science), this number is uncertain (see Hansen, 2007). It is likely to be changed by additional science in the next few decades and it could be either increased or decreased. This creates substantial uncertainty for the Delta and its infrastructure.

The Delta levee system is the infrastructure most directly affected by sea level rise and its uncertainty. Since Delta levees were generally built only high enough to meet minimum requirements for freeboard, there is not extra levee height available. If Delta levees are not raised in response to sea level rise, the Delta will not be sustained. It appears that the levees can be raised a couple of feet at costs that are relatively reasonable. This would buy time to see what new information on sea level rise is forthcoming and to see how other issues (such as earthquake risk) evolve.

Even if the levee system is adequately improved, sea level rise still affects other Delta infrastructure. It directly affects the quantity of fresh water required to meet Delta water quality standards during low flow periods and thus subtracts from the amount of water available for in-Delta or export water supply. Increased Delta outflows of 5% to 32% have been calculated for the range of sea level rise considered by DRMS. It also increases the amount of accommodation space on the islands, just as subsidence does. It increases the scour that will occur in the context of a levee breach. It decreases the clearance under bridges. It increases the pumping required to discharge drainage water, storm water and wastewater.

***Regional Climate Change (More Winter Floods)* –** With a warmer climate, atmospheric moisture will increase, resulting in more intense and warmer storms. This is expected to increase the size of winter floods (or their frequency) because of more precipitation in each storm and more moisture falling as rain rather than snow. With four simulation results from global climate model scenarios that were made available to DRMS, the Flood Hazard Team found increases in peak flows into the Delta for 100-year events that were between 17% and 111% in 2050 and between 33% and 233% in 2100 (see Appendix A). The size of winter floods is expected to increase, but the wide range of calculation results indicates substantial uncertainty regarding just how much increase.

Again, the Delta levee system is the infrastructure most affected by an increase in the size of winter floods and the indicated uncertainty. Large improvements to flood conveyance capabilities (levee raises, setbacks, and/or bypass systems) may be required to maintain the degrees of flood protection now provided.

A second impact of this driver of change is to decrease the yields of most California water supply projects. With more winter precipitation as rain and less as snow, runoff will be routed through reservoirs to preserve flood control space and snow packs will be less extensive and less thick. They will melt more quickly in the spring. Thus, late spring and summer inflows to reservoirs will be decreased and this source will not be available to sustain summer and fall water uses. Decreased yields for the federal and state water projects have been calculated ranging from 4% to 16% in 2050 and 4% to 34% in 2100 (see Appendix A). This will also affect the amount of water available to manage Delta water quality.

Seismic Activity* –** The possibility of a major earthquake-caused levee breach event is becoming more recognized (URS/JBA, 2007b). Delta infrastructure planners may adopt approaches that protect against this possibility. For example, East Bay Municipal Utility District (EBMUD) is considering a tunnel under the southern Delta as a means to ensure that its Mokelumne Aqueduct can continue functioning reliably after such an event (EBMUD, 2007). This would make ***the prospect of seismic activity a driver of change for infrastructure and it may come into play relatively soon.

If a major earthquake causes many levee failures in the Delta, this could precipitate changes in the ways that Delta infrastructure systems are configured (upon rehabilitation or replacement) and on how they are planned, designed and operated in the future. This would make ***the occurrence*** of seismic activity a driver of change and it may come into play as soon as we experience a significant earthquake.

For a given fault, the expected frequency of seismic events also increases modestly as time passes after the previous seismic event. Thus, if a particular facility (such as a levee) were vulnerable to seismic shaking, the likelihood of that shaking and the resulting damage would increase modestly in the future – by about 10% in 2050 and 20% in 2100 (see Appendix A). Thus, seismic activity has ***increasing potential*** to be a driver of change in the long run, assuming little seismic activity occurs in the interim.

***Introduced Species* –** Introduced species are driving changes in Delta infrastructure now, through their past and present impacts on the Delta ecosystem that contribute to the jeopardy of threatened and endangered species. This is evidenced by recent court decisions. More introductions of species must be anticipated, in spite of best efforts to prevent them. Thus, they are likely to influence Delta infrastructure, especially all types of interaction with Delta waterways, well into the future.

Population Growth and Urbanization – Population growth and urbanization on two scales are driving Delta changes with respect to infrastructure. First, the Delta area as a whole (particularly the Secondary Zone) is under intensive development pressure. This creates a demand for more urban and local infrastructure of all types – from urban levees to protect low-lying areas to streets, water and sewer systems, electric and phone systems, etc. Delta-area population and urbanization increases of at least 100% by 2050 and 200% by 2100 are expected (see Appendix A). With the present vulnerability of low-lying Delta areas augmented by sea level rise and larger future floods, Delta-area development will increase potential future consequences from levee failures caused by a major flood or earthquake.

Regional (Greater Bay Area) and state population and economic growth are also driving change. Projections indicate state population increases of 61% by 2050 and 143% by 2100 (see Appendix A). This growth of population and economic activity will be accompanied by a more intensive dependence on Delta-area, statewide infrastructure – interstate highways, state highways, railways, navigation, natural gas and petroleum pipelines, the Mokelumne Aqueduct, and especially water exports by the state and federal water projects. This more intensive dependence will occur even if, for example, no more water is exported. More users will use the water more efficiently and more economic activity will be supported – and disrupted when something goes wrong.

Summary on Drivers of Change – The drivers of change influence infrastructure operation, design, planning, performance, and consequences both now and in the future. They are relevant under both "normal" conditions and when considering flood- or earthquake-caused levee breaches. Presently, the momentum of past practice, combined with tight budgets, points toward next-step infrastructure projects that accomplish some improvement at reasonable cost. But there is now a major departure from "more of the same" infrastructure projects. A certain type of Delta infrastructure is being driven by court findings that endangered species are being adversely impacted by the South-Delta pumps of the state and federal water projects. This type of court decision may continue to affect various examples of Delta infrastructure in the future.

Under future "normal" (no levee breach) conditions, assuming levees are raised in response to sea level rise, regional climate change (less snow pack) is expected to decrease water supply yields and sea levee rise is expected to increase Delta outflows needed to achieve water quality standards.

However, levee breaches due to floods and earthquakes seem most likely to precipitate large changes involving infrastructure – in planning, design and operation (either anticipating or reacting to levee breaches) and in infrastructure-related consequences from levee breaches. These risk factors are substantial now, and they are increasing with time. Analyses of the risk factors into the future showed no factor that decreases risks of, or consequences from, levee breaches and many factors that increase risks (see Appendix A).

3. The Importance of Exposure Period

Risks are generally analyzed and communicated as annual risks – the calculated annual "frequency of exceedance" of a given magnitude event, e.g., the 1% annual frequency or 100-year flood. This standard means of quantification is convenient because, as a practical matter, the events being discussed (floods or earthquakes) have the same likelihood each year. But if a policy maker wants to consider a longer exposure period, say 25 years, some translation is required.

For example, a major flood- or earthquake-caused levee breach event (20 or more flooded islands) now has an annual frequency of approximately 0.03 (or a probability of 3%), per the recent DRMS assessment (URS/JBA, 2007b). This translates to a 50/50 chance of 20 or more flooded islands during a 25-year exposure period (see Appendix A). The low risk numbers given for annual exposures can mislead policy makers and the public.

4. Strategies for Addressing Risk and Uncertainty

Appendix B describes and reviews a report by the National Research Council and Transportation Research Board about ***Potential Impacts of Climate Change on US Transportation*** (NRC, 2008). As seen in Section 2, climate change is associated with much uncertainty. In contrast, transportation planners usually develop their plans without any recognition of future uncertainty. They use a definitive population projection (or forecast of daily trips) and plan highway or other projects to satisfy the predicted need for a 20- or 30-year period. By that time (or earlier if their projections are a bit low) the next-step improvement project will be developed. The authors of the NRC report make the following general points, which this writer then supplements with a Delta example:

Factors Considered in Transportation Decisions are Limited – The focused scope and limited time frames typically used by transportation planners are inadequate for considering relevant long term-factors and including adaptive strategies that are oriented toward such issues as sea level rise, more intense storms, and larger floods. Policy and decision makers need to find ways to incorporate these broader considerations. The present consideration of Highway 12 improvements in the Delta is an example.

Adaptive Actions Can Occur (Need to Occur) on All Time Scales – If adaptive strategies are included in short-term (operational) actions, medium-term projects (design and rehabilitation) and long-term planning (major upgrades and new projects), much more progress can be achieved than if efforts are concentrated on one time scale such as long-term planning. Adaptive strategies are a major tool for addressing uncertainty. With Delta infrastructure, there is a full range of such adaptive opportunities.

Impacts Often Occur Through Extreme Occurrences – Rather than a gradual progression of change, impacts from climate change will often occur through the coincidence of natural variations on top of the progressive change – resulting in extreme events that exceed the bounds of current experience. The report uses the example of heat waves. For the Delta, the coincidence of an extreme tide with a low-pressure surge on top of sea level rise would be an example of how natural variations can be magnified.

Consequences of Extreme Occurrences to "Vital Links" Can Be Severe – Due to the network character of transportation infrastructure, it may be either resilient or vulnerable to damage. If the network has redundancies (i.e., several ways of getting between points), loss of a few links may be overcome by taking an alternate route. However, if one link is essential in getting from point "a" to point "b", loss of that "vital link" disrupts operation. The Delta has two infrastructure systems, which are "vital links" – the Mokelumne Aqueduct and the through-Delta conveyance for the water projects. Both are highly vulnerable and neither of these systems has an adequate backup.

Use Probabilistic Risk Analysis and Multiple Scenarios in Planning – To analyze uncertainty, especially in the long term, the report recommends using multiple scenarios and probabilistic risk analysis to assess prospective outcomes from a variety of alternatives. It gives the example of CalTrans using this approach in establishing its seismic retrofit program. DWR has applied this approach to the Delta through DRMS. The tool is available for further use in addressing infrastructure issues in the Delta.

Summary – The NRC report is particularly helpful in understanding concepts and sorting through approaches and strategies for addressing thorny planning issues. It is useful for infrastructure other than transportation and for issues other than climate change. It has much to offer for addressing the major drivers of change and the associated risks that prevail in the Delta.

5. Other Subtasks

Highlights from the other three subtasks are the following:

Gulf Coast Study: Phase 1 – The report is described and reviewed in Appendix C. This report is Phase 1 of a three-phase effort. The work concentrated on data collection and synthesis with some development of analysis methodologies for assessing and communicating risks. Several approaches were similar to those suggested in the NRC report (see Appendix B). Two of the more interesting suggestions were:

- *Connectivity* – It is "useful for planners to examine the connectivity of the (various modes and geographic levels of the transportation systems and their sensitivity to) long-term changes in the natural environment, including changes induced by climate. This helps to identify critical links in the system and ways to buttress them against exposures to climate factors or other variables, or to create redundancies to maintain critical mobility…."
- *Adaptation Strategies* – The aim of the risk-based approach is to identify and adopt transportation designs and facility locations that improve the resiliency of the system. "Structures can be hardened, raised, or even relocated as need be, and – where critical to safety and mobility – expanded redundant systems may be considered as well."

The emphases on "vital links" as vulnerabilities, "redundancy" as an opportunity to reduce vulnerability and "adaptation strategies" as a valuable way to build "resiliency" and address uncertainty is complementary to the NRC report and useful for the Delta.

Prospective Use of Infrastructure Corridors – The obvious opportunity for an infrastructure corridor in the Delta is in the vicinity of Highway 4 and could also include the Burlington Northern Santa Fe (BNSF) railroad, the Mokelumne Aqueduct, the Pacific Gas and Electric (PG&E) natural gas pipelines and the Kinder-Morgan petroleum products pipeline. This corridor concept was one of the "Building Blocks" considered in the preliminary work performed by DRMS Phase 2 (URS/JBA, 2007c). The data available from DRMS was analyzed in more detail (see Appendix D), but the analysis is not sufficient to be conclusive on whether such a corridor is an economically viable option (or even nearly viable). Some of the evaluations needed are not yet available. For example, DRMS only assessed damage and disruption due to levee failures and flooding (including scour). It did not assess direct seismic damage to such facilities as the Mokelumne Aqueduct, BNSF railroad, or Highway 4 and thus did not evaluate the costs of those repairs or the disrupted service due to direct damage. These are things an infrastructure corridor would be designed to prevent. They need to be included as benefits in a justification of corridor costs. That is not yet possible because the needed information has not been developed.

Incentives and Liabilities Relative to State Participation in Protection of Infrastructure Owned by Others – Inquiries were made to DWR, CALFED, and the Public Utilities Commission (PUC) on this topic. The primary feedback was that public interest projects, particularly in damage prevention (like flood control) naturally have residual risk. When failures occur, there is potential for lawsuits and liability – especially in the legal environment following the Paterno decision. If a public agency is to perform its mission and its mission includes flood protection (as is the case with DWR), it must go ahead and perform projects so the best of its ability. If it considers involvement in protecting infrastructure owned, controlled, or operated by others, it should negotiate indemnity or hold harmless agreements first.

Infrastructure owners, such as public utilities and water agencies, need to recognize the risks associated with the location of their infrastructure. They need to have backup systems in place, if warranted. They also need to be financially responsible in supporting flood protection and recognize the need to insure for residual risk.

At least one entity appears to have interest in state assistance. EBMUD's tunnel conceptual design is expensive ($445 to $950 million, nominally $650 million). Comments from EBMUD personnel indicate that financing this project is viewed as challenging. Discussions that may lead to funding assistance from the state would probably be welcome. As part of an overall solution to the Delta challenges, there may be a state interest in cost sharing on large public infrastructure relocation efforts.

6. Policy Options

In examining drivers of change, strategies for addressing difficult infrastructure problems in the context of uncertainty, and the suggestions in the NRC report, a few policy options stand out. They are offered for discussion:

- ***Large Sea Level Rise and Floods –*** There are two drivers of change with important long-term uncertainties – the possibilities of 1) large sea level rise (potentially several meters) and 2) very large increases in Delta inflow floods (potentially doubling or tripling peak inflows). Although some would consider these ideas "not well supported," "far out," or "alarmist," it seems prudent to examine them further and consider whether major infrastructure projects that are proposed can adapt to them.

- ***Population and Urban Growth in the Delta Region –*** The most dramatic and relatively certain driver of change, given present policies, is growth of population and urban areas in the Delta region, not only in the Secondary Zone, but also as infill in towns in the Primary Zone. Given the present high risk of flooding, increasing future risks, and questions on whether adequate flood protection can be provided in the longer-term, it seems prudent to examine, and perhaps alter, present Delta-area development policies.
- ***Population and Economic Growth in the Greater Bay Area and the State –*** Regional and state population and economic growth are second only to the very high growth in the Delta region. These larger areas are dependent and are becoming more intensively dependent on the "vital links" of two water supply systems that cross the Delta. Neither the EBMUD Mokelumne Aqueduct nor the State Water Project and Central Valley Project through-Delta conveyance has adequate backup. It seems prudent to insist that adequate backup or hardening be provided for both these "vital links," given the high risks in the Delta and high consequences of disruption.
- ***Seismic Activity –*** The risk of seismic activity is already high, and the prospective consequences of a major seismic levee breach event are high and increasing rapidly because of other drivers of change – especially Delta area and statewide population growth. It is simply a matter of time until some version of seismic disruption occurs in the Delta. It seems prudent to increase recognition of this eventuality and increase our preparedness.

Other more comprehensive and detailed discussions of potential infrastructure policies are provided the appendices, in the Transportation Context Memo (Mann, 2007), and in the Utilities Context Memo (Branson, 2007).

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Appendix A

Drivers of Change for Delta Infrastructure

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1. Introduction

This appendix reviews and evaluates long-term drivers of change relative to pertinent infrastructure systems in the Delta. Transportation and utilities systems are to be emphasized, identifying policy issues and options relative to risk and long-term sustainability of the subject infrastructure systems.

Specific drivers of change to be considered begin with the following that are listed in the Delta Vision document ***Status and Trends of Delta Suisun Services*** (URS, 2007):

- Subsidence
- Global Climate Change (Sea Level Rise)
- Regional Climate Change (More Winter Floods)
- Seismic Activity
- Introduced Species
- Population Growth and Urbanization

Specific infrastructure systems that could be considered are many and varied. They include:

- Highways (State Highways in the Delta and Interstate Highways on the periphery)
- Railroads (BNSF across the Delta and Union Pacific on the periphery)
- Navigation (commercial)
- Navigation (private/recreational)
- Pipelines (petroleum, and natural gas)
- Natural Gas Storage (McDonald Island)
- Natural Gas Well Fields
- Aqueducts (Mokelumne Aqueduct)
- Open Channel Water Conveyance (for floods and fresh water)
- Levees (for land and infrastructure protection and for channel definition and maintenance)
- Electrical Transmission
- Communications
- Urban-Area Land Use Infrastructure and Utilities (streets, water mains, sewers, gas and electric distribution, etc.)

Alternatively, these features could be identified as individual subsystems, such as Interstate Highway 5, State Highway 12, the South Sacramento Pocket Area, West Stockton, the town of Isleton, etc.

Many of these infrastructure systems have been addressed in detail in other documents. These include:

- ***Status and Trends of Delta-Suisun Services*** (URS, 2007)
- ***Context Memorandum: Transportation*** (Mann, 2007)
- ***Context Memorandum: Utilities*** (Branson, 2007)
- ***DRMS Phase 1: Risk Analysis Report (Draft)*** (URS/JBA, 2007a)
- ***DRMS Phase 1: Risk Analysis Report (Final)*** (URS/JBA, 2008a, in review)
- ***Technical Memorandum: … DRMS … Impacts to Infrastructure, Draft 2*** (URS/JBA, 2007b)

Given the extensive information already available, the present document will be selective in the topics discussed and provide summary information, rather than attempting to be comprehensive. It will start from drivers of change and highlight those that may have particularly influence on Delta infrastructure systems.

There are four distinct ways in which "drivers of change" can exercise influence relative to infrastructure in the Delta:

- *Normal conditions – present accumulation of circumstances:* Now, in 2008/2009, the situation with Delta infrastructure, considering normal conditions (i.e., excluding floods and earthquakes) is mainly one of momentum. With tight budgets and an emphasis on short-term improvements, the typical decision is to implement the next-step project, one that will yield some immediate improvement relative to focused objectives at a relatively low cost (Branson, 2007). There is essentially no priority for considering the long view, contingencies for unusual events, or a change of direction that requires a significant monetary commitment over time. Thus, the infrastructure decisions are to repave or add another lane to a highway, to replace a corroded section of pipe with new pipe, to closely parallel a pipe or railway in order to increase capacity, or to add another subdivision or shopping center to a spreading urban area. Suggestions of substantial change are unwelcome.

  There is one exception to this "more of the same" approach. The Delta has reached a point where the declined health of the ecosystem (particularly of pelagic organisms) is precipitating consequences to and impacts from a major infrastructure system (the state and federal water projects) through the judicial interpretation of endangered species protections. Exports from the south Delta are believed to be at least partially to blame for species declines. Pumping has been restricted and deliveries to federal and state water contractors have been curtailed. A major governmental initiative, the Bay Delta Conservation Plan (BDCP, 2007), is underway to alter this infrastructure system and its impacts so it can more reliably perform its function without damaging sensitive, protected species. Thus, ecosystem health (at least of endangered species) is a driver of change for this large-scale transportation (water conveyance) system. Although its influence on this infrastructure system is widely recognized, it would not generally be included in the present discussion of drivers of change. It is mentioned here for comparison and to recognize that it is a current driver and could continue to force Delta infrastructure changes in the future.

- *Normal conditions – future accumulation of circumstances:* The drivers of change listed above may cause infrastructure-related changes in the future, even without much focus on earthquakes or floods and the potential for levee breaches. This is addressed below in Section 2.
- *Focusing on floods and earthquakes – present accumulation of circumstances:* Now, in 2008/2009, a major flood or earthquake could cause multiple, approximately simultaneous levee breaches and flood 20 or more Delta islands. An event of this magnitude presently has a calculated annual frequency of exceedance of about 0.03, or three times greater than that of a 100-year flood (URS/JBA, 2007a, Phase 1 Report, Section 13). Such an event would be expected to have large impacts on Delta infrastructure systems and substantial consequences within the Delta region, within the San Francisco Bay Area and, more broadly, throughout the state. Delta infrastructure systems were not generally designed to perform well in this type of event. This possibility of multiple simultaneous levee breaches and the associated impacts is the focus of the risk analyses performed in Phase 1 of the Delta Risk Management Strategy. Its draft report was issued last year (URS/JBA, 2007a) and its final report is now being reviewed and will be released soon. The real possibility of this type of event is becoming more recognized and it is possible that infrastructure planners will adopt approaches that protect against this eventuality. For example, East Bay Municipal Utility District is considering a tunnel under the southern Delta as a means to ensure that its Mokelumne Aqueduct can continue functioning reliably after such an event (EBMUD, 2007).

  In addition to widespread damage and disruption of infrastructure services, a major flood or earthquake occurring soon could precipitate changes in the ways that infrastructure systems are configured (upon rehabilitation or replacement) and on how they are planned, designed and operated in the future. This writer is not aware of any effort to anticipate what the resulting changes in the Delta or its infrastructure systems would be, other than a repair effort to restore existing facilities and services. However, it should be recognized that a major levee breach event occurring now could precipitate changes, particularly in efforts to avoid similar future disruptions to infrastructure services. The EBMUD tunnel, which is now a concept, might more quickly become a reality.
- *Focusing on floods and earthquakes – future accumulation of circumstances:* The influence of future drivers of change on prospects for floods and earthquakes, the associated potential for multiple, simultaneous levee breaches with flooding of multiple islands, the resulting consequences, and the relationships to infrastructure are addressed in Section 3 below.

To summarize, there are significant current and prospective near-term drivers of change pertinent to the Delta that, even now, influence infrastructure. One example is the judicial response to the pelagic organism decline, based on the Endangered Species Act. Another is anticipation of a major flood or earthquake. An example of a prospective driver would be the presently unknown response to a near-term, major levee breach event in the Delta caused by a flood or earthquake. In the following discussions of future changes (and their major causes or drivers), it is important to also keep the presently active drivers in mind.

The focus of this document, however, is on the future – especially on how future changes in circumstances will act as causative factors and influence the planning, design, operation, performance, and impacts of Delta infrastructure systems. The future changes and their implications are addressed in the next two sections.

2. Drivers of Infrastructure Change Under Future "Normal" Circumstances – Without Consideration of Floods or Earthquakes

The broadly defined drivers of change are considered in more detail below, focusing on the ways in which future changes in circumstances may influence the design and performance of infrastructure systems under "normal" conditions:

***Subsidence* –** In the Delta, land surface subsidence occurs as two distinct processes. In the interiors of Delta islands and tracts, organic soils (if present) are oxidized or otherwise lost, especially in conjunction with agricultural practices, and the elevation of the land surface decreases at a rate that may approach an inch per year (URS/JBA, 2007c, Subsidence Technical Memorandum (TM)). Ignoring prospective levee breaches, this oxidation of Delta fields usually has little impact on infrastructure. The cover over buried pipelines or the backfill against the footings for transmission towers or supports for elevated pipelines may decrease and (eventually) this may need to be addressed. But changes to infrastructure are minor. Close to the levees, peat oxidation may slightly decrease the inboard buttressing support for the levee system and may require localized maintenance in the form of a toe berm – extra soil piled up next to the levee to help hold it in place. Such a berm covers the organic soil and stops the oxidation, in addition to supporting the levee and reducing seepage. Peat oxidation does not usually lead to long-term infrastructure changes under "normal" conditions.

In contrast to the oxidation described above, Delta levees and other Delta infrastructure facilities (e.g., roads) may settle due to the unconsolidated and sometimes squishy soils in their foundations. This may simply be tolerated on the interiors of the islands. For the levee system, settling must be monitored and material must be added to the crest and slopes of the levees in order to maintain their crest elevation and the levee stability needed for the designed level of protection. This should be addressed in routine levee maintenance and, if it is not neglected, it does not have major consequence.

Thus, if one is not focusing on the prospects for floods or earthquakes and the consequences of levee breaches, subsidence does not qualify as a major driver of change for Delta infrastructure. It simply requires some additional maintenance of levees and other infrastructure.

***Global Climate Change (Sea Level Rise)* –** The infrastructure changes caused by sea level rise will obviously depend on the amount of sea level rise that occurs and this is a subject of much debate and uncertainty. The amounts of sea level rise recommended for consideration by the DRMS Climate Change TM (URS/JBA, 2007d) are:

- For 2050: Between 4 and 16 inches
- For 2100: Between 8 inches and 4.6 feet

These amounts constitute a significant percentage of the 1.0 to 1.5 feet of freeboard required over the 100-year water elevation, the design standard for most Delta levees.

However, these losses of freeboard do not have to accumulate; levee crests can be raised and equivalent static stability and seepage control can be maintained at an approximate cost of $200,000 per mile per foot of increased elevation (Betchart, 2008). Thus, raising levee crest elevations by 1 to 2 feet and extending levees on the Delta periphery may adequately address levee concerns associated with sea level rise until 2050 and perhaps even longer (provided we postpone consideration of floods and earthquakes until the next section). Continuation of these levee raises after the first couple of feet may require a major policy review, including consideration of interim experience and reflection on the new information that should become available in the next few decades regarding actual observations of sea level rise and improved methods of assessing future sea level rise.

It must be recognized that, presently, the amounts of sea level rise indicated above are estimates based on current science. There is disagreement, especially on the higher end of the range for 2100. That number (4.6 feet), although it is presently "reasonable," has a high likelihood of being revised over the next several decades, as more "science" is generated. And we don't know whether it will be decreased (say to 3 feet) or increased (say to 10 feet or more). For example, one respected climate scientist believes other scientists have been overly cautious (reticent) in stating higher possibilities for sea level rise. He states: "as a physicist, I find it almost inconceivable that BAU climate change would not yield a sea level change of the order of meters on the century timescale" (Hansen, 2007a). This was subsequently more directly stated in the popular scientific press as the thought that, unless greenhouse gases are curtailed, meters of sea level rise should be expected by 2100 (Hansen, 2007b).

Maintenance of Delta water quality during the low flow seasons may be the most significant other impact of sea level rise on Delta infrastructure. Three-dimensional simulations of sea level rise impacts on the salinity interface (X2) at the Delta/Suisun boundary indicated the approximate increases in net Delta outflow that would be required to meet the X2 water quality standard during low flow condition. The results are presented in Table A-1 below (URS/JBA, 2007e, WAM TM, Appendix H3). Net Delta outflow is important to infrastructure because increased outflow requirements translate directly into decreased amounts of water available for water supply.

Table A-1 Impact of Sea Level Rise on Required Net Delta Outflow During Low Flows

Sea Level Rise	Increase in Net Delta Outflow
8 inches	5%
20 inches	12%
3 feet	23%
4.6 feet	32%

Other sea level rise impacts on Delta infrastructure would occur, but may not be substantial. For example, sea level rise would decrease the clearance below bridges for navigation. However, most Delta bridges are drawbridges, so the effect could be negligible. The exception is the Highway 160 bridge from Antioch to Sherman Island, but it is a relatively high bridge and would likely see minimal effects, at least until the latter part of the century.

For larger amounts of sea level rise, it may become necessary to raise all bridges, just to maintain reasonable clearance beneath them. Another example of a prospective infrastructure change is that urban areas may have to begin pumping or may need to pump against increased water elevations to discharge their wastewater and storm water flows.

Regional Climate Change (More Winter Floods) – Postponing consideration of large floods and potential levee breaches, regional climate change would still have at least one significant impact on infrastructure. Warmer storms will result in more precipitation falling as rain instead of snow, resulting in less snow pack. If adequate storage is not available to capture the increased runoff from rain, or if it is being allocated to flood control, the yield of the state's water supply systems would be decreased. The DRMS Water Analysis Team (URS/JBA, 2007e, WAM TM, Appendix F) indicates that:

- For 2050: Median yields for the CVP will decrease between 4% and 16% from 2005 and, for the SWP decreases will be between 4% and 11% from 2005
- For 2100: Median yields for the CVP will decrease between 7% and 34% from 2005 and, for the SWP decreases will be between 4% and 27% from 2005.

Figure A-1 shows an example of how this impact occurs for one climate change scenario and how significant it may become. This figure is from DRMS analyses (URS/JBA, 2007e, WAM TM, Appendix F). The figure demonstrates that, over time, a significantly smaller percentage of the runoff into Oroville occurs during the late spring and summer. Thus, it will not be available to keep the reservoir level up for uses later in the summer and early fall. This will impact most California water users, not just the state and federal projects. Supplies will be less and drought impacts more severe. Even in the Delta, more frequent salinity intrusion during low flow periods must be anticipated and adverse effects on Delta water users are likely.

Other types of Delta infrastructure would have more storm damage from the more intense winter storms expected, but these impacts would be limited and transient as long as we postpone consideration of floods (and associated levee breaches) to the next section.

Seismic Activity – The discussion of seismic activity as a driver of change is postponed to Section 3. Consideration of earthquakes has little impact on Delta infrastructure design under normal conditions; infrastructure projects would simply proceed with normal seismic designs.

Introduced Species – Introductions of exogenous species are expected to continue and to have impacts on the ecosystem. The most likely impact on infrastructure is through continued or increased jeopardy of endangered species and continued or increased restrictions on water exports for the state and federal water projects. The increased jeopardy for endangered species may also make it more difficult and expensive to implement other Delta infrastructure projects. Mitigation of adverse impacts from existing Delta infrastructure projects may also be required. The obvious example is Delta water diversions for in-Delta uses such as agricultural irrigation. These diversions now are generally unscreened and may adversely impact endangered fish. Other infrastructure systems, such as wastewater discharges, are likely to be critically reviewed.

Population Growth and Urbanization in the Delta – Forecasts for Delta area population and land use under current policies foresee infill in present Primary Zone communities and intensive development in the Secondary Zone of the Delta (see URS, 2007, URS/JBA, 2007a, Phase 1 Report, and URS/JBA, 2007g, Economic Consequences TM).

Delta Population – Data and projections of Delta area population are difficult to obtain because they are typically developed for smaller or larger geographic areas. However available data reported in the ***Status and Trends*** report (URS, 2007) indicate that population on Delta/Suisun islands and tracts is expected to increase from 26,000 to 67,000 from 2000 to 2030 – that is to approximately 260% of its present amount. The population of the legal Delta in 2000 was approximately 470,000. ***Status and Trends*** indicates that the Delta-Suisun will have 600,000 more people by 2050, pointing to a 2050 total population of 1,070,000. Thus, it is estimated that full development of the Secondary Zone could lead to a Delta-Suisun population of well over a million people. These areas are now experiencing high rates of growth. These estimates of future population are uncertain as to timing and they will be quite variable geographically during any particular period. For example, housing units on Stewart Tract, Bishop Tract, Shima Tract and Sargent Barnhart Tract are expected to increase from 1,700 to 14,200 units between 2000 and 2030, an increase of over 800%.

Delta Business Activity – Business activity is usually reported in terms of the value of output, employment and labor income. Projections for these measures were developed to the year 2030 by Woods and Poole (2006) – (see URS/JBA, 2007g, Economic Consequences TM). The projections for 2030 that address Delta area counties and combined statistical areas are:

- Regional product: 100 to 160% increases over year 2000
- Earnings: 90 to 150% increases over year 2000 amounts
- Employment: 50 to 80% increases over year 2000 amounts

Agriculture, natural gas production and recreation are important economic activities in the Delta Primary Zone. Natural gas and agricultural production values will probably not increase significantly in the future. Recreation-related expenditures in the Delta were recently estimated to be over $500 million annually. These recreation expenditures will probably increase in the future with population in the Delta and the larger Bay Area region. Economic activity tied to residential development will increase dramatically by 2030 on some Delta islands near Stockton and can be expected to continue increasing thereafter. There is no useful projection for economic activity after 2030; however, business activity is expected to continue growing with population.

Thus, population growth and urbanization are occurring and are projected to continue throughout the Delta. These populated areas will require upgraded levee systems to protect inhabitants against flooding, and the levee systems will need to be more robust in order to adequately address sea level rise and the larger design floods. Other infrastructure systems in the new urban areas also would likely need to implement more costly designs. But the ideas driving these developments would be the same as it is presently. The design criteria would be suitable to protect against the design storm (generally, the 100-year or 200-year flood). Other infrastructure changes would not be necessary. There is no indication these development trends will slow under BAU policies.

3. Drivers of Infrastructure Change Under Future Circumstances – Considering Floods and Earthquakes and Risks of Major Levee Breach Events

In thinking about drivers of infrastructure change for future circumstances, consideration of floods and earthquakes, and the resulting risk of major levee breach events needs to be separated into several distinct lines of thought. For convenience, the following are used:

- Driver effects on the frequency of occurrence of a given event in a given future year
- Driver effects on the consequences of that event if it does occur in that future year
- Combined impacts of drivers of change on annual levee breach risks
- The risk presented by several years of exposure.

A subsection is provided below on each of these topics. The first two will be discussed relative to the drivers of future change. Then, the final two will be discussed in overview.

The results of this discussion would be dramatically different, depending on whether we assume Delta levees are upgraded as necessary: 1) to achieve compatibility with the land uses and infrastructure uses they are intended to protect, and 2) to keep up with sea level rise (see the discussion in Section 2). To better focus this discussion and to achieve more interesting results, it is assumed here that needed levee maintenance and upgrades occur on a timely basis. If the levee maintenance and upgrades don't keep up (e.g., if budgets for upgrades get behind or if sea level increases too rapidly), then multiple, simultaneous levee breach events due to high tides and minor floods are likely to become a routine occurrence, even without an earthquake or major flood.

For reference, the present (2005) annual frequency of occurrence for a major Delta levee breach event that floods 20 or more islands is about 3% – i.e., three times the likelihood of a 100-year flood (URS/JBA, 2007a, Table 13.7). The consequences of a 20-island event, based on its timing and other circumstances, may include (URS, JBA, 2007a, Section 13.3):

- Population at risk on flooded islands – 6,000 to 20,000 people
- Duration of levee repairs – up to 5 years
- Cost of levee repairs – about $6 billion
- Duration of no CVP/SWP exports – 11 to 21 months
- Amount of water not exported – 6 million acre-feet
- Delta Region Costs – $10 billion
- Additional Statewide Costs – $3 to 15 billion, almost entirely due to water export disruption
- Statewide Economic Impacts – 70,000 to 250,000 lost jobs; $12 to $56 billion lost output, again almost entirely due to water export disruption
- Ecological Consequences – likely severe, especially to sensitive fish species, but impact models are less reliable and results are uncertain.

Our objective is to understand how future circumstances may change these consequences, particularly with respect to infrastructure.

Note that simply upgrading the condition of the levees to be compatible with the type of land or infrastructure use that they are intended to protect will help. Full accomplishment of such upgrades may reduce the 3% annual frequency for the event described above by 0.5% or more – i.e., much of the risk from a 100-year inflow flood may be removed. Only minor reductions of the earthquake risk can be expected.

3.1 Likelihood of Floods and Earthquakes

Four of the drivers of future change are not likely to significantly alter the frequency of occurrence or size of future floods or earthquakes, assuming that Delta levees are adequately maintained and raised to keep up with sea level rise. These are subsidence, sea level rise, introduced species and population-growth/urbanization (see Section 2 above). Accordingly, only the other two are discussed in this subsection.

Regional Climate Change (More Winter Floods) – Regional climate change is expected to cause intensification of storms (more precipitation per event) and warmer storms (higher snow lines and a larger portion of storms falling as rain rather than snow) (URS/JBA, 2007a, Phase 1 Report and URS/JBA, 2007d, Climate Change TM). This will increase the size or the frequency of occurrence of major Delta inflow floods. For example, the year-2000, 100-year storm has a Delta inflow of 900,000 cfs. The 100-year inflow is expected to grow in size over time. The DRMS Climate Change Team was able to provide four simulation outputs of general circulation climate model scenarios used in the fourth assessment by the Intergovernmental Panel on Climate Change (IPCC, 2007). These results had been downscaled to the regional level in order to provide daily, unimpaired runoff at key sites tributary to the Delta. The DRMS Flood Hazard Team analyzed these outputs and found the following 100-year peak Delta inflows (URS/JBA, 2007f, Flood Hazard TM):

- 2000 – 0.9 million cfs
- 2050 – 1.05 to 1.9 million cfs
- 2100 – 1.2 to 3.0 million cfs

Although the amounts of increase in peak inflow vary, all four simulations showed increases. Currently, it is not clear whether these increases will turn out to be quite large or only moderate. Flow increases will translate directly into higher water levels. Preliminary calculations (assuming no relief from levee breaches) indicate a 50% increase in the 100-year peak flow may mean approximately one foot higher stage at Antioch, 1.5 to 2.5 feet higher stage in the mid Delta and 2.5 to 5 feet higher stages at the tributary entrances.

Another way to look at this driver of change is to characterize the increased frequency of Delta inflow floods of a given size. The Flood Hazard Team found the following trends in the frequency of the year-2000 one percent annual frequency (i.e., the 100-year) inflow flood event (i.e., 900,000cfs). The ranges of frequency increases are indicated below:

For 2050: Frequency increases of the present 100-year flood are between 40% and 500%

For 2100: Frequency increases of the present 100-year flood are between 130% and 1,140%

Again, it is not clear now whether the increases in frequency will be very large or moderate. It seems, however, that the present 100-year inflow flood will be occurring with a mean annual frequency of 0.02 within several decades; it will become the 2% or 50-year flood. It will become even more frequent thereafter, possibly becoming the 10-year flood.

Even with increased compatibility between levee designs and land or infrastructure uses, levee raises to keep up with sea level rise and adequate levee maintenance, the opportunity for major flood-caused multiple levee breach events is likely to increase. These increases can be prevented by additional upgrades to Delta levees. Further examination (perhaps considerable research) to understand the actual magnitudes of inflow flood increases and their impacts, and then settle on appropriate design criteria would be necessary. The needed improvements to the flood control system to continue protecting against the (new) 100-year inflow may require significant expenditures.

***Seismic Activity* –** For a given fault, the expected frequency of seismic events increases modestly as time passes since the previous seismic event. Thus, if a particular facility (such as a levee) were vulnerable to seismic shaking, the likelihood of that shaking and the resulting damage would increase modestly in the future – by about 10% in 2050 and 20% in 2100 (URS/JBA, 2007a), assuming little seismic activity occurs in the interim. This is considered relatively certain. It means that the possibility of a major earthquake-caused multi-island levee breach event is increasing, although at a modest rate.

3.2 Consequences of Floods and Earthquakes and Major Levee Breaches

In addition to the effects on the frequencies of floods and earthquakes that lead to major levee breach events, drivers of future change are expected to alter the consequences of the events that do occur. These mechanisms of change are described below.

***Subsidence* –** Even if Delta levees are addressed in subsided areas with toe berms, as necessary, and if levees that experience settling are maintained to their designed crest elevation and static stability criterion (see Section 2), island subsidence will make a difference in “accommodation space” (the volume of flood water entering the island or tract) if a levee breach occurs (Mount and Twiss, 2005). The medium expectation of lost elevation in areas with organic soils and the resulting increased island flooding volumes, relative to 2005 sea level are (URS/JBA, 2007c, Subsidence TM):

- For 2050: Up to 3 feet of subsidence and about a 25% increase of accommodation space
- For 2100: Up to 8 feet of subsidence and about a 50% increase of accommodation space

These increases will have important consequences when a levee breach occurs. If the breach happens during the low flow season, more salty water will be drawn into the Delta to fill the flooding islands. More time will be required and more flushing water used to clear the salinity out of the Delta. Thus, fresh water withdrawals for local uses and exports will be disrupted for longer times. Also, deeper island surfaces and a greater volume to flood will increase scour, with resulting additional damage to the land and nearby infrastructure. This will add repair time and costs, delaying restoration of fresh water quality.

***Global Climate Change (Sea Level Rise)* –** For sea level rise, as with subsidence, the main effect on levee breach consequences will be an increase in flood volume for islands that have levee breaches. A medium estimate of the amount of flood volume due to expected sea level rise is:

- For 2050: Between 4 and 16 inches – say 1 foot or about a 15% increase in accommodation space
- For 2100: Between 8 inches and 4.6 feet – say 3 feet or about a 50% increase in accommodation space.

Again, as with subsidence, this increased flood volume will increase the extent of salinity intrusion during low flow periods and will increase the amount of scour and damage to nearby infrastructure as an island fills after a levee breach. The cost and time for repairs will be increased and so will the recovery period for water quality.

Sea level rise will also increase the volume of tidal exchange and will cause increased dispersion of salinity throughout the Delta. This will lengthen the recovery period.

Regional Climate Change (More Winter Floods) – As described for "normal" conditions in Section 2, regional climate change will result in less water supply yield when there are levee breaches. More precipitation will have fallen as rain and less as snow, so late spring and summer runoff from snowmelt will be less. In the context of a flood, this may not be as important as for an earthquake. During a Delta inflow flood, there is so much fresh water that salinity is kept downstream and it does not get into Delta islands through levee breaches. However, in a seismic event with lower flows, salinity will be a concern for any major breach event (especially for 10 or more islands). The availability of water in upstream reservoirs is very important for flushing the salinity out of the Delta and reestablishing usable water quality. Less water availability will mean longer times for Delta water quality recovery and longer disruptions of in-Delta and export water uses.

Seismic Activity – As indicated in Section 3.1, changes in seismic activity will increase the frequency of a given seismic event. It is assumed levees are upgraded and maintained with toe berms for subsidence, as needed, and with levee raises for sea level rise. Given these assumptions, additional factors that may increase the earthquake effects on breaching and flooding due to the increased height of the levee will be neglected for this discussion.

Introduced Species – Changes in the species present in the Delta and in their relative populations certainly must be expected over the next several decades, given the record of exotic species introductions in the past, the difficulty of preventing these introductions, and the expected continuation of threats of extinction for existing Delta species (URS 2007; URS/JBA 2008b, Impact to Ecosystem TM). However, not enough information is available to forecast long-term changes to the diverse and dynamic Delta ecosystem, even under "normal" (non-breach) conditions.

Translating such changes into an assessment of whether the impacts to the ecosystem from a given major levee breach event will increase or decrease in the future is similarly daunting. However, the assumed continued introductions of exotic species make it difficult to argue that a continuation of present practices will result in a more robust and healthy ecosystem that is less impacted by levee breaches. For purposes of the DRMS future-years analysis it was assumed (optimistically) that the future ecosystem (without levee breaches) would be similar to today's ecosystem and that the effects of levee breaches would therefore be start from a similar reference point. Obviously, there is massive uncertainty in this assumption. However, this allows analysts to focus on how other future changes might result in greater or lesser impacts to the ecosystem.

***Population Growth and Urbanization* –** Delta area population growth and urbanization is described in Section 2. This will obviously include the many associated upgrades and improvements to infrastructure. This population and infrastructure growth will be a principal driver of change in increasing the future consequences from levee breach events. More Delta area people, property, and associated urban and other infrastructure improvements will be subject to flooding, so the damage and disruption from levee breaches will increase accordingly. However, it is not only the Delta-area population and economy that is affected by a major levee breach event. The regional and state populations and economies are also affected because regional and statewide infrastructure services will be disrupted. Thus, if increases in regional and state population and economic activity occur, they will also be drivers of future change.

Available forecasts (see URS/JBA, 2007g, Economic Consequences TM) indicate continuing population and economic growth for the Bay region and for the state as a whole. This will result in an increased dependence on infrastructure that traverses the Delta and especially on the water supplies that are conveyed through the Delta (see URS 2007; DWR, 2005; URS/JBA, 2007g, Economic Consequences TM).

State Population – The California Department of Finance (DOF 2007a) provides state population projections to 2050. It estimates 59.5 million people will reside in California by that date, a 61% increase over the 2005 base (37 million). Although official projections are not available beyond 2050, the "Status and Trends" report (URS, 2007) indicates a potential California population of 90 million by 2100, a 143% increase over 2005.

State Economic Activity –The historical data available from DOF (2007b) indicate that economic activity is closely tied to population growth. As with population, official projections are not available for the long term. The state DOF provides forecasts through 2010 (DOF 2007c). The projections to 2030 by Woods & Poole (2006) are:

- State product: 94% increase over year 2000
- Earnings: 87% increase over year 2000
- Employment: 47% increase over year 2000

The population and urban growth and the associated increases in infrastructure that are to be expected both 1) locally in the Delta region and 2) more broadly throughout the state are large compared with other drivers of change. Thus, the increased consequences from even exactly the same levee breach, with no decreases in available water supply or increases in sea level, subsidence, earthquake frequency, or flood frequency would have consequences that are much greater in 2050 than in 2005. Another increase factor would occur for 2100.

3.3 Combined Impacts of Drivers of Change on Breach Consequences

When the various drivers of change are analyzed in progression through a model of causation for flood or earthquake consequences, the results are striking, even assuming that levees are improved and maintained to counter subsidence and sea level rise. Note that these stipulated levee improvements assume two potentially large drivers of change have been addressed by a much more aggressive levees program:

- Subsidence near the levees (in the zone of influence) can likely be neutralized so that seepage and levee stability are not compromised. This will require toe berms to compensate for or prevent at least 3 feet of subsidence in affected areas by 2050 and 8 feet by 2100.
- Sea level rise may be 4 to 16 inches by 2050 and 8 inches to 4.6 feet (or more) by 2100. Levee raises can probably keep up until 2050, but they may not succeed in the last half of the century. However, we are assuming here that levee raises do keep up.

Consider Tables A-2 for floods and A-3 for earthquakes and their implications for increased risks from major levee breach events, even given these aggressive assumptions:

Table A-2 Summary of Future Risk Factor Changes for Floods

Factor	2050	2100
Increase in Flood Frequency	40% to 500%	130% to 1,140%
Increase in Repair Time/Cost	10%?[a]	20%?[a]
Salinity / Delta Recovery Time	N/A[b]	N/A[b]
Population / Economy Exposed		
Delta Area	100%+/-	200%+/-
Bay Area and State	61%+/-[c]	143%+/-[c]

[a]Estimate of increase due to increased scour with increased flooding head (not supported by calculations).
[b]Assumes levees repaired quickly to prevent tidal action from drawing in salinity after flood flows recede.
[c]Reflects assumed increased dependence with Bay Area/state population and economic growth on Delta regional infrastructure (roads, railways, pipelines, etc.); based on state population projections.

Table A-3 Summary of Future Risk Factor Changes for Earthquakes

Factor	2050	2100
Increase in Seismic Frequency	10%	20%
Increase in Repair Time/Cost	10%?[a]	20%?[a]
Salinity / Delta Recovery Time		
More Net Delta Outflow (sea level rise)	10%	23%
Less Water Supply (warmer storms/less snowpack)	8%	20%
Increased Accommodation Space (subsidence)	15%	50%
Increased Accommodation Space (sea level rise)	25%	50%
Increased Tidal Exchange / Dispersion	+?%	+?%
Population/Economy Exposed		
Delta Area	100%+/-	200%+/-
Bay Area and State	61%+/-[b]	143%+/-[b]

[a]Estimate of increase due to increased scour with increased flooding head (not supported by calculations).
[b]Reflects assumed increased dependence with Bay Area/state population and economic growth on Delta water exports and regional infrastructure (roads, railways, pipelines, etc.); based on state population projections.

Note that some of these percentages are additive. Others need to be converted into multiplicative factors. Still others have minor overlap. We must also remember that, if sea level rise is more than 2 or 3 feet, our assumption that levee raises will keep up with sea level rise needs to be reviewed. The important point, however, is that all the change factors are implying increasing risk. Together they point to large increases in risk. It should be noted that DRMS performed a much more detailed and meticulous analysis and did not find any future change factor that would decrease risks. All factors point toward increasing risk consequences from major Delta levee breaches. The ones described here combine to point to large increases.

3.4 Exposure Period

Although the trends in factors that influence the estimate of future risks combine to indicate steadily increasing annual risks from Delta levee failures, there is another important dimension in considering future risk. That dimension is the exposure period to an already high-risk situation.

In performing a risk analysis, engineers usually work with the annual frequency of events. The important concept about such events is that they have essentially the same likelihood of occurrence every year.

The risk of adverse events increases as a longer period of exposure is considered. Figure A-2 indicates the increased likelihood of occurrence as the length of the exposure period grows. In 30 years of exposure, a one percent annual event has a 26% chance of being equaled or exceeded. In 50 years, the chance is 39.5%. And in 100 years, the chance is 63.4%. Figure A-2 also illustrates the increasing probabilities for other annual frequencies.

In the Delta, a severe levee breach incident (20 or more flooded islands) has an annual frequency of approximately 0.03 (3%) (URS/JBA, 2007a). The (0.03) frequency has been given a bold line on Figure A-2 to highlight it. It is just a matter of time (exposure period) until a severe event occurs. The figure indicates a 50/50 chance of a 3% frequency event within 25 years.

4. Drivers of Change Relevance to Infrastructure and Potential Policy Responses

In this section, the goal is to summarize the foregoing discussions in terms of what each driver that is changing the Delta's future means in terms of impacts on Delta infrastructure systems and how policies and plans might respond.

Subsidence – Subsidence is relevant to infrastructure in two ways – 1) its potential impact on levee stability (loss of soil near the toe or settling of the levee itself) and 2) the resulting increase in accommodation space from lowering land surfaces on the interior of an island. If one recognizes levees as an infrastructure system that deserves proper maintenance, the subsidence threat to levee stability can be monitored, addressed, and need not have a significant impact. The increase in accommodation space is important when there is a levee breach; it can mean more salinity intrusion and a longer time until the Delta waters again become fresh and usable for in-Delta irrigation and export by the state and federal water projects. Other impacts on infrastructure include more scour when levees breach and thus more potential for damage to adjacent infrastructure. Policy initiatives for subsidence with infrastructure in mind could include:

- Maintain Delta levees adequately to address soil loss at levee toes and settlement of the levees.
- Encourage land use practices that are intended to reduce field subsidence.
- Avoid infrastructure exposure to scour by locating infrastructure away from levees or providing protective structures.
- Avoid infrastructure placement or major improvements within the Delta, given the present high risk of flooding and the increasing future risks.

Global Climate Change (Sea Level Rise) – Sea level rise is expected to be significant. It may or may not become overwhelming. The next several decades will provide essential information for a better forecast. Sea level rise is relevant to infrastructure in many ways, including 1) loss of levee freeboard and increased risk of flooding, unless levees are raised and extended, 2) more area on the Delta periphery vulnerable to flooding, 3) more Delta outflow required to meet Delta salinity standards and to restore Delta freshness in event of salinity intrusion, and 4) more accommodation space on Delta islands (in event of flooding). Policy initiatives relative to sea level rise with infrastructure in mind could include:

- Maintain levees adequately (even aggressively).
- Raise Delta levees two feet during all projects for repair or improvement.
- Support intensive monitoring and research to better assess and project sea level rise.
- Avoid or minimize infrastructure placement or major improvements within the Delta, given the present high risk of flooding, the increasing future risks, and the possibility that future sea level rise will be overwhelming.
- Avoid or minimize urban growth within the Delta (Primary Zone) and in the Delta's periphery (Secondary Zone and more), given the present high risk of flooding, the increasing future risks, and the possibility that future sea level rise may be overwhelming.

Regional Climate Change (More Winter Floods) – Regional climate change will have two major effects 1) larger (or more frequent) Delta inflow floods and 2) reduced water supply yield, since less rain will fall as snow and snowmelt will provide less flow in the late spring and summer. It is not clear from presently available information whether the increased size of Delta inflow floods will be moderate or large. The next several decades should provide much improved information. Policy initiatives relative to regional climate change with infrastructure in mind could include:

- Support intensive monitoring and research to better characterize flood hydrology changes.
- Revise flood analysis and flood control project design procedures to recognize and apply changing flood hydrology.
- Implement flood control project improvements (setback levees, levee raises, bypasses, etc.) as necessary to address increasing flood sizes (or frequencies), especially for areas that are now highly developed.

- Avoid or minimize infrastructure placement or major improvements within the Delta, given the present high risk of flooding, the increasing future risks, and the possibility that inflow flood sizes will become very large.
- Avoid or minimize urban growth within the Delta (Primary Zone), in the Delta's periphery (Secondary Zone and more), and in tributary flood plains – given the present high risk of flooding, the increasing future risks, and the possibility that inflow flood sizes may become very large.
- Support water supply enhancements – both 1) conservation to further stretch present supplies and 2) groundwater and surface water storage to improve decreasing yields.

***Seismic Activity* –** The possibility of an earthquake causing multiple simultaneous levee breaches in the Delta with many flooded islands is already with us. Although the probability will increase in the future, the increases will be modest. Unlike flood-caused major levee breach events, an earthquake-caused event can occur any time. Delta inflows may be low, allowing saltwater to intrude from the Bay. Special types of damage may occur, such as slumping of channel banks into shipping lanes or structural failures of infrastructure facilities such as bridges, roads, railways or pipelines that are independent of levee failures and island flooding. Levee failures and island flooding can make repairs more difficult and time consuming. The vulnerability of Delta levees to seismic failures is difficult and expensive to remedy because of poor foundation conditions and poor construction practices at the time the levees were built. Policy initiatives relative to seismic activity with infrastructure in mind could include:

- Implement Delta infrastructure improvements with seismic protection features selectively based on careful project analyses, considering uncertain future scenarios such as very large sea level rise or much larger Delta inflow floods.
- Avoid or minimize infrastructure placement or major improvements within the Delta, given the present high risk of seismic flooding, the increasing future risks, and the large and increasing consequences from seismic failures.
- Avoid or minimize urban growth within the Delta (Primary Zone) and in the Delta's periphery (Secondary Zone and more), given the present high risk of seismic flooding, the increasing future risks, and the increasing consequences of seismic failures.

***Introduced Species* –** Introduced species are already pertinent to Delta infrastructure and will continue to be relevant. Their obvious significance is their effect on the health and vitality of the Delta ecosystem, particularly its threatened and endangered species. Delta infrastructure can both affect and be affected by introduced species and the ecosystem. Policy initiatives relative to introduced species with infrastructure in mind could include:

- Require all forms of infrastructure to avoid introducing non-native species into the Delta. This would target commercial shipping (ballast tanks, etc.), recreational boating, fishing, agricultural returns and drainage water, wastewater discharges, and levee slope vegetation.
- Insist that new Delta infrastructure projects be designed to avoid such introductions.

Population Growth and Urbanization – Population growth, urbanization, and associated economic activity are directly related to infrastructure in all its forms. Delta area population growth and urbanization is occurring very rapidly and creates both local infrastructure demand and regional services infrastructure demand (e.g., highway traffic) at every step. Greater Bay Area and state population / economic growth also put increasing pressure on the Delta region's infrastructure in the form of highway and interstate traffic, railway and marine cargo, and cross Delta pipelines (natural gas, petroleum products, and EBMUD water supply). Finally, as Bay Area and state populations and industries grow, they become more intensely dependent on the through Delta conveyance of the State Water Project and Central Valley Project water exports. Policy initiatives relative to population growth, urbanization, and related economic activity with infrastructure in mind could include:

- Avoid or minimize infrastructure placement or major improvements within the Delta, given the present high risk of flooding, the increasing future risks, and the possibility of very large sea level rise or inflow floods.
- Avoid or minimize urban growth within the Delta (Primary Zone) and in the Delta's periphery (Secondary Zone and more), given the present high risk of flooding, the increasing future risks, and the possibilities that sea level rise or inflow floods may become very large.
- For "vital link" infrastructure facilities located in the Delta (i.e., facilities that have no adequate backup – namely EBMUD's Mokelumne Aqueduct and State Water Project and Central Valley Project water conveyance), insist on improvements that either harden the facilities to ensure continuous operating capabilities or provide a redundant link that is capable of adequate backup until the primary link is restored. These facilities must be adaptable to both large increases in sea level and large increases in Delta inflow floods – two potential impacts of climate change that are not certain, but could jeopardize the sustainability of these infrastructure systems if they were not able to adapt. The reason for suggesting this demanding criterion is that the regional and state population and economy are now dependent and, with foreseen growth, will be even more intensively dependent on these vital links.

5. Concluding Comments

The purpose of this document has been to review and evaluate long-term drivers of change relative to pertinent infrastructure systems in the Delta. Transportation and utilities systems have been emphasized. The previous section identified policy options relative to each driver of change and the risks relative to long-term sustainability of infrastructure. In examining each driver in turn, a few concepts stand out:

- ***Large Sea Level Rise and Floods –*** There are two drivers of change with important long-term uncertainties – the possibility of large sea level rise (potentially several meters) and of very large increases in Delta inflow floods (potentially doubling or tripling peak inflows). Although some would consider these ideas "not well supported," "alarmist," or "far out," it seems prudent to examine them further and consider whether proposed infrastructure projects can adapt to them.

- ***Population and Urban Growth in the Delta Region –*** The most dramatic and relatively certain driver of change, given present policies, is growth of population and urban areas in the Delta region, not only in the Secondary Zone, but also as infill in towns in the Primary Zone. Given the present high risk of flooding, increasing future risks and questions on whether adequate flood protection can be provided in the longer-term, it seems prudent to examine, and perhaps alter, present development policies.
- ***Population and Economic Growth in the Greater Bay Area and the State –*** Regional and state population and economic growth are second only to the very high growth in the Delta region. These areas are dependent and are becoming more intensively dependent on vital links of two water supply systems that cross the Delta. Neither the EBMUD Mokelumne Aqueduct nor the State Water Project / Central Valley Project through-Delta conveyance has adequate backup. It seems prudent to insist that adequate backup be provided for both these "vital links," given the high risks in the Delta and the high consequences of disruption.
- ***Seismic Activity –*** The risk of seismic activity is already high, and the prospective consequences of a major seismic levee breach event are high and increasing rapidly because of other drivers of change, especially Delta area and statewide population growth. It is simply a matter of time until some version of seismic disruption occurs in the Delta. It seems prudent to increase recognition of this eventuality and increase our preparedness.

Other more comprehensive and detailed discussions of potential infrastructure policies are provided in the previous section of this appendix, in the Transportation Context Memo (Mann, 2007), and in the Utilities Context Memo (Branson, 2007).

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Figure A-1. Oroville Changes in Monthly Runoff Pattern (One of Four Simulations; SRESa2, gfdl).

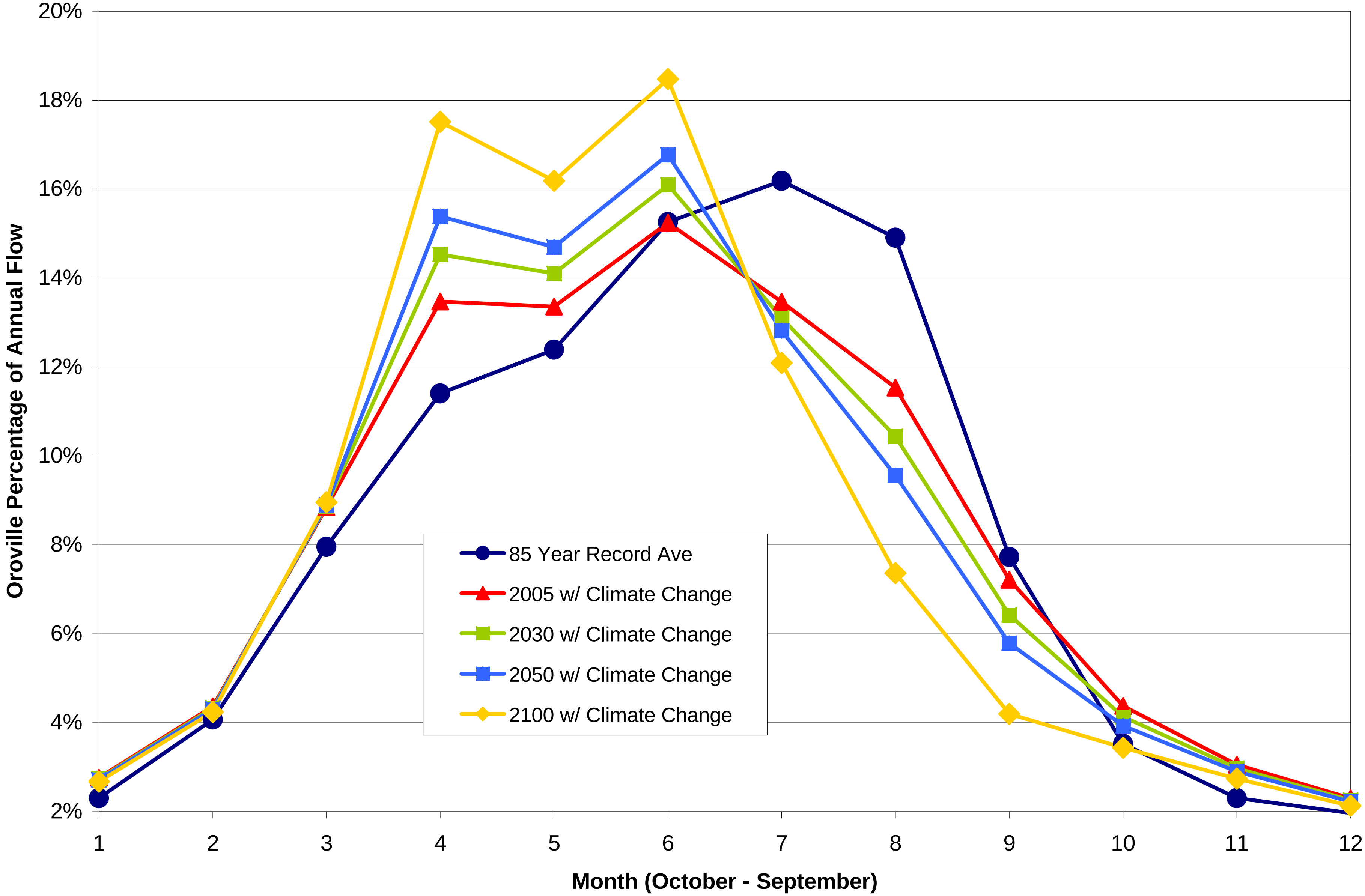
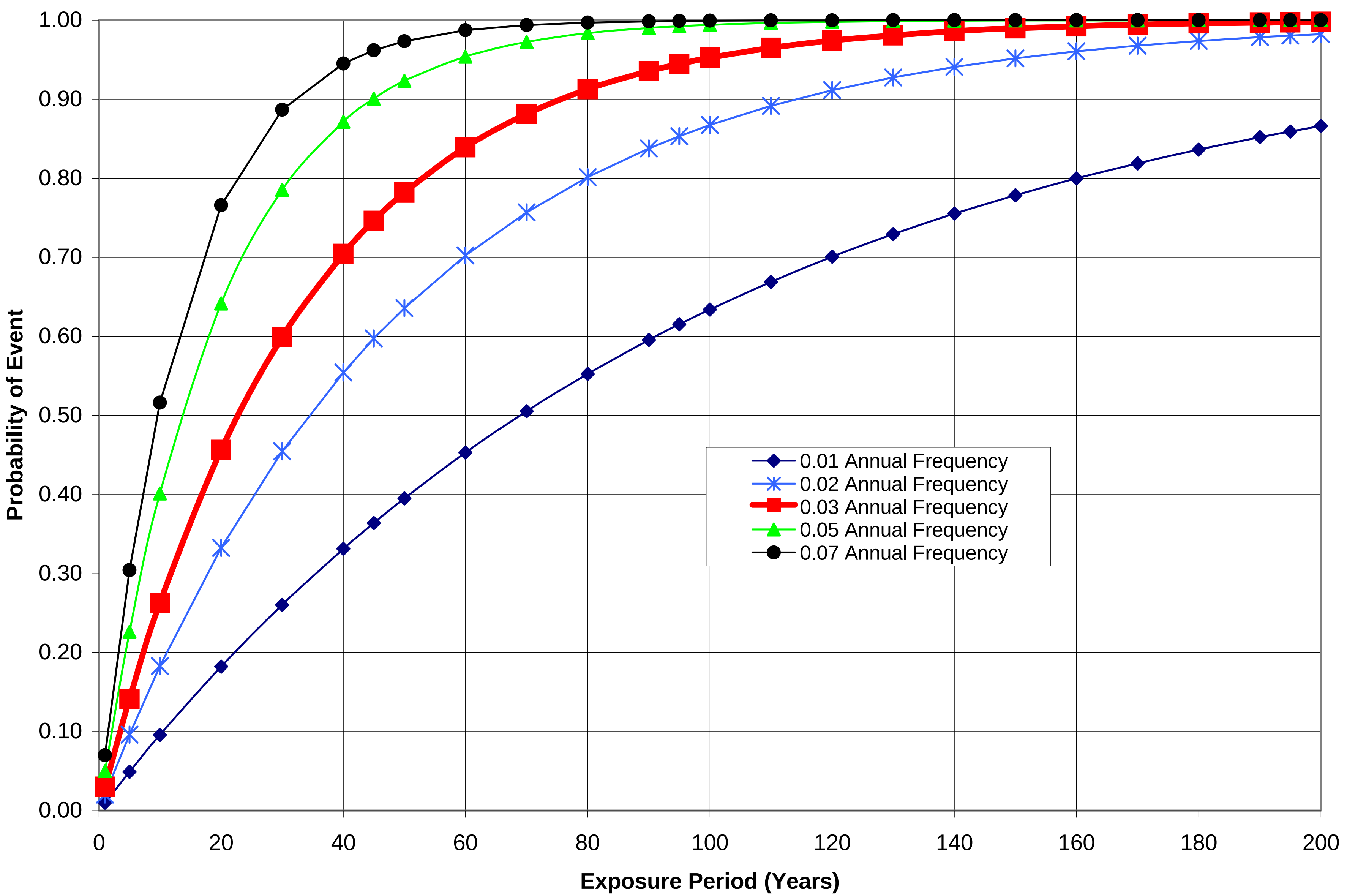


Figure A-2. Event Probability Versus Exposure Period



Appendix B

Review of

Potential Impacts of Climate Change on U.S. Transportation[a]

[a]Full Citation: NRC, 2008. Committee on Climate Change and U.S. Transportation, Transportation Research Board, Division on Earth and Life Studies, National Research Council of the National Academies. ***Potential Impacts of Climate Change on U.S. Transportation.*** Transportation Research Board Special Report 290. Transportation Research Board. Washington, D.C., 2008. Prepublication copy http://www.nap.edu/catalog.php?record_id=12179#toc

1. Introduction

This appendix reviews the Transportation Research Board Special Report 290 regarding ***Potential Impacts of Climate Change on U.S. Transportation*** (NRC, 2008). The report was compiled by the Committee on Climate Change and U. S. Transportation of the National Research Council. This review is for the use of the Delta Vision Blue Ribbon Task Force (BRTF) and its staff. The report itself includes a carefully compiled summary. The intent in this review is to highlight concepts that yield insights for or have applicability to the Sacramento – San Joaquin Delta, particularly regarding the ways in which infrastructure is vulnerable or may need to adapt to climate change as part of the Delta's future.

The NRC Committee goals that are most relevant to the Delta were to:

- Summarize possible impacts (of climate change) on transportation, such as those due to rising sea levels, higher mean temperatures with less extreme low temperatures and more heat extremes, and more frequent intense precipitation events.
- Analyze options for adapting to these impacts, including the possible need to alter assumptions about infrastructure design and operations, the ability to incorporate uncertainty into long-range decision making, and the capability of institutions to plan and act on mitigation and adaptation strategies at the state and regional levels.
- Suggest policies and actions for preparing for the potential impacts of climate change.

The scope of the report includes all modes of transportation, including pipelines. Although the report does not explicitly recognize water conveyance in canals and natural or semi-natural channels, this is an obvious extension that is important in considering the Delta. Water conveyance across the Delta (the Mokelumne Aqueduct) and through the Delta channels (state and federal water projects) are special transportation activities that may require similar approaches to deal with climate change impacts.

The Committee identifies the audience for its report as the transportation community broadly defined. The stated overall goal of the report is to "demonstrate to decision makers responsible for transportation infrastructure, both public and private, why they should plan for climate change." At the same time, the Committee's report attempts to "moderate expectations about the level of precision with which the report can provide guidance on specific impacts of climate change and their time frames."

The Committee focuses primarily on adaptation strategies that can lessen the impacts of climate change on transportation and transportation users. Thus, the report's concern is for coping with and lessening impacts of climate change rather than lessening the causes of climate change (see their Figure 1-1 below). "Its primary focus is on the direct impacts of climate change on transportation infrastructure and system operating performance, although indirect impacts are noted (e.g., potential shifts in the location of economic activities and use of transportation modes …). These indirect impacts are highly uncertain because they depend on assumptions about population and economic growth, the rate of technological innovation, and policy decisions (e.g., government regulations and controls on coastal land use and development, private-sector decisions about business operations and logistics)."

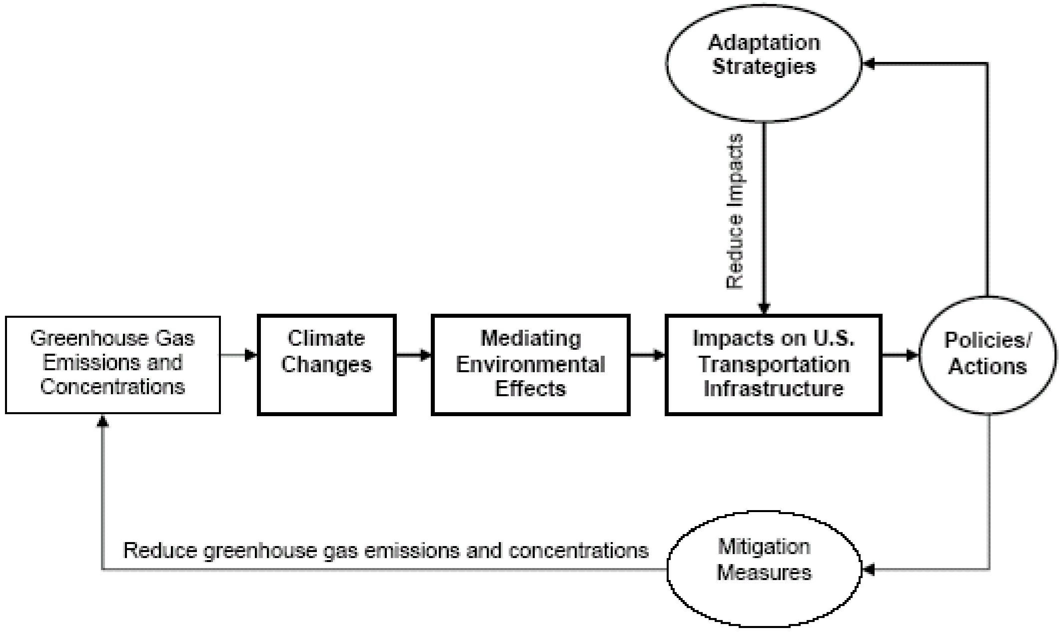


FIGURE 1-1 The role of mitigation measures and adaptation strategies in addressing climate change impacts on U.S. transportation infrastructure.
Note: Bolded areas denote the primary focus of this study.

(from NRC, 2008)

The report is organized into the following chapters:

- Summary
- 1. Introduction
- 2. Understanding Climate Change
- 3. Impacts of Climate Change
- 4. Challenges to Response
- 5. Meeting the Challenges
- 6. Summing Up

The initial Summary consists primarily of a report overview with the Committee's "Findings" and "Recommendations" and abbreviated discussions and examples. It is similar to more extensive discussion and examples provided in Chapter 6. The Summary is recommended for those readers who wish to view the Committee's findings and recommendations directly.

A key paragraph from the summary conveys a main point of the report (emphasis added):

"Climate change will have significant impacts on transportation, affecting the way U.S. transportation professionals plan, design, construct, operate, and maintain infrastructure.

Decisions taken today, ***particularly those related to the redesign and retrofitting of existing or the location and design of new transportation infrastructure,*** will affect how well the system adapts to climate change far into the future. Focusing on the problem now should help avoid costly future investments and disruptions to operations. The primary objective of this report is to provide guidance for transportation decision makers on how best to proceed."

2. Review

The report is exceptionally informative and carefully structured. It is abundantly supported by references to scientific, engineering and public policy literature. The concepts are applicable to the Sacramento – San Joaquin Delta and the Delta Vision mission. Indeed, the concepts, findings, and recommendations are more broadly applicable than just to transportation or climate change. They can be interpreted for use in the water resources sector and relative to other Delta-area threats such as subsidence, floods, and earthquakes. The following are concepts that deserve special emphasis:

Factors Considered in Policy and Decision Making – Institutions and professional disciplines tend to define limited scopes for their activities and can easily miss important factors that should be considered. The most obvious example from the report is that "long-term" transportation plans usually do not consider more than a 30-year time frame. This is inadequate to include adaptive strategies for climate change impacts such as sea level rise and more intensive storms.

Impacts through Extreme Occurrences – The major impacts of climate changes will often be from their convergence with expected variability to create extreme events that exceed the bounds of past experience. For example, the gradual amount of sea level rise (though uncertain and potentially large) may not be as important by itself as its combination with more intense storms including higher storm surges, more violent wind and waves, and larger flood flows.

Consequences of Extreme Occurrences – Due to the network characteristic of transportation infrastructure, the system can be either resilient or vulnerable in extreme events. In a mature transportation network, loss of some links can often be overcome by shifting to an alternate link or mode. For example, in the Delta, flooding of a state highway (though inconvenient and costly) can usually be overcome by traveling a different route. Similarly, outage of an electrical transmission line may be bypassed by using other parts of the network. Loss of a petroleum product pipeline may be addressed by use of trucks.

On the other hand, loss of a key link in a network can have severe consequences. For example, the Mokelumne Aqueduct (consisting of its three pipelines) is the only link through which East Bay MUD can convey water from its Sierra source to its service area. Extending this concept, the conveyance of state and federal project water from the north Delta through Delta channels to their pumps is a similar key link in a transportation system. Neither example of water conveyance has satisfactory backup. Temporary pipelines or trucking enough water around the Delta is simply infeasible. So water users will have to either make due with other sources (which may be inadequate or committed) or go without.

Adaptive Actions Can Occur (Need to Occur) on All Time Scales – In addressing climate change (and other significant threats) adaptive strategies can be developed on all time scales – short term (operational), medium term (design and rehabilitation), and long term (new projects and major upgrades). In combination, these adaptations can create substantial improvements in system resiliency and reduction of adverse consequences. Concentrating on a single time scale (e.g., long-term planning) is likely to make progress much slower and more difficult to achieve. Examples are the following:

- *Operational Level / Short Term* – The Delta Levees Program annually provides financial assistance to Levee Maintaining Agencies (LMAs) to maintain and improve Delta levees. These annual projects could begin to address climate change by including a modest increase in crest height (say two feet) for each section of levee that a project addresses. After 20 years, a large portion of the levees would be more capable of defending against sea levels rise. Improving the remaining levees would be much more manageable.
- *Design & Rehabilitation / Medium Term* – There is now discussion of improving State Highway 12 through the northern part of the Delta. There is opportunity here to look into the future beyond the normal highway planning horizon and consider such issues as – a) whether the highway should be raised (to serve as an evacuation route, if needed, or to continue providing service when a levee breach occurs), b) whether the highway's capacity should be increased given its vulnerable location, and c) whether development adjacent to the highway should be restricted in some way, recognizing that additional development would be increasingly vulnerable to flooding and that the highway rehabilitation project might be putting people and property in harm's way.
- *New Projects & Major Upgrades / Long Term* – If there is to be some version of an Isolated Facility for conveyance of state and federal project water through or around the Delta, where will it be located? Is its proposed location adaptable to substantial increases in inflow floods from more intense and warmer winter storms and to a large amount of sea level rise (say five to ten feet) if parts of the Greenland and Antarctica ice sheets melted? Note that Hansen (2007a, 2007b), a respected climate scientist, indicates that sea level rise measured in meters should be expected by 2100 if GHG emissions are unchecked. The decision on Isolated Facility right-of-way location is very important because the state certainly doesn't want to relocate the facility after it is initially built. Should we count on the world to control GHG emissions sufficiently and quickly enough? The NRC Committee would be likely to indicate that adaptability in the face of this future uncertainty is the most important near-term application of the findings and recommendations in its report.

Use Probabilistic Risk Analysis and Multiple Scenarios in Planning – The report strongly advocates 1) taking a long-term view, 2) recognizing that the future is uncertain (especially relative to climate change), and 3) applying probabilistic risk analysis in order to assess a range of potential outcomes from a variety of alternatives. The State of California and DWR are at the forefront of applying these techniques. The California Department of Transportation bridge seismic retrofit program is used in the report as an example where this approach has been applied successfully. DWR's DRMS project has applied probabilistic risk analysis to Delta levee vulnerability under business as usual conditions focusing primarily on risks from floods and earthquakes. The technique can be extended to more completely cover the range of possible futures with climate change and to analyze and compare the vulnerability of alternative Delta conveyance locations and designs.

Concluding Thoughts* –** The NRC Committee's report on ***Potential Impacts of Climate Change on U. S. Transportation is excellent and directly applicable to the Delta. The concepts and insights are more broadly applicable than just to climate change and transportation. They are also applicable to Delta water resources (water conveyance and flood management) and to ecosystem revitalization. They are helpful in addressing hazards other than climate change – namely earthquakes, floods and subsidence. Many of the findings and recommendations can be interpreted for advantageous application to the specifics of transportation, infrastructure and the broader policy dilemmas of the Delta.

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Appendix C

Review of

Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I [a]

[a]Full Citation: USCCSP, 2008. U.S. Climate Change Science Program. ***Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.*** A Report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research, Synthesis and Assessment Product 4.7. Department of Transportation, Washington, DC. March, 2008.
http://www.climatescience.gov/Library/sap/sap4-7/default.php

1. Introduction

This appendix reviews the U.S Climate Change Science Program report on ***Impacts of Climate Change and Variability on Transportation Systems and Infrastructure: Gulf Coast Study, Phase I.*** The report is an inter-agency, multi-disciplinary study sponsored primarily by the U.S. Department of Transportation. This review is for the use of the Delta Vision Blue Ribbon Task Force (BRTF) and its staff. The report itself includes a carefully compiled summary. The intent in this review is to highlight concepts that yield insights for or have applicability to the Sacramento – San Joaquin Delta, particularly regarding ways in which infrastructure is vulnerable or needs to adapt to climate change for the Delta's future.

The report is Phase I of a three-phase effort. The objectives of the overall study are to:

- Develop knowledge about potential transportation infrastructure sensitivities to climate changes and variability through an in-depth synthesis and analysis of existing data and trends.
- Assess the potential significance of these sensitivities to transportation decision makers in the central U.S. Gulf Coast region.
- Identify potential strategies for adaptation that will reduce risks and enhance the resilience of transportation infrastructure and services.
- Identify or develop decision support tools or procedures that enable transportation decision makers to integrate information about climate variability and change into existing transportation planning and design processes.

The three phases are:

- Phase I – Data Collection and Assessment of Risks
- Phase II – In-Depth Assessment of Impacts and Risks to Selected Areas and Facilities
- Phase III – Identify the Range of Potential Adaptation Strategies.

The two primary objectives of Phase I of the central Gulf Coast transportation impact assessment were to:

- Collect data needed to characterize the region – its physiography and hydrology, land use and land cover, past and projected climate, current population and trends, and transportation infrastructure.
- Demonstrate an approach for assessing risks and vulnerability of transportation at regional and local scales.

The results of this analysis are presented in the report. The methodologies developed during Phase I of the study can be applied to assess transportation risk and vulnerability at a community, county, or regional level.

The report is organized in a summary and six chapters as follows:

- Executive Summary

- Chapter 1 – Why Study Climate Change Impacts on Transportation?
- Chapter 2 – Why Study the Gulf Coast?
- Chapter 3 – How is the Gulf Coast Climate Changing?
- Chapter 4 – What are the Implications of Climate Change and Variability for Gulf Coast Transportation?
- Chapter 5 – How Can Transportation Professionals Incorporate Climate Change in Transportation Decisions?
- Chapter 6 – What are the Key Conclusions of this Study?

2. Review

Given the above objectives and phasing, this report does not provide innovative answers to the dilemmas posed by climate change and its impacts on transportation. It is more a documentation and quantitative assessment of what those impacts are expected to be for the Gulf Coast (and the uncertainties involved) and an evaluation of their significance. Some of the assessment methods used may be applicable to the Delta. On a general level, the report does provide indications of orientations and approaches that appear to be productive in addressing climate change.

***Data Synthesis* –** The report's strength is its synthesis of available data on the Gulf Coast environment, climate, transportation infrastructure, and the expected impacts of climate change. The most important drivers are "relative sea level rise" and storm surge from hurricanes and other tropical storms. The following points need to be understood:

- Relative sea level rise is the combined effect of absolute sea level rise and general subsidence in the Gulf Coast area. Subsidence occurs due to several different factors that are of different significance in different areas. There is some general settling due to the sedimentary nature of soils in the area. In the Houston area, there has been substantial subsidence due to water and petroleum withdrawals. In the New Orleans area, subsidence occurs due to the decomposition or dispersal of peat.
- The study evaluated the lumped impacts of subsidence and sea level rise together for two different amounts of "relative sea level rise" – two feet and four feet. Note that this does not factor in different amounts of subsidence in different areas.
- The study also looked at storm surge amounts of 18 feet and 23 feet – amounts that are not unusual for major tropical storms. Katrina had storm surge high water marks of up to 28 feet, per the report. In contrast, a San Francisco storm surge of one foot is considered high (Flick, 2007).

Two highlights from the report abstract are:

- Relative sea level rise will make much of the existing infrastructure more prone to frequent or permanent inundation – 27 percent of the major roads, 9 percent of the rail lines, and 72 percent of the ports are built on land at or below 122 cm (4 feet) in elevation.

- Increased storm intensity may lead to increased service disruption and infrastructure damage. More than half of the area's major highways (64 percent of Interstates; 57 percent of arterials), almost half of the rail miles, 29 airports, and virtually all of the ports are below 7 m (23 feet) in elevation and subject to flooding and possible damage due to hurricane storm surge.

***Approaches for Addressing Climate Change* –** The report suggests the following approaches for transportation professionals to incorporate climate change in their decisions:

- *Planning Timeframes* – The present "long-range" planning timeframe for transportation is short compared to the multi-decade periods over which climate changes occur. Planners need to extend their vision of the long term in order to better consider the aspects of their decisions that have lasting influence, such as where transportation facilities are located.
- *Connectivity* – It is "useful for planners to examine the connectivity of the (various modes and geographic levels of the transportation systems and their sensitivity to) long-term changes in the natural environment, including changes induced by climate. This helps to identify critical links in the system and ways to buttress them against exposures to climate factors or other variables, or to create redundancies to maintain critical mobility…."
- *Integrated Analysis* – **"**From a transportation planning perspective, it is unnecessary and irrelevant to separate impacts due to climate change from impacts occurring from other naturally occurring phenomena like subsidence or storm surge due to hurricanes. In fact, such impacts are integrally related. Climate change is likely to increase the severity or frequency of impacts that already are occurring. Any impact that affects the structural integrity, design, operations, or maintenance that can be reasonably planned for should be considered in transportation planning."
- *Risk Analysis Approach* – The report advocates adopting a risk analysis approach in order to better address the range of the circumstances and risks that may develop. It suggests an approach considering exposure, vulnerability, resilience, and adaptation.
- *Adaptation Strategies* – The aim of the risk-based approach is to identify and adopt transportation designs and facility locations that improve the resiliency of the system. "Structures can be hardened, raised, or even relocated as need be, and – where critical to safety and mobility – expanded redundant systems may be considered as well."

Concluding Thoughts* –** The general approaches identified above are very similar to those suggested by the NRC Committee's 2008 report on ***Potential Impacts of Climate Change on U. S. Transportation and are also similar to approaches being applied to the Sacramento – San Joaquin Delta, especially by DRMS.

3. Reference

Flick (2007). Flick, Reinhard E. "In California, Mean Sea Level Doesn't Run Over Your Doorstep!" Fourth Annual Climate Change Research Conference. 10 September, 2007. Sacramento, California.

Appendix D

Prospective Use of Infrastructure Corridors[a]

[a]Based on URS/JBA, 2007a. URS Corporation / Jack R. Benjamin & Associates, Inc. ***Delta Risk Management Strategy (DRMS) Phase 2 Building Block "Flash Cards" (PRELIMINARY).*** Prepared for California Department of Water Resource (DWR). August 20, 2007.

1. Introduction

This appendix considers the prospective use of an infrastructure corridor to lessen the risk of disruptions to services that can be caused by levee breaches in the Sacramento – San Joaquin Delta. It is based primarily on the work done and reported (on a preliminary basis) by the Delta Risk Management Strategy (DRMS) project, Phase 2 Building Blocks (URS/JBA, 2007a). It is supported by several other recent documents: the DRMS Phase 1 Report (URS/JBA, 2007b), the DRMS Technical Memorandum on Infrastructure (URS/JBA, 2007c, and the Delta Vision Context Memos on Transportation (Mann, 2007) and Utilities (Branson, 2007). Additional relevant information is presented in an East Bay Municipal Utility District summary report that evaluates options for addressing Delta risks to its Mokelumne Aqueduct (EBMUD, 2007).

The obvious opportunity for an infrastructure corridor is across the Delta in the vicinity of Highway 4 from Stockton to Brentwood – including protection for State Highway 4, the Burlington Northern Santa Fe (BNSF) railway, the East Bay Municipal Utility District (EBMUD) Mokelumne Aqueduct, the Kinder Morgan petroleum pipeline and the Pacific Gas and Electric (PG&E) gas pipelines. The corridor upgrade was considered by DRMS as two options, one with facilities between (and on) two new, seismically designed levees and the other with facilities placed on the crest of a new, wider, seismically designed levee. The project information and cost comparison of the two approaches is shown below and in Figures D-1 and D-2 (URS/JBA, 2007a):

Project Information: An armored (seismically resistant) infrastructure corridor would be provided across the central Delta. The length of the corridor would be approximately 15 miles. The crest elevation of the new levee is 13.0 feet, with 3 feet of freeboard above the 100-year flood level. The peat layer averages 10 feet thick along the corridor and liquefiable sand layers are anticipated through much of the levee length.

Option 1: Construct northern and southern levees across the central Delta. Relocate State Highway 4 onto the new southern levee and the BNSF railway onto the northern levee. The EBMUD, Kinder-Morgan, and PG&E pipelines would remain largely in their present locations, except where they must be moved to take advantage of the protected area between the two new seismically resistant levees. Preliminary Construction Cost Estimate is $3.3 billion.

Option 2: Construct a larger levee (also seismically resistant) that can carry the relocated State Highway 4, BNSF railway, and the EBMUD, Kinder-Morgan, and PG&E pipelines. Preliminary Construction Cost Estimate is $3.9 billion.

The primary cost components are new seismically resistant levee foundation preparation and embankment construction. The costs per mile indicated are approximately $52.6 million per mile for each levee in Option 1 (about 90% of the cost) and $107 million per mile for Option 2 (about 77% of the cost).

Risk Reduction Benefits: Estimating project benefits requires additional analysis beyond that presented in URS/JBA (2007a). The benefits should be limited to (but include all of) the disruption costs and impacts that would be caused, under present circumstances by earthquakes, floods and associated levee failures and the resulting flooding of the islands that have the subject facilities – provided that the disruption would be prevented by the infrastructure corridor project. Appropriate adjustments would be required for the annual frequency of occurrence of disruptive events and flooding, the duration of disruption and the appropriate discount rate to allow for the annual cost of the project. These calculations have not yet been made in DRMS Phase 2 work.

Using a 50-year project life and a 5% discount rate, the $3.3 billion of capital cost of Option 1 is equivalent to $181 million/year annual cost. If we assume that normal annual costs for operation and maintenance will be equal with and without the project, the expected reduction of disruption would need to be worth $181 million per year in order to justify the project. The consequence evaluation data that DRMS has available is based on the cases analyzed for the Phase 1 Risk Analysis Report (URS/JBA, 2007b); see Table D-1:

Table D-1 Disruption Cost Estimates for Infrastructure Corridor Islands From DRMS Phase 1 Seismic Case Analyses (URS/JBA, 2007b)[a]

Case	No. Islands Flooded	Corridor Islands Infra-structure Repair[b]	Highway 4 Disrupt-ion Cost (est.)[c]	PG&E Gas Transmis-sion Dis-ruption[d]	EBMUD cost of service disrupt-ion[e]	Other State Disruption (Railway, Petroleum Pipeline)[f]	Total Cost of Disruption (Upper Bound Estimate)
1	1	0	0	0	Not Avail	0	0 + EBMUD
2	3	20	0	0	Not Avail	0	20 + EBMUD
3	3	20	0	0	Not Avail	0	20 + EBMUD
4	10	117	0	0	Not Avail	0	117 + EBMUD
5	20	236	586	801	Not Avail	0	1,623+EBMUD
6	30	279	883	1,106	Not Avail	0	2,268+EBMUD

[a]This table summarizes the estimated cost consequences from earthquake-caused levee failures as evaluated in the June 2007 draft of the DRMS Phase 1 report for infrastructure corridor islands. Since the Phase 1 analysis focused on consequences of levee failures, it did not estimate the direct consequences of the earthquake. For example, no disruption costs are assessed for failure of the EBMUD aqueducts because the cases considered did not have aqueduct failures caused by levee failures (e.g., from scour if a breach had been close to the aqueduct). However there may have been EBMUD disruption caused by the earthquake – e.g., Aqueducts No.1 and No.2 have not been seismically upgraded and may have failed due to ground shaking. This was not evaluated in DRMS Phase 1. But it is a risk consequence that would be relevant in evaluating potential risk reduction from an infrastructure corridor – the risk would be eliminated by Option 2 (placing the aqueducts on the crest of a seismically designed levee and designing the new aqueducts to survive earthquakes) but it would be unaffected by Option 1 (leaving the aqueducts where they are and building two protective levees), unless the aqueducts were seismically upgraded.
[b]Corridor island infrastructure repair costs are for the whole island. The repairs that would be unnecessary because of the infrastructure corridor would be less, possibly much less, because they may be in other areas.
[c]Highway 4 disruption is estimated as an upper bound by taking half of the total Delta highway disruption costs including Highways 4, 12 and 160. Highways 12 and 160 are both disrupted in Cases 5 and 6.
[d]PG&E gas transmission disruption costs are only partly due to damage to pipelines that would be protected by the infrastructure corridor. Much of the indicated cost is due to disruption of operations on McDonald Island and damage to pipelines connecting McDonald operations to the pipes that would be in the infrastructure corridor. Thus, these numbers are an overestimate, possibly a large over estimate.
[e]EBMUD costs of service disruption were not estimated; see note a.
[f]Other statewide infrastructure disruption was not caused by levee failures; see note a.

Clearly, the constraints and assumptions pertinent to the cost of disruption estimates presented in Table D-1 make it of limited value for estimating the benefits of an infrastructure corridor.

In order to proceed with our discussion, however, let's assume that more appropriate evaluations have been performed and that we have the following estimates of total costs of disruption that can be prevented by an infrastructure corridor:

- Case 4 – $500 million
- Case 5 – $2,000 million
- Case 6 – $3,500 million

We would then need to assess these prospective benefits based on the frequencies of such cases. This requires more simplifying assumptions, in view of our limited information. But, to continue, let's assume that Case 4 is representative (say an average) of all 10-island cases, Case 5 of all 20-island cases and Case 6 of all 30-island cases. These benefits would need to be interpreted to calculate expected annual benefits. The seismic frequency information available is the following from Table 13-2 of the DRMS Phase 1 Report draft (URS/JBA, 2007b):

- 10 flooded islands – annual frequency of exceedance is 0.029
- 20 flooded islands – annual frequency of exceedance is 0.017
- 30 flooded islands – annual frequency of exceedance is 0.011

A very rough estimate of expected annual benefits due to avoided seismic disruption costs can be made by multiplying and summing as follows:

- (0.029-0.017) x $500 million = $6 million
- (0.017-0.011) x $2,000 million = $12.0 million
- (0.011) x $3,500 million = <u>$38.5 million</u>

Sum = $56.5 million

Similar analyses would be performed for disruption impacts (the secondary consequences of disruption). And similar cost and impact analyses would be performed for flood cases. In the DRMS Phase 1 report draft (URS/JBA, 2007b), the flood cases examined do not impact the islands addressed by the corridor, thus no costs or impacts are indicated. Other cases would need to be analyzed. In order to conclude that the infrastructure corridor was economically justified, we would need to perform a meticulous version of this analysis for seismic disruption costs with many more cases. A similar analysis of seismic disruption impacts would be required. And both costs and impacts of floods would need to be assessed so those avoided consequences could be recognized as well. Overall, the annual avoided seismic and flood costs and impacts would need to be assessed as equivalent to or exceeding the estimated annual costs of $181 million. The cost of the project (represented by the $181 million annual cost) should also be reviewed and refined. A more meticulous analysis is needed in order to conclude whether overall expected annual benefits exceed estimated annual costs. Such an analysis may be justified. It could be performed using the DRMS tools, given a sufficient budget and schedule.

2. Alternatives

EBMUD (2007) has considered a large collection of alternative approaches for reducing the risk of failure for the Mokelumne Aqueduct along its route across the Delta. Some 19 alternatives were considered. Those that were assessed to be the most favorable long-term options were:

- A tunnel beneath the Delta containing two new 87-inch steel pipes
- Elevate the pipelines above flood level on pipe supports and provide scour protection near all levees
- Place the pipelines on a berm (causeway)
- Place the pipelines on a bridge, including scour protection at all levees

Each of these alternatives was assessed as addressing all hazards, but the causeway and bridge were relatively expensive. The elevated pipelines alternative appeared to be competitive, but approximately 50% more costly than the tunnel. EBMUD concluded that the tunnel was the most attractive approach because it addressed all risks and had a relatively reasonable estimated cost ($445 to $950 million, or nominally $650 million). Thus, a tunnel beneath the Delta is presently EBMUD's preferred strategy for reducing Delta risks.

Of the infrastructure risks in the Delta, EBMUD's is one of the most significant. Their aqueduct is a vital link in their water supply system serving 1.2 million people. They have no backup supply for their service area, except for a few terminal reservoirs of quite limited capacity. Thus, they simply cannot tolerate an extended aqueduct outage. They do see funding of the tunnel as a major challenge.

3. Concluding Thoughts

Infrastructure risk reduction in the vicinity of Highway 4 will need to address the Mokelumne Aqueduct as a top priority because it is a vital water conveyance link with no adequate backup. Highway 4, the BNSF railway, the Kinder-Morgan pipeline, and the PG&E gas pipelines have various backup choices, although some are expensive. A more meticulous evaluation of avoided disruption costs and impacts is needed to better assess the viability of various infrastructure protection options. These potentially avoided disruptions need to include direct damage to infrastructure facilities (e.g., to the Mokelumne Aqueduct, the railroad, and Highway 4) and not just the damage caused by levee failures. Especially important is an assessment of potential disruptions to EBMUD users. Also, it is important to separate PG&E gas-related disruptions into those that an infrastructure corridor can protect versus those that are caused by damage outside the prospective corridor.

4. References

Branson, Jane, 2007. ***Context Memorandum: Utilities.*** Prepared by URS Corporation. Prepared for Delta Vision. June 22, 2007.

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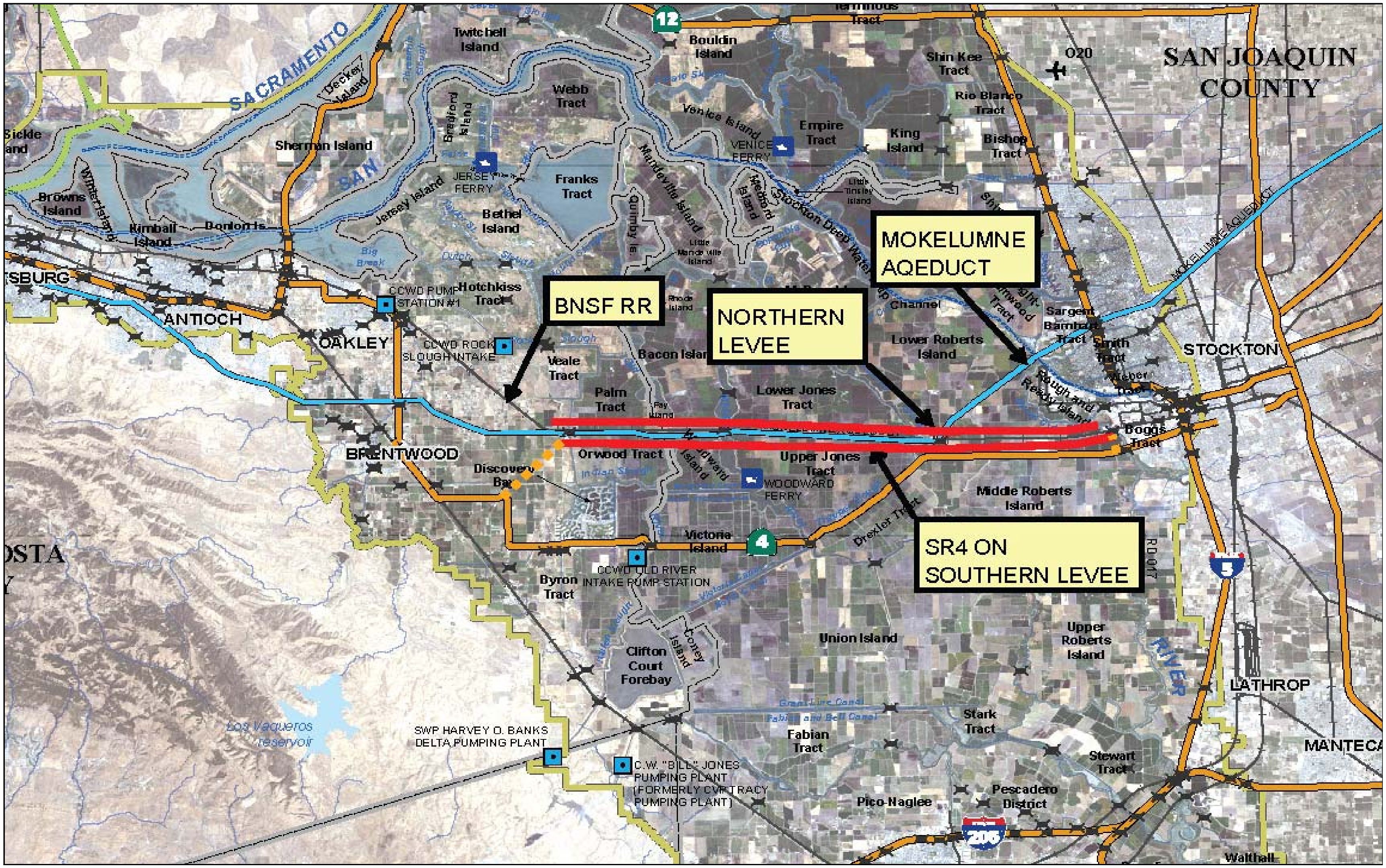
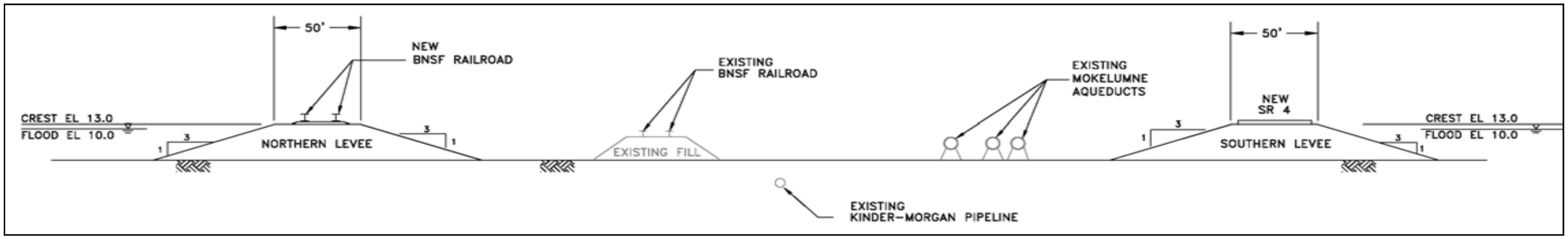
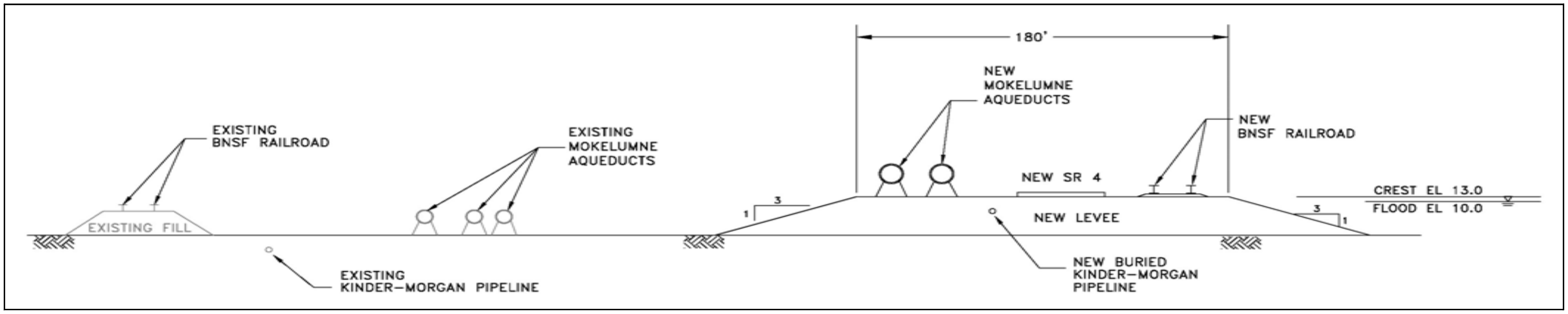


Figure D-1 Infrastructure Corridor (Plan)



TYPICAL SECTION – OPTION 1



TYPICAL SECTION – OPTION 2

Figure D-2 Infrastructure Corridor (Sections)

Appendix E

Incentives and Liabilities Relative to State Participation in Protection of Infrastructure Owned by Others

October 27, 2008

1. Introduction

This appendix explores participation of the state in projects that protect infrastructure systems owned and controlled by others. Both incentives for such participation and disincentives or potential liabilities regarding such participation are considered.

An incentive for such participation is the greater public good. For example, an infrastructure corridor (see Appendix D) might be developed that provides a high level of protection for several infrastructure owners and (in combination) avoids damage and disruption that justifies the project costs. In that case, the state may be the logical party to bring those parties together and facilitate the project. This is consistent with the idea that the state should work for the common good of its citizens.

Unfortunately, such projects often are not so straightforward. Cooperation is difficult. And, in projects that provide flood or earthquake protection, there is always residual risk. When something goes wrong, there is often finger pointing and this can be followed by lawsuits.

The legal concept that is most pertinent to this topic is “inverse condemnation.” The contention by the damaged party in such cases is that the government (in this case the state) has taken his rights to use his property – by physically encroaching on it, by excessively regulating it, or by damaging it (through specific action or inaction). In the case of a flood control project, the contention would be that the state caused or should have prevented a failure that led to flood damage, or that the project (as implemented) subjected the damaged party to a disproportionate risk.

The most relevant case on this topic is *Paterno v. the State of California* (the “Paterno Case”) that arose from the failure of the Linda Levee (a Sacramento River Flood Control Project Levee) on the Yuba River on February 20, 1986. Litigation was finally completed in 2005 after nineteen and one-half years of effort and the state was found to be liable. Per one of the plaintiff’s lawyers (Livaich, 2005) a key issue in this case was the finding that the levee that failed was not constructed to pertinent engineering standards necessary to achieve its intended performance and this had not been corrected even though there had been opportunity to do so during an earlier levee “rehabilitation.” Undoubtedly, other parties knowledgeable about the case would have other opinions and emphasize other issues.

2. Findings

Inquiries were made to DWR, CALFED, and the Public Utilities Commission (PUC) on this topic. The primary feedback was that public interest projects, particularly in damage prevention (like flood control) naturally have residual risk. When failures occur, there is potential for lawsuits and liability – especially in the legal environment following the Paterno decision. If a public agency is to perform its mission and its mission includes flood protection (as is the case with DWR), it must go ahead and perform projects to the best of its ability. If it considers involvement in protecting infrastructure owned, controlled, or operated by others, it should negotiate indemnity or hold harmless agreements first.

Infrastructure owners, such as public utilities and water agencies, need to recognize the risks associated with the location of their infrastructure. They need to have backup systems in place, if warranted. They also need to be financially responsible in supporting flood protection and recognize the need to insure for residual risk.

At least one entity appears to have interest in state assistance. EBMUD's tunnel conceptual design is expensive ($445 to $950 million, nominally $650 million). Comments from EBMUD personnel indicate that financing this project is viewed as challenging. Discussions that may lead to funding assistance from the state would probably be welcome. As part of an overall solution to the Delta challenges, there may be a state interest in cost sharing on large public infrastructure relocation efforts.

3. Reference

Livaich, 2005. Livaich, Gary. "Testimony to the Little Hoover Commission Hearing." Thursday, October 27, 2005, 9 a.m. Sacramento, California.