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ECONOMIC IMPACTS OF DELTA LEVEE FAILURE DUE TO CLIMATE CHANGE: A SCENARIO ANALYSIS

PIER PROJECT REPORT

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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Energy Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

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The California Climate Change Center (CCCC) is sponsored by the PIER program and coordinated by its Energy-Related Environmental Research area. The Center is managed by the California Energy Commission, Scripps Institution of Oceanography at the University of California at San Diego, and the University of California at Berkeley. The Scripps Institution of Oceanography conducts and administers research on climate change detection, analysis, and modeling; and the University of California at Berkeley conducts and administers research on economic analyses and policy issues. The Center also supports the Global Climate Change Grant Program, which offers competitive solicitations for climate research.

The California Climate Change Center Report Series details ongoing Center-sponsored research. As interim project results, these reports receive minimal editing, and the information contained in these reports may change; authors should be contacted for the most recent project results. By providing ready access to this timely research, the Center seeks to inform the public and expand dissemination of climate change information; thereby leveraging collaborative efforts and increasing the benefits of this research to California's citizens, environment, and economy.

The work described in this report was conducted under the Impacts of Bay Delta Levee Failure from Climate Change contract, contract 500-01-007, work authorization 138-P-05 by the University of California, Berkeley.

For more information on the PIER Program, please visit the Energy Commission's website www.energy.ca.gov/pier/ or contract the Energy Commission at (916) 654-5164.

Table of Contents

Executive Summary

Climate change induced sea level rise in association with storm events has been recognized as a potential threat for major Sacramento-San Joaquin Delta levee failure. Using estimates of hydrologic conditions associated with climate change under the Geophysics Fluid Dynamics Laboratory's (GFDL) model run under A2 emission scenario (GFDLA2), this study estimated the economic impacts to urban and agriculture users of major Delta pump outages caused by levee breaches.

The levee failure analysis considered three possible scenarios with regards to the year the failure could occur as relates to hydrologic conditions in the years following or preceding the failure: (1) levee failure before a drought, (2) level failure after a drought, and (3) levee failure during a wet period. The hydrologic conditions of these scenarios also include the adjustments related to the climate change conditions associated to simulate the joint impact of the failure and climate change on water supplies.

The analysis estimates the economic cost of levee failure to farmers in the Central Valley and cities in Southern California. To derive this cost, it was necessary to estimate (a) costs due to climate change and drought, and (b) costs due to levee failure plus climate change and drought. This study considered the costs of levee failure beyond those of climate change and drought.

Levee failure is expected to decrease water supplies from the state and federal projects, leading to land fallowing and declines in farm profitability and gross revenue. The impacts of levee failure are expected to last up to three years, which in some cases result in an extension of the length of the drought periods, from the point of view of urban consumers.

Levee failure in the after-drought scenario causes land fallowing of about 1 million acres in the San Joaquin Valley and a loss of farm profitability equal to $0.25 billion. Loss of farm revenue from that event equals $1.3 billion. Farm revenue is the gross return to the crop sales; farm profitability is the net return, equal to crop revenue less crop production costs. Failure in the wet scenario has slightly smaller impacts, leading to fallowing of 740 thousand acres and loss of about $170 million in farm profits. Levee failure in the before-drought scenario is least damaging, and results in fallowing of 700 thousand acres, and a decline in farm profits equal to $100 million. Farm revenue in the 1986 scenario declines about $700 million. This scenario is least damaging because supplies in this period were already limited by the drought so the net impact of levee failure is small.

Levee failure will restrict State Water Project (SWP) deliveries to Southern California and impose water shortage costs on residential users and other customer classes. Shortage costs include a loss of consumer surplus experienced by residents from a forced decline in water usage. The size of residential shortage costs in that region is dependent upon the source of other, non-SWP imported water supplies in Southern California. If non-SWP supplies are not vulnerable to levee failure (i.e., if they do not come directly or indirectly from the Delta) shortage costs are relatively small. In this case, the after-drought scenario results in $1.8 billion shortage costs to urban users. The before-drought scenario is more severe, and results in $4.1 billion shortage costs, but the 1983 scenario imposes no shortage costs at all. That is because in that year other water supplies not arriving from the Delta are assumed to be sufficient to supply residents in Southern California. However, when non SWP supplies are vulnerable to levee failure (e.g., if Southern California is dependent on large water transfers from the San Joaquin Valley), shortage costs may be immense. In this case, the after-drought levee failure scenario imposes $14 billion shortage costs on Southern California residents. The before-drought scenario causes $12 billion shortage costs, and the wet scenario results in costs of about $10 billion.

1.0 Introduction: Climate Change and Sacramento-San Joaquin Delta Levee Failure

The Sacramento-San Joaquin Delta can be considered the hub of California's water supply system. About two-thirds of Californians and 3.6 million acres of farmland rely on water from the Delta (Chung et al., in preparation). Despite its importance, the Delta itself is a fragile, hydraulically disconnected system of channels and islands. These channels and islands are protected by more than 1700 kilometers (km) (1100 miles) of levees which provide the necessary water quality standards at the south Delta pumping plants of the Central Valley Project, the State Water Project, and the Contra Costa Water District. Historic farming practices in the islands that form the Delta have caused a widespread subsidence and reduced the stability of Delta levees. In addition to these fragile conditions, the Delta levees face large failure risks associated with earthquakes and flood events.

A recent paper by Mount and Twiss (2005) estimated that there is a two-in-three chance that 100-year recurrence interval floods or earthquakes will cause catastrophic flooding and significant change in the Delta by 2050 (Mount and Twiss 2005). A significant factor contributing to this failure risk is the expected sea level rise associated with climate change conditions.[1] Mount and Twiss (2005) estimated that approximately 30% of the increase in levee failure risk by 2050 was associated with a scenario of sea level rise of between 2 and 3 mm/year (0.08 and 0.12 inches/year). Considering that this is a rather conservative estimate of sea level rise (Cayan et al. (2005), for example, show predictions ranging from 2 to 7 mm/year (0.08 and 0.28 inches/year) considering a series of Global Circulation Models and greenhouse gas emissions scenarios), it is clear that climate change poses a major threat of potential Delta levee failure. This threat has been recognized by the California legislature, which has required through AB 1200 to analyze the consequences of a major Delta levee failure caused by climate change:

> "This bill would require the Department of Water Resources to evaluate the potential impacts on water supplies derived from the Sacramento-San Joaquin Delta resulting from subsidence, earthquakes, floods, changes in precipitation, temperature, and ocean levels, and a combination of those impacts." (AB 1200)[2]

2.0 Economic Impacts of a Major Levee Outage Under a Climate Change Scenario

The consequences of a major levee outage that could happen under the events described by Mount and Twiss (2005) could be catastrophic. Depending on the number of levee breaches, pumping operations from the Tracy and Banks pumping plants could be halted due to high salinity concentrations at the pumps intakes. Jack R. Benjamin & Associates (2005) recently presented the results of a preliminary seismic risk analysis to

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[1] Rising sea levels increase the hydrostatic pressure on the face of the levees, increasing the risk of failure (see Mount and Twiss (2005) for more details).

[2] Assembly Bill 1200 (AB 1200, Laird, Chapter 573, Statutes of 2005).

estimate the effects of seismically initiated levee failures on Delta water quality and export and the economic consequences to the state. The methodology followed by Jack R. Benjamin & Associates (2005) included three major steps. The first created two levee failure scenarios (occurring hypothetically in July of 2002), one involving 30 levee breaches and the other involving 50 levee breaches.[3] Based on hydrodynamic simulations on the Delta under these two scenarios, Jack R. Benjamin & Associates (2005) estimated the amount of time the pumping plants needed to be shut due to water quality considerations. The second step of the methodology estimated the likely shortages (both magnitude and durations) resulting from these pumping disruptions, based on likely water district and project operator responses and available alternative water supplies. Finally, statewide economic impacts associated with these shortages were estimated for different regions in the state and for different types of users (urban and agricultural). The results of the analysis showed economic impacts to the state ranging from approximately $3 billion to $4.8 billion (for both urban and agricultural users) under the 30-breach scenario and from $7 billion to $10.7 billion under the 50-breach scenario. The results showed that the impacts for different users were dependant on the availability of alternative water supply resources. It was also recognized that the results were contingent on the month of failure occurrence (July in the analysis) and the hydrologic conditions for the year of analysis. The analysis did not consider any changes in re-operations of reservoirs such as Friant Dam.

The results presented by Benjamin & Associates (2005) were based on the assumption that the levee failure occurred due to seismic event in a particular month (July) and under the hydrologic conditions pertaining to the year 2002. They admit that the results could be very different if the failure occurred in a different month of the year or under different hydrologic conditions. Thus, it is of interest in this regard to predict the impact of levee failure under different hydrologic conditions, including different months, water years, and climate change scenarios.

This study predicts the economic impacts of a Delta levee failure caused by a major flood event under a range of hydrologic conditions coupled with a changing climate scenario.[4] The base case was water deliveries as predicted by the simulation (using CalSim-II) of the hydrologic conditions for the GFDL Global Circulation model run using A2 GHG emissions scenarios for the period 2070–2090 (see Vicuña 2006). On top of these hydrologic conditions, the research team created three scenarios under which Tracy and Banks pumping plants were shut down following the same closing schedule used by Jack R. Benjamin & Associates (2005) for their 50-levee breach scenario. This closing schedule was composed of 14 months of complete shutdown and 14 sequent months of partial shutdown (more lax in winter than in summer, due to water quality considerations). The three levee failure scenarios represent three possible dates of failure

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[3] The difference between the two scenarios was an upgrade of Sherman Island prior to the seismic event, which prevented 20 of the 50 breaches in the levee system.

[4] This is a hazard with high probability of occurrence, due to the increased failure potential associated with sea level rise, as explained before.

occurring in the midst of different hydrologic conditions. The first two dates, corresponding to March 1983 and February 1986[5] are associated with big storms events and represent the highest and second highest Delta inflow months over the 1970–1994 study period. Year 1983 occurs in the middle of a wet period and hence is called hereafter the "wet" scenario. On the other hand, 1986 is just before the 1987–1992 drought, and this scenario is called "before-drought." The last date, corresponding to January of 1978 occurs in a year with above-average precipitation (Sacramento Inflow to Shasta Reservoir is the fourth month in the record) and although not associated with a particular strong storm event is included to represent hydrologic conditions after the 1976–1977 drought ("after-drought" scenario).

The changes in deliveries from Central Valley Project (CVP) and State Water Project (SWP) South of the Delta are shown in Figures 1 and 2.[6] These figures show deliveries for the historic condition, climate change condition under GFDLA2, and deliveries for the climate change condition plus the three levee failure scenarios. As expected, the results show that the impacts of levee failure are contingent upon hydrologic conditions both prior to and after the failure. For example, if the failure occurs in the midst of wet years (wet scenario, yellow line in Figure 1 and 2) the system will deliver significant amounts of water in the first year of disruption, because local reservoirs will be full at that time and the system will quickly recover when the Delta pumps resume normal operations three years later. However if the failure occurs before or after a major

[5] These dates represent not the actual historic conditions but the historic conditions perturbed to represent climate change conditions for the period 2070–2099 under the GFDLA2 model run (see Vicuña 2006).

[6] As stated previously, this study assumed that the pumps' closing schedule will follow that used in the Jack R. Benjamin & Associates (2005) study. It is unclear, though, whether the hydrologic conditions of the years under consideration here will result in a different disruption pattern to achieve the necessary water quality levels to resume pumping operations. Some other considerations:

- Exchange Contractors in the Delta Mendota Pool are loosing water according to the results of the different scenarios (not shown). Considering their seniority in terms of water rights, it is most probable that Friant Dam will be operated under these conditions in order to meet Exchange contractors demands.
- In order to make some runs feasible, the research team had to relax Vernalis Adaptive Management Plan (VAMP) San Joaquin water quality constraints in the height of the pump closure. Under a scenario like this, it is unclear which will be the role of water quality constraints in the San Joaquin River.
- Net Delta outflow is higher under the levee failure scenarios (not shown). This was suggested by the study of Benjamin & Associates (2005) as a way to reduce the number of months to keep the pumps closed (as opposed to storing that water in reservoirs north of the Delta). Determining which is best strategy is something that requires more specific studies, which were outside the scope of this report.

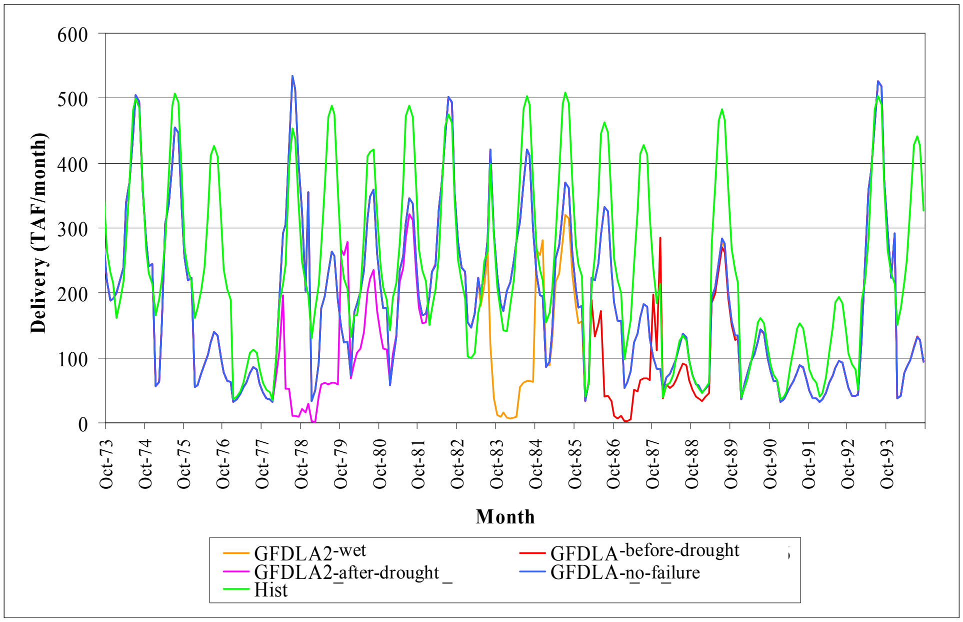

Figure 1. SWP South of Delta Deliveries under Base and Climate Change hydrologic conditions (GFDLA2 2070–2099), plus levee failures scenarios

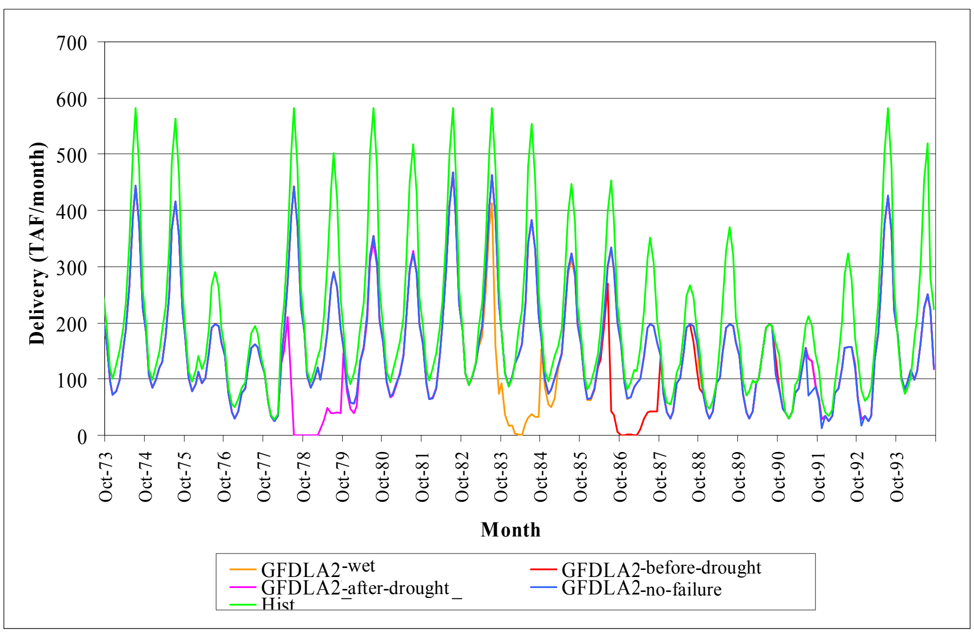

Figure 2. CVP South of Delta Deliveries under Base and Climate Change hydrologic conditions (GFDLA2 2070–2099), plus levee failures scenarios

drought (red line and magenta line respectively) the levee failure will effectively extend the drought's impact period an additional two or three years. Climate change also has the effect of extending drought's impact periods in the analysis. For example, the analysis of failure occurring in the before-drought scenario illustrates the combined impact of climate change, levee failure and subsequent drought. Climate change effectively extends the 1988–1992 drought's impacts one year; levee failure, plus climate change extends the drought's impacts two years. The coupled effect of climate change and failure is to extend a four-year drought, one of the longest droughts on record, into a six-year drought-like period. Similarly, climate change, coupled with levee failure in the "after-drought" scenario, extends the single-year worst drought on record in California now into a drought-like period that lasts for four years.

This study estimated the economic impacts associated with the levee failure scenarios using the results from the CalSim-II water model on predicted changes in project deliveries to agricultural and urban users south of the Delta. The Central Valley Production Model (CVPM) was used to estimate economic impacts to agriculture, and the urban shortage cost methodology to estimate economic impacts to urban users (see details of the methodology on Hanemann et al. 2006).

For the agriculture sector, the first estimates focused on the impacts associated with the climate change hydrologic conditions for three periods of analysis: 1976–1980, 1983–1985, and 1986–1992. The first and last periods include major historic droughts (1976–1977 and 1987–1992); the second period is relatively wet. Reservoir inflows in all three periods were altered, to reflect changes in climate and associated hydrologic conditions over the next century.

The results in Table 1 indicate the combined impact of climate change and levee failure on crop acres, net revenue, and gross revenue. Compared to critical historic hydrologic conditions, climate change causes a significant drop in crop acres, especially during the 1976–1980 and 1986–1992 periods. Crop acres decline 13% below baseline in the 1976–1980 period and 20% below the baseline in the 1986 and 1992 period. Net revenues also drop significantly in these periods: $1.8 billion (12% of baseline) for the 1976–1980 period, and $2.6 billion (14% of baseline) for the 1986–1992 period.[7]

Now when these climate change scenarios are coupled to the levee failure scenarios, we see (in columns 6–9 of Table 1) an even higher drop in the number of acres planted and in revenues perceived by farmers. Net revenues fall now $2 billion (13%) for the 1976–1980 period (an increase in 14% as compared to the no-levee-failure scenario), $0.7 billion (8%) for the period 1983–1985 (an increase of 29%), and $2.7 billion (15%) for the

[7] Using average agricultural production multiplier of 2.1, the decline in farm revenue causes gross state revenue to decline $3.8 billion and $5.5 billion over the two drought periods.

Table 1. Impacts to California Agriculture sector of the compounding effects of climate change and a Delta levee failure

Period	Region	Climate Change Conditions: Drop in Acreage (thousand acres)	Climate Change Conditions: Drop in Net Revenues (thousand $)	Climate Change Conditions: Drop in Gross revenues (thousand $)	Climate Change Conditions plus Levee Failure scenarios: Drop in Acreage (thousand acres)	Climate Change Conditions plus Levee Failure scenarios: Drop in Net Revenues (thousand $)	Climate Change Conditions plus Levee Failure scenarios: Drop in Gross revenues (thousand $)	Levee Failure scenario
1976-1980	SAC	803	133,096	680,897	806	118,691	680,599	**After drought**
	SJQ	1,342	745,210	2,481,399	1,877	900,180	3,163,925	
	TUL	1,957	909,289	3,408,637	2,356	1,014,109	4,069,434	
	TOTAL	***4,102***	***1,787,595***	***6,570,933***	***5,039***	***2,032,981***	***7,913,959***	
1983-1985	SAC	386	78,105	286,650	391	66,691	283,914	**Wet**
	SJQ	301	153,539	342,350	700	257,689	823,740	
	TUL	775	345,342	1,159,110	1,108	420,164	1,634,452	
	TOTAL	***1,461***	***576,986***	***1,788,110***	***2,199***	***744,544***	***2,742,106***	
1986-1992	SAC	1,790	232,585	1,214,524	1,773	225,786	1,219,331	**Before drought**
	SJQ	2,551	850,587	2,709,034	2,853	922,979	3,067,951	
	TUL	3,533	1,537,625	5,808,580	3,809	1,581,617	6,130,441	
	TOTAL	***7,875***	***2,620,797***	***9,732,139***	***8,434***	***2,730,381***	***10,417,723***	

period 1986–1992 (an increase of 4%).[8]

The hydrologic conditions at the time of the failure help determine the overall effect of the levee failure. For example the period 1986–1987 is a relatively wet period with large water supplies in all regions. These relatively high supplies counterbalance the effect of reduced SWP/CVP deliveries resulting from levee failure during those years. On the other hand non project sources are not sufficient to offset the effects of a levee failure occurring in 1978, so the effects are much larger in that scenario year.In addition to estimating impacts to the agriculture sector, this study estimated the economic impacts of reducing SWP deliveries to the Southern California Region.[9] Following the approach developed in Hanemann et al. (2006*)* the research team first estimated the changes in water supplies to the Southern California Region for each of the levee failure scenarios. Part of that approach consists of determining the quantity of new base water supplies needed to satisfy increasing demands due to urban population growth and offset decreases in average supplies due to climate change. The impact of levee failure is dependent upon the sensitivity of these new base water supplies to changes in the climate and to the failure itself.

To illustrate this dependence, the research team first assumed, following Hanemann et al. (2006*)*, that half of the necessary new water supplies are independent of changes in the climate (e.g., desalinization and recycling) and half vary with changes in the climate, as measured by the variability of State Water Project (SWP) and Los Angeles Aqueduct (LAA) supplies. Significantly, the research team also assumed that these new supplies are not affected by the levee failure. Following this assumption, it was found that failure during a wet period is less costly than in other years, because high SWP deliveries in wet years counterbalance the effect of the levee disruption. Similarly, a failure after a drought period is more costly than otherwise, since the failure effectively extends the drought's impacts at such times. However, at no time does levee failure cause massive damages under this assumption.

Next, the research team assumed that half of new supplies were independent of changes in the climate and half of new supplies were subject to disruption from levee failure in addition to drought and climate (as above). An example of this type of supply is a water transfer from agricultural users of Central Valley project water in the San Joaquin Valley, which will be also facing shortages in their supplies due to levee failure disruptions, and therefore might be reluctant to transfer that water south. Both supply cases are considered in the results below. The final result should fall in between these cases. Future work will include a sensitivity analysis of this and other assumptions made in this study.

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[8] Using average agricultural production multiplier of 2.1, the decline in farm revenue causes gross state revenue to decline \$4.2 billion and \$3.7 billion over the two drought periods and \$1.5 billion for the wet period.

[9] This report does not examine the economic costs associated with levee failures to the San Francisco Bay urban region.

Tables 2 and 3 present water shortages associated with both water supply cases for the climate change and the climate change plus levee failure scenarios.[10] When new water supplies are not affected by a failure occurring in the after-drought scenario (1978), shortages exceeding the 5% threshold occur in the year that follows the drought (Table 2). Similarly, the before-drought scenario (1986) increases subsequent water shortages from 9.1% to 18.9%. On the other hand, a disruption in wet scenario (1983) causes no shortages, because supplies from other sources (column 6 in Table 2) counterbalance the effects of the levee failure. In no years following this levee failure scenario do shortages exceed the 5% threshold.

When new water supplies are affected by the failure (Table 3), the after-drought scenario for levee failure creates shortages in subsequent years that fall below the 5% shortage threshold. The wet scenario leads to large shortages in the following year. Finally, the levee failure occurring in the before-drought scenario increases the water supply shortage in the following year from 9.1% to 30.8%.

Tables 4 and 5 show the economic loss associated with the levee failure disruption scenarios.[11] Table 4 show results when Southern California's non-SWP supplies are not affected by the levee failure. Under this scenario, the after-drought scenario imposes a loss of consumer surplus worth about $1.8 billion and a before-drought scenario lowers consumer surplus around $4 billion. Levee failure in the wet scenario has no economic costs.

Table 5 shows results when levee failure affects Southern California's non-SWP water supplies. In this case the results show shortage costs of around $14 billion associated with the after-drought failure scenario, $10 billion associated with the wet scenario, and $12 billion associated with the before-drought levee failure scenario.

Is important to mention that in the case of the two levee failure scenarios happening close to drought periods, the costs reported above need to be viewed in conjunction with the already elevated costs associated with the drought episodes themselves: $12 billion for the 1976–1977 drought and $31 billion for the 1988–1992 drought (see Tables C and D in Appendix A and Hanemann et al. 2006).

[10] Extended, more detailed versions of these tables are shown in Appendix A.

[11] Extended, more detailed versions of these tables are shown in Appendix A.

Table 2. Impact on urban supplies deliveries, new supplies not affected by levee disruption

LEVEE FAILURE EVENT	"YEAR"	2000 SOURCES OF SUPPLY: NO CLIMATE CHANGE ('000 AF)	2070-2099 CLIMATE ('000 AF)	2070-2099 CLIMATE + LEVEE FAILURE ('000 AF)		NEW SUPPLIES ('000 AF): CLIMATE SENSITIVE	NON-CLIMATE SENSITIVE	TOTAL SUPPLY ('000 AF)	SUPPLY AS % OF 6.8 MAF
		TOTAL	TOTAL	LEVEE FAILURE (4)	TOTAL				
(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)	(9)
After drought	1978	3,972	4,341	-922	3,419	1,987	1,514	6,920	101.8%
	1979	4,346	4,091	-1,047	3,044	1,685	1,514	6,243	91.8%
Wet	1984	4,412	4,513	-1,440	3,073	2,194	1,514	6,781	99.7%
Before drought	1987	4,352	3,589	-669	2,920	1,080	1,514	5,514	81.1%

Note: AF = acre feet

Table 3. Impact on urban supplies deliveries, new supplies affected by levee disruption

LEVEE FAILURE EVENT	"YEAR"	2000 SOURCES OF SUPPLY: NO CLIMATE CHANGE ('000 AF)	2070-2099 CLIMATE ('000 AF)	2070-2099 CLIMATE + LEVEE FAILURE ('000 AF)		NEW SUPPLIES ('000 AF): SWP+LAA SENSITIVE	NON-SWP+LAA SENSITIVE	TOTAL SUPPLY ('000 AF)	SUPPLY AS % OF 6.8 MAF
		TOTAL	TOTAL	LEVEE FAILURE (4)	TOTAL				
(1)	(2)	(3)	(4)		(5)	(6)	(7)	(8)	(9)
After drought	1978	3,972	4,341	-922	3,419	875	1,514	5,808	85.4%
	1979	4,346	4,091	-1,047	3,044	423	1,514	4,981	73.3%
Wet	1984	4,412	4,513	-1,440	3,073	458	1,514	5,045	74.2%
Before drought	1987	4,352	3,589	-669	2,920	274	1,514	4,708	69.2%

Note: AF = acre feet

Table 4. Economic cost of levee failure disruption in urban water supply, new supplies not affected by levee failure

LEVEE FAILURE EVENT	"YEAR"	HISTORIC CONDITIONS	CLIMATE CHANGE CONDITIONS		CLIMATE CHANGE PLUS LEVEE FAILURE			
		OVERALL SYSTEM SHORTAGE (%)	OVERALL SYSTEM SHORTAGE (%)	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	NET LOSS OF CONSUMER'S SURPLUS $ million
After drought	1978	No Shortage	No Shortage	$0	No Shortage	0.0%	$0	$0
	1979	No Shortage	No Shortage	$0	8.2%	12.2%	$1,831	$1,831
Wet	1984	No Shortage	No Shortage	$0	No Shortage	0.0%	$0	$0
Before drought	1987	No Shortage	9.1%	$2,146	18.9%	25.6%	$6,211	$4,065

Table 5. Economic cost of levee failure disruption in urban water supply, new supplies affected by levee failure

LEVEE FAILURE EVENT	"YEAR"	HISTORIC CONDITIONS	CLIMATE CHANGE CONDITIONS		CLIMATE CHANGE PLUS LEVEE FAILURE			
		OVERALL SYSTEM SHORTAGE (%)	OVERALL SYSTEM SHORTAGE (%)	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	NET LOSS OF CONSUMER'S SURPLUS $ million
After drought	1978	No Shortage	No Shortage	$0	14.6%	19.2%	$3,820	$3,820
	1979	No Shortage	No Shortage	$0	26.7%	34.8%	$10,626	$10,626
Wet	1984	No Shortage	No Shortage	$0	25.8%	33.4%	$9,879	$9,879
Before drought	1987	No Shortage	9.1%	$2,146	30.8%	40.8%	$14,098	$11,952

3.0 Conclusions

Climate change induced sea level rise in association with storm events has been recognized as a potential threat for major Sacramento-San Joaquin Delta levees' failure. Using estimates of hydrologic conditions associated with climate change under the GFDLA2 climate change scenario, this study estimated the economic impacts to urban and agriculture users of major Delta pump outages caused by levee breaches.

This analysis considered three possible scenarios on the timing of the levee failure in order to understand how different hydrologic conditions occurring before and after the outages might affect the results. Two of the scenarios considered a failure occurring close to major drought events. A third scenario considered the failure happening during a relatively wet span of years.

The results show economic impacts to the agriculture sector between $100 million and $250 million summed over the years that were impacted by a modeled levee failure. In terms of urban sector impacts, the economic costs associated with levee failure depend upon the independence of new Southern California base supplies from levee failure disruptions. In case these supplies are independent of the Delta, the economic costs are $1.8 billion and $4 billion for the after-drought and before-drought failure scenarios, respectively. The hydrologic conditions associated with the wet scenario are wet enough to counterbalance the effect of a levee failure disruption occurring in that year, and as result urban users would not face supplies shortages. If levee failures were to affect these new supplies, the economic costs associated with the levee failure scenarios would be $14 billion, $10 billion, and $12 billion for the after-drought, wet, and before-drought failure scenarios, respectively.

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Appendix A. Impacts of Levee Disruption on Urban Water Supply Deliveries

TABLE A. IMPACT ON URBAN SUPPLIES DELIVERIES, NEW SUPPLIES NOT AFFECTED BY LEVEE DISRUPTION

LEVEE FAILURE EVENT	2000 SOURCES OF SUPPLY NO CLIMATE CHANGE ('000 AF) "YEAR"				SUPPLY AS % OF 4.2 MAF	2000 SOURCES OF SUPPLY 2070-2099 CLIMATE (('000 AF)			2000 SOURCES OF SUPPLY 2070-2099 CLIMATE + LEVEE FAILURE (('000 AF)				SUPPLY REDUCTION ('000 AF)	NEW SUPPLIES ('000 AF)		TOTAL SUPPLY ('000 AF)	SUPPLY AS % OF 6.8 MAF	SUPPLY AS % OF 6.8 MAF NO LEVEE FAILURE
		SWP & LAA	OTHER	TOTAL		SWP & LAA	OTHER	TOTAL	LEVEE FAILURE DISRUPTION	SWP & LAA	OTHER	TOTAL		CLIMATE SENSITIVE	NON-CLIMATE SENSITIVE			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	1976	1,728	2,693	4,421	105.3%	851	2,693	3,545		851	2,693	3,545	-876	1,026	1,514	6,085	89.5%	89.5%
	1977	766	2,693	3,459	82.4%	372	2,693	3,065		372	2,693	3,065	-394	449	1,514	5,028	73.9%	73.9%
After drought	1978	1,278	2,693	3,972	94.6%	1,648	2,693	4,341	-922	726	2,693	3,419	-552	1,987	1,514	6,920	101.8%	115.3%
	1979	1,652	2,693	4,346	103.5%	1,398	2,693	4,091	-1,047	351	2,693	3,044	-1,301	1,685	1,514	6,243	91.8%	107.2%
	1980	1,614	2,693	4,307	102.6%	1,466	2,693	4,159	-226	1,240	2,693	3,934	-374	1,768	1,514	7,215	106.1%	109.4%
Wet	1983	1,469	2,693	4,162	99.1%	1,793	2,693	4,486	-170	1,623	2,693	4,316	154	2,161	1,514	7,991	117.5%	120.0%
	1984	1,718	2,693	4,412	105.0%	1,820	2,693	4,513	-1,440	380	2,693	3,073	-1,338	2,194	1,514	6,781	99.7%	120.9%
	1985	1,827	2,693	4,521	107.6%	1,473	2,693	4,166	-315	1,158	2,693	3,851	-669	1,776	1,514	7,141	105.0%	109.6%
Before drought	1986	1,739	2,693	4,433	105.5%	1,435	2,693	4,128	-399	1,036	2,693	3,729	-703	1,730	1,514	6,973	102.5%	108.4%
	1987	1,659	2,693	4,352	103.6%	896	2,693	3,589	-669	227	2,693	2,920	-1,432	1,080	1,514	5,514	81.1%	90.9%
	1988	864	2,693	3,558	84.7%	616	2,693	3,309		616	2,693	3,309	-249	742	1,514	5,565	81.8%	81.8%
	1989	1,384	2,693	4,077	97.1%	894	2,693	3,587		894	2,693	3,587	-490	1,078	1,514	6,179	90.9%	90.9%
	1990	980	2,693	3,673	87.4%	702	2,693	3,395		702	2,693	3,395	-278	846	1,514	5,754	84.6%	84.6%
	1991	661	2,693	3,354	79.9%	424	2,693	3,117		424	2,693	3,117	-237	511	1,514	5,142	75.6%	75.6%
	1992	747	2,693	3,440	81.9%	375	2,693	3,068		375	2,693	3,068	-373	452	1,514	5,033	74.0%	74.0%

TABLE B. IMPACT ON URBAN SUPPLIES DELIVERIES, NEW SUPPLIES AFFECTED BY LEVEE DISRUPTION

LEVEE FAILURE EVENT	2000 SOURCES OF SUPPLY NO CLIMATE CHANGE ('000 AF) "YEAR"				SUPPLY AS % OF 4.2 MAF	2000 SOURCES OF SUPPLY 2070-2099 CLIMATE (('000 AF)			2000 SOURCES OF SUPPLY 2070-2099 CLIMATE + LEVEE FAILURE (('000 AF)				SUPPLY REDUCTION ('000 AF)	NEW SUPPLIES ('000 AF)		TOTAL SUPPLY ('000 AF)	SUPPLY AS % OF 6.8 MAF	SUPPLY AS % OF 6.8 MAF NO LEVEE FAILURE
		SWP & LAA	OTHER	TOTAL		SWP & LAA	OTHER	TOTAL	LEVEE FAILURE DISRUPTION	SWP & LAA	OTHER	TOTAL		SWP+LAA SENSITIVE	NON-SWP+LAA SENSITIVE			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
	1976	1,728	2,693	4,421	105.3%	851	2,693	3,545		851	2,693	3,545	-876	1,026	1,514	6,085	89.5%	89.5%
	1977	766	2,693	3,459	82.4%	372	2,693	3,065		372	2,693	3,065	-394	449	1,514	5,028	73.9%	73.9%
After drought	1978	1,278	2,693	3,972	94.6%	1,648	2,693	4,341	-922	726	2,693	3,419	-552	875	1,514	5,808	85.4%	115.3%
	1979	1,652	2,693	4,346	103.5%	1,398	2,693	4,091	-1,047	351	2,693	3,044	-1,301	423	1,514	4,981	73.3%	107.2%
	1980	1,614	2,693	4,307	102.6%	1,466	2,693	4,159	-226	1,240	2,693	3,934	-374	1,495	1,514	6,943	102.1%	109.4%
Wet	1983	1,469	2,693	4,162	99.1%	1,793	2,693	4,486	-170	1,623	2,693	4,316	154	1,956	1,514	7,786	114.5%	120.0%
	1984	1,718	2,693	4,412	105.0%	1,820	2,693	4,513	-1,440	380	2,693	3,073	-1,338	458	1,514	5,045	74.2%	120.9%
	1985	1,827	2,693	4,521	107.6%	1,473	2,693	4,166	-315	1,158	2,693	3,851	-669	1,396	1,514	6,761	99.4%	109.6%
Before drought	1986	1,739	2,693	4,433	105.5%	1,435	2,693	4,128	-399	1,036	2,693	3,729	-703	1,249	1,514	6,492	95.5%	108.4%
	1987	1,659	2,693	4,352	103.6%	896	2,693	3,589	-669	227	2,693	2,920	-1,432	274	1,514	4,708	69.2%	90.9%
	1988	864	2,693	3,558	84.7%	616	2,693	3,309		616	2,693	3,309	-249	742	1,514	5,565	81.8%	81.8%
	1989	1,384	2,693	4,077	97.1%	894	2,693	3,587		894	2,693	3,587	-490	1,078	1,514	6,179	90.9%	90.9%
	1990	980	2,693	3,673	87.4%	702	2,693	3,395		702	2,693	3,395	-278	846	1,514	5,754	84.6%	84.6%
	1991	661	2,693	3,354	79.9%	424	2,693	3,117		424	2,693	3,117	-237	511	1,514	5,142	75.6%	75.6%
	1992	747	2,693	3,440	81.9%	375	2,693	3,068		375	2,693	3,068	-373	452	1,514	5,033	74.0%	74.0%

TABLE C. ECONOMIC COST OF LEVEE FAILURE DISRUPTION IN URBAN WATER SUPPLY, NEW SUPPLIES NOT AFFECTED BY LEVEE FAILURE

		HISTORIC CONDITIONS			**CLIMATE CHANGE CONDITIONS**			**CLIMATE CHANGE PLUS LEVEE FAILURE**			
LEVEE FAILURE EVENT	"YEAR"	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	NET LOSS OF CONSUMER'S SURPLUS $ million
	1976	No Shortage	0.0%	$0	10.5%	13.2%	$2,078	10.5%	13.2%	$2,078	$0
	1977	17.6%	21.3%	$4,545	26.1%	33.8%	$10,081	26.1%	33.8%	$10,081	$0
After drought	1978	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1979	No Shortage	0.0%	$0	No Shortage	0.0%	$0	8.2%	12.2%	$1,831	$1,831
	1980	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
Wet	1983	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1984	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1985	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
Before drought	1986	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1987	No Shortage	0.0%	$0	9.1%	13.5%	$2,146	18.9%	25.6%	$6,211	$4,065
	1988	15.3%	20.3%	$4,172	18.2%	24.5%	$5,758	18.2%	24.5%	$5,758	$0
	1989	No Shortage	0.0%	$0	9.1%	13.6%	$2,171	9.1%	13.6%	$2,171	$0
	1990	12.6%	16.2%	$2,887	15.4%	20.4%	$4,215	15.4%	20.4%	$4,215	$0
	1991	20.1%	25.0%	$5,962	24.4%	31.3%	$8,803	24.4%	31.3%	$8,803	$0
	1992	18.1%	22.0%	$4,784	26.0%	33.7%	$10,015	26.0%	33.7%	$10,015	$0

TABLE D. ECONOMIC COST OF LEVEE FAILURE DISRUPTION IN URBAN WATER SUPPLY, NEW SUPPLIES AFFECTED BY LEVEE FAILURE

		HISTORIC CONDITIONS			**CLIMATE CHANGE CONDITIONS**			**CLIMATE CHANGE PLUS LEVEE FAILURE**			
LEVEE FAILURE EVENT	"YEAR"	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	OVERALL SYSTEM SHORTAGE (%)	% SHORTAGE FOR RESIDENTIAL USERS	LOSS OF CONSUMER'S SURPLUS $ million	NET LOSS OF CONSUMER'S SURPLUS $ million
	1976	No Shortage	0.0%	$0	10.5%	13.2%	$2,078	10.5%	13.2%	$2,078	$0
	1977	17.6%	21.3%	$4,545	26.1%	33.8%	$10,081	26.1%	33.8%	$10,081	$0
After drought	1978	No Shortage	0.0%	$0	No Shortage	0.0%	$0	14.6%	19.2%	$3,820	$3,820
	1979	No Shortage	0.0%	$0	No Shortage	0.0%	$0	26.7%	34.8%	$10,626	$10,626
	1980	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
Wet	1983	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1984	No Shortage	0.0%	$0	No Shortage	0.0%	$0	25.8%	33.4%	$9,879	$9,879
	1985	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
Before drought	1986	No Shortage	0.0%	$0	No Shortage	0.0%	$0	No Shortage	0.0%	$0	$0
	1987	No Shortage	0.0%	$0	9.1%	13.5%	$2,146	30.8%	40.8%	$14,098	$11,952
	1988	15.3%	20.3%	$4,172	18.2%	24.5%	$5,758	18.2%	24.5%	$5,758	$0
	1989	No Shortage	0.0%	$0	9.1%	13.6%	$2,171	9.1%	13.6%	$2,171	$0
	1990	12.6%	16.2%	$2,887	15.4%	20.4%	$4,215	15.4%	20.4%	$4,215	$0
	1991	20.1%	25.0%	$5,962	24.4%	31.3%	$8,803	24.4%	31.3%	$8,803	$0
	1992	18.1%	22.0%	$4,784	26.0%	33.7%	$10,015	26.0%	33.7%	$10,015	$0