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Introduction

Large-scale water problems of the nature discussed in this book are inherently difficult to solve. Water distribution and use decisions must be made within a complex system with economic, political, engineering, legal, and ecological dimensions. Any policy choice will impact all of these dimensions. Two critical tasks in the resolution of such debates are to characterize these multi-dimensional impacts for each potential solution and to identify instruments capable of implementing particular choices. Because of the system's complexity, however, it is virtually inevitable that stakeholders' interests will conflict under any chosen policy path. These conflicts would be relatively manageable in a world in which (a) property rights were fully defined, (b) benchmarks were available and generally accepted as bases for interpersonal welfare comparisons, and (c) interpersonal compensation was feasible. In such a world, the logical approach would be to choose the policy that maximized aggregate welfare, thus ensuring economically efficient outcomes. The winners could then compensate the losers to guarantee that all stakeholders ended up better off thus ensuring that all equity effects are incorporated into the outcome.

In water allocation problems, typically, none of the conditions listed above will be satisfied, which makes it very difficult to identify a single, social welfare-maximizing solution. There is almost always ambiguity about what property rights exist and who holds them. For instance, environmental and agricultural stakeholders often value objectives like "eco-system health" or (the) "agricultural way of life." It is difficult to assign a precise property right to these diffuse objectives. Moreover, many of the scarce resources at issue in water debates—especially those relating to the environment and "ways of life"—are non-market goods. Because they are not traded, there is no market price that can provide a basis for welfare comparisons.1 Finally, to the extent that a property right can be defined, it is often unclear who holds that right. For example, the Endangered Species Act (ESA) could perhaps be interpreted as endowing each endangered species with a property right to survival. Obviously, however, one cannot compensate a species for its extinction.

Without some degree of consensus about how to weigh competing interests, expert assessments of the policy route that most equitably balances these interests are bound to be challenged by stakeholders, whose subjective views about the appropriateness of any given inter-stakeholder tradeoff will surely be wildly divergent. In such contexts, political factors will play a particularly important role in shaping the ultimate policy outcome. In order to understand the political process from which a solution may emerge, it will be helpful to analyze the relative impacts of alternative policies on each stakeholder group. A policy option that is ranked reasonably highly by all stakeholders may provide a natural starting point from which to construct a politically viable way forward, even if it is not economically efficient.

In this paper, we conduct an analysis along these lines of the political debate over the future of California's Sacramento-San Joaquin Delta (hereafter, "the Delta"). The Delta serves a critical role in the state's water distribution system. Water that flows through the Delta provides drinking water to two-thirds of the state's residents and irrigation water for nearly 2.5 million acres of some of the most productive agricultural land in the world. The Delta also occupies a unique and important ecological niche. It is part of the largest estuary on the west coast of North America and is home to 55 species of fish and 750 species of plants and wildlife (Isenberg et al 2008, pg. v).

Today, it is widely acknowledged that the Delta is in crisis. While many of the concerns expressed regarding the Delta are familiar to long-time observers of California water policy, we do not attempt here to provide a history of the evolution of California water policy. Today, there is a remarkable degree of consensus that the Delta's condition is ever-worsening, and that now is a critical time for action. The Delta's ecosystem is changing, and as a result it is failing to provide some of the ecological functions it has performed in the recent past. Due at least in part to this failure, several species are on the verge of extinction. Moreover, its infrastructure is highly vulnerable to floods and earthquakes. Since 2007, at least five major reports have been released detailing alternative management strategies and providing policy recommendations. In 2006, Governor Schwarzenegger signed an executive order creating several entities tasked with studying the Delta's problems and recommending a solution. The entire initiative is known as Delta Vision. The Vision process seeks to meet two objectives that it terms "co-equal" goals: "environmental quality of the Delta" and "the economic and social well being of the people of the state" (Blue Ribbon Task Force, 2007).Two key entities are the Blue Ribbon Task Force and the Delta Vision Committee. The Blue Ribbon Task Force is an independent group of experts from a variety of backgrounds charged with examining a broad variety of possible solutions and recommending a strategic direction. The Delta Vision Committee consists of five members of the governor's cabinet whose responsibility is to review the Task Force's work and make final recommendations. The Task Force released a report outlining its objectives, "Delta Vision" in late 2007 (Blue Ribbon Task Force, 2007, hereafter "Delta Vision") and its final report, "Delta Vision Strategic Plan" at the end of October 2008 (Blue Ribbon Task Force 2008, hereafter "Strategic Plan") and the Delta Vision Committee released its recommendations for implementation about two months later (Delta Vision Committee 2008, hereafter "Implementation Report").

In addition to the work initiated by the governor, several independent organizations have issued substantial reports on policy options for the Delta. Through the Public Policy Institute of California (PPIC), a multidisciplinary group of researchers has released two reports on the Delta (Lund, et al. 2008, hereafter "PPIC Report"; Lund, et al. 2007). Immediately following the publication of the PPIC Report, the Pacific Institute and the Environmental Defense Fund (EDF) each issued their own analyses (Cooley, Christian-Smith and Gleick 2008; Koehler, et al. 2008). Each of these reports evaluates a variety of policy options for the Delta's future. Most of them provide specific policy recommendations.

Finally, in response to the Delta's failing ecosystem, a number of state, federal, local and private agencies have joined forces to create what will be known as the "Bay Delta Conservation Plan" (BDCP).2 This group has released several documents (BDCP 2007; 2008b; 2009). In the words of one of these documents, "The purpose of the Bay Delta Conservation Plan (BDCP) is to help recover endangered and sensitive species and their habitats in the Delta in a way that also will provide for sufficient and reliable water supplies" (BDCP 2008b).

In this chapter, we use these analyses as a starting point to investigate the political dimensions of the debate over policy alternatives. Our goal is to evaluate their political consequences in a comprehensive framework capable of identifying politically feasible solutions to the Delta crisis. The framework incorporates key physical and biological relationships that determine stakeholder groups' welfare under each possible solution. An analysis focused on identifying economically efficient outcomes would attempt to monetize these welfare measures to permit the construction of a social welfare function. In contrast, our focus is on identifying politically feasible solutions. Since economic efficiency does not guarantee political feasibility, we assess the feasibility of an alternative directly from its impact on the welfare of each stakeholder group. Because we do not evaluate the economic efficiency of the alternatives, we are not required to take the controversial step of monetizing different objectives. Instead, we offer a discussion of what alternatives are likely to be politically feasible given the identified impacts on the stakeholder groups.

In Section 2, we provide a description of the Delta's role in the state's water system, a description of the current pressures facing the Delta, and a discussion about the political debate over the region's future. In Section 3, we construct a stylized model of the major policy decisions and their impacts on several key stakeholders. In Section 4, we use that model to discuss the political feasibility of the policy alternatives currently under consideration. In the final section, we offer concluding comments, including a discussion of further uses of the model developed within this chapter.

The Sacramento-San Joaquin Delta

Water has been a critical issue in California since the first days of its development. One of the state's most striking geographical features is the immense Central Valley in its middle. This 42,000 square mile region comprises approximately 40% of the state's area (Umbach 1997) and is drained by two large river systems: the Sacramento River in the northern half and the San Joaquin River in the southern half. These rivers meet east of the Coastal Range in the Delta.3 (See Figure 1 for a stylized map of the Delta region.) Under natural conditions, water from both the Sacramento and San Joaquin Rivers flows through the Delta to Suisun Bay, and on to San Francisco Bay and then the Pacific Ocean. In an average year, absent water diversions, the Sacramento and San Joaquin River systems would transport approximately 30 million acre feet (maf) of water to the Pacific Ocean.

An important consequence of the state's climate is that water supply is highly variable, both within a given year and across years. In an average year, after accounting for rainfall used directly by crops and other vegetation before entering the water supply, evaporation and flows to the ocean and other salt sinks, precipitation and imports from neighboring states, most importantly from the Colorado River, provide approximately 80 maf of water available to meet California's specific water demands. In a dry year that number could shrink to approximately 65 maf, while in an unusually wet year it could be as high as 95 maf (Department of Water Resources 2005). Typically, the state receives most of its precipitation during the winter and little to none over the hot, dry summers. Much of the winter precipitation falls as snow in the Sierras.

Since the Delta drains nearly half of the state's annual precipitation, this variability has important consequences for the Delta's natural ecosystem. Historically, under natural flow regimes, conditions in the Delta varied substantially with variations in water flows. In the spring, as the snow pack melted, huge quantities of fresh water flowing down the Sacramento and San Joaquin Rivers flooded the Delta with cold, fresh water. As flows in the rivers lessened over the summer and into the fall with the snow pack gone, salt water from San Francisco Bay would move further into the Delta creating brackish conditions in parts of the western and northern Delta. In dry years, brackish conditions would prevail for longer periods and penetrate further into the Delta, while in wet years the reverse would be true.

Development has dramatically altered this system. Prior to large-scale settlement, the Delta was a marshy region with shifting channels and varying water salinity. In the 1860s, farmers began settling parts of the Delta, dredging channels through the marsh to facilitate shipping and using the sediments to build levees and convert marshland into farms. These activities changed the Delta from a region of shifting channels and land masses to a progressively more static system of islands and channels. By 1930, approximately 1,100 square miles of land had been reclaimed in the Delta (Brooks, Levine and Weiser 2008).

While settlement drastically changed the nature of the Delta itself, the state's water infrastructure has changed flow conditions. The heavy spring floods typical of California were a problem for early settlers for two reasons: the floods themselves could damage houses and farms, and the water contained in those spring floods would have been extremely valuable in the dry summer and fall months that followed had it been available. The solution was to dam the rivers, permitting flood control and a means to capture and store the snowmelt for later use. Today, large quantities of water are diverted upstream of the Delta. Even after accounting for return flows, more than 25% of the water that would naturally flow to the Delta never reaches it (PPIC Report, p. 25). Diversions on the San Joaquin River are so large that a substantial section of the river bed is actually dry in all but the wettest periods. Water that reaches the Delta through this river today is the result of drainage canals that flow into the river bed, carrying water polluted with agricultural runoff.4

During the twentieth century, the Delta system was altered further by two large water projects. In 1937, Congress authorized the Central Valley Project (CVP), which constructed facilities for water storage upstream from the Delta in both the Sacramento and San Joaquin River systems and water transportation facilities in the Delta. Water from the Sacramento River system, our focus here, is released from storage and flows through the Delta. It is then diverted from the southern end of the Delta and sent south to water users in the Central Valley. In 1960, California voters approved construction of the State Water Project (SWP), which performs a similar function, and also supplies water to urban Southern California. Together these projects divert approximately 5.5 maf of water each year.5

Water conveyed through the Delta provides critical supply for many of the state's water users. Nearly two-thirds of the state's residents are at least partially dependent on the Delta for drinking water. These include residents of urban Southern California and parts of the Bay Area. Farmers, especially in the southern and western Central Valley, are dependent on the Delta for irrigation water. In addition to users who rely on the Delta for water conveyance, farms and communities within the Delta region divert water directly from the Delta for their uses. Since 1990, less than half of the Delta's natural outflows have reached the ocean.

While this system has fueled substantial economic growth in many regions, it has drastically changed the character of the Delta. Today's Delta is a series of static, levee-lined channels that flow between reclaimed islands, home to farms and communities. Carefully timed water releases from projects upstream on the Sacramento River keep salinity within the Delta at a relatively constant level that is low enough to be useful for drinking water and agricultural purposes. As documents released through the BDCP process point out, "In an effort to engineer the Delta for water conveyance and agriculture, we have created a fairly static environment—

while the water still flows, and the tides still fluctuate, the land and the water have become disconnected, and the complexity of the ecosystem has diminished considerably" (BDCP 2008b).

The Delta in Crisis

Stakeholders in the region agree that the Delta is in crisis, due to a large and complex set of inter-related problems. They disagree, however, on the relative contribution of various causes and the potential performance of various solutions. In simple terms, there are two major concerns: the health of the Delta ecosystem and the risk of levee failure. As the Strategic Plan notes:

> The Delta ecosystem, by almost any measure, is in serious decline and threatened by catastrophic failure from earthquake, floods, sea level rise, global warming, land subsidence, and urban development. These ecosystem threats equally endanger the current Delta water export system.

These problems guarantee that today's Delta has a limited lifespan. The PPIC report notes that "the Delta of the future will be very different from the Delta of today and the Delta of the past, regardless of what management and policy actions are taken and what happens to California's environment and economy." This statement should not be interpreted as suggesting that current policy choices are irrelevant. The choice of management and policy actions today will determine the nature of the Delta of the future.

The substantial alteration of the Delta's natural ecosystem described in the previous section has had severe consequences. One ecologically and politically important effect has been the severe decline in the populations of several fish species in recent years. Some populations have declined to the extent that the species have been listed under the ESA. Fish declines in the

Delta are likely the result of many factors, but water export operations are widely believed to play a major role.

Exporting water through the Delta in the current fashion causes three major problems for fish: water flow reversals, deaths at the pumping facilities, and altered hydrodynamics within the Delta (BDCP 2008b). The pumping plants in the southern Delta that deliver export water to the CVP and SWP are extremely powerful. When operating, they reverse the direction of water flow in much of the Delta. While San Joaquin River water would naturally flow northward through the Delta, the pumps pull water from the Sacramento River south. These flow reversals confuse native fish species and draw them toward the pumps. Once near the pumps, the fish face extreme dangers from the pumps themselves. Large numbers of fish (particularly Delta smelt) are killed at the pumping plants each year, despite the presence of a fish recovery operation designed to mitigate this impact.

Within the Delta, altered hydrodynamics have caused considerable changes. As noted above, the Delta today is a much more static system than it was historically. Many biologists believe this has been detrimental to native fish species, through two mechanisms. First, the reduced variability has altered the ecosystem to which native species evolved and adapted. In particular, fish species that adapted to live in an environment of varying salinity are at a disadvantage in one with constant salinity. Second, the altered Delta ecosystem has provided a home to several invasive species and has favored certain predatory ones. These species have exacerbated the pressures on several species of native fish (Moyle and Bennett 2008).

The government has already undertaken ESA-mandated efforts in order to address fish population declines. In 2007, federal court Judge Oliver Wanger ruled that the effects of current water operations in the Delta on the delta smelt violated the ESA. In response, exports from the

Delta were reduced by nearly a third in 2008, reducing the water available for urban and agricultural uses.6 Enforcement of the ESA for the fall-run Sacramento River salmon has also required government action. The National Marine Fisheries Service closed all commercial salmon fishing off the California and Oregon coasts in 2008 due to a particularly low count of fall-run Sacramento River salmon.

In addition to its failing ecosystem, the Delta in its current form is threatened by a large risk of island flooding with potentially disastrous consequences. When farmers built levees around marshy land in the Delta and reclaimed the land, they initiated an on-going change in the system. Over the intervening years, the land making up these diked islands has subsided, due primarily to the decomposition of organic carbon in the peat soils characterizing the Delta (Ingebritsen et al., 2000). Sea levels have also increased, causing water levels in San Francisco Bay to rise approximately 8 inches over the last century (PPIC Report, p. 38), leading to an increase in water levels in the Delta.7 Today, many Delta islands are as much as 20 feet below sea level, and continue to subside at long-run rates estimated at 1–3 inches per year (Ingbritsen et al., 2000). Moreover, the levees surrounding many islands are considered insufficient for flood protection, either because they are too low given current water levels, because they have not been adequately maintained, or both.

As the islands continue to subside, and as sea levels continue to increase, as many observers predict, the likelihood of levee failure will increase. The consequences of a levee failure are expensive and severe. As soon as a levee is breached, water rushes in to fill the "bowl" and equalize water levels. This causes immediate destruction of homes and farms. In 2004, a levee breach along the Middle River within the Delta flooded an island known as the Jones Tract. Within a day, 20 homes and 50 other structures were under approximately 12 feet of water (Bulwa, et al. 2004). Repairs cost approximately $90 million and were largely funded by the state (Lund, et al. 2008).8

Although the Jones Tract failure involved only one island, observers are increasingly concerned about the possibility of multiple, simultaneous levee failures. Two likely scenarios for such an event are a massive flood on the Sacramento River system or an earthquake on one of the faults that runs through the region. Geologists warn that such an earthquake *will* occur, the only question is *when.*

The result of a massive levee failure event is likely to be the destruction of the Delta system in its current form. Water from the Delta would rush in to fill multiple islands simultaneously and Delta water levels would drop precipitously. As a result, salty water from San Francisco Bay would be drawn into the Delta, creating brackish conditions. Exporting water through the Delta for either residential or agricultural uses would cease to be an option until levees were repaired and sufficient fresh water from the rivers feeding the Delta reached the area. The consequences of such a large and sudden disruption of the state's water supply cannot be overstated. A sudden change to the Delta's salinity regime would also have adverse consequences for the region's ecosystem. Although many biologists believe that greater variation in salinity would benefit native Delta fish species, it is unlikely that a sudden and drastic change in salinity would benefit any fish, native or otherwise.

According to all major policy reports regarding the Delta in recent years, climate change is expected to exacerbate the Delta's problems over the coming years. Three major negative impacts on the Delta are anticipated. The first two are the consequences of increased climatic variability: more frequent droughts and larger floods. More frequent droughts will further stress an already stressed water supply. Minimum water needs for fish will likely mean little to no water available for other uses in a growing number of critically dry years. On the other hand, increased frequency of heavy floods raises the risk of a large flood event triggering simultaneous levee failures. The third impact of climate change may be even more problematic for the Delta (over the long run). Sea levels are expected to rise over time. Estimates of the degree of sea level rise vary widely, but all major analyses of the Delta include some projected sea level rise. The PPIC Report considered sea level increases of between 0.5 and 1.5 feet by 2050. This sea level rise exacerbates the problem of levees that are insufficient to protect islands from floods. The PPIC Report argues that the probability of a massive levee failure event by 2050 could be as high as 95%.

The Debate over the Delta's Future

Due to the Delta's role as the hub of the state's water system, decisions about its future affect a broad set of stakeholders. Any policy decisions will create winners and losers. Unsurprisingly, discussions over the region's future have triggered an active political and scientific debate. As discussed in the introduction, this debate has resulted in the publication of several major reports providing recommendations for the Delta's future.

We proceed by providing a general description of the policy options available to the state and a discussion of the strengths and weaknesses of each option. In the process, we discuss the recommendations made by each report along with the justifications for those recommendations. We divide our examination into two sections. The first discusses possible strategies for water exports. The second discusses other policy options.

Water export strategies

The PPIC Report argues that the fundamental choice facing the state is the selection of a strategy for Delta water exports. It identifies four basic options: continue through Delta exports ("through Delta"), stop exporting water ("no exports"), build a canal to convey all water exports around the Delta ("peripheral canal"), or build a canal and export water both through the canal and through the Delta ("dual-conveyance"). In this subsection, we describe each of these alternatives and review the major arguments for and against each option.

The first option is to continue exporting water through the Delta using the current system. To be viable, this option would require upgrading and improving Delta infrastructure to minimize the risk of system collapse due to levee failure. A key element of any successful through Delta strategy would be a substantial reduction in export volumes in order to comply with the ESA. The PPIC Report estimates that reductions of 25% to 40% from historical levels prior to the Wanger decision are likely. Pursuing this strategy means accepting a growing risk of numerous simultaneous levee failures. It also requires export users to continue to spend significant resources treating Delta water to meet quality standards. If rising sea levels cause the Delta to become more saline, treatment costs would increase. Over time, the desirability of the through Delta option will likely deteriorate. The PPIC Report argues that this option is likely to be dominated by other choices on both cost and environmental performance criteria.

This conclusion is far from universal, however. In particular, many groups representing in-Delta interests believe that a modified through-Delta strategy could be successful. For instance, the South Delta Water Agency (SDWA), which delivers water to farmers in (the) southern Delta, argued in their public comments on drafts of the Strategic Plan that "the potential for a greatly improved through-Delta system without a canal was . . . ignored" (Hildebrand, 2008).

The second option—-the “no export” strategy—-represents the extreme alternative of reducing Delta exports: stopping them altogether. This approach would likely result in the best environmental outcomes as all issues related to (fish) deaths at the pumps and altered flow regimes would be eliminated. However, if this approach were adopted, water users that rely on Delta exports would be forced to reduce their use and/or seek alternative supplies. Conservation efforts and reductions in irrigated acreage would meet some of the shortfall, as shown by growers’ responses to the dramatic reductions in SWP deliveries for 2009. Likely alternative water supplies include desalination, reclaimed wastewater, and, perhaps, increased reliance on groundwater. This shift in supplies would impose a monetary burden on all export users.

The third option is the “peripheral canal” alternative. This alternative would convey water around the Delta instead of through it by constructing a canal. The canal would start on the Sacramento River upstream of the Delta and transport water around the Delta to the existing pumps in the southern Delta. The idea of building such a canal is not new. In 1982, a bond initiative for the construction of a peripheral canal supported by then-governor Jerry Brown was defeated due to overwhelming opposition from Northern California. The canal proposed at the time would have provided for a dramatic increase in water exports. Following the initiative’s defeat, building a canal was considered a non-viable option, politically, for many years. Due to ESA-mandated water delivery restrictions in the past few years, (however,) the possibility of canal construction has been re-introduced. Here we do not compare in detail differences between the peripheral canal options discussed today and the 1982 peripheral canal proposal. In today’s context, the goal is not to increase water deliveries to southern California, but to separate as much as possible the needs of the state’s water supply system from those of the Delta’s ecosystem. Optimal timing of water releases and flow patterns with the Delta for ecosystem management differs from the optimal timing of water releases and flow patterns for agricultural and urban uses in southern California. While a canal would mitigate the timing and flow problems, it cannot increase the total available water supply. As such, the proposals call for a much smaller canal than that proposed thirty years ago.

Today, a revised canal plan is a very real part of the debate, although it is subject to much controversy. In fact, even the name is controversial. Proponents of a canal plan generally avoid the term "peripheral canal," likely due to its negative associations with the failed 1982 bond initiative. Instead, many documents refer to an "isolated conveyance." For instance, neither the Delta Vision nor the Strategic Plan contains the word "peripheral" although both recommend exploring the construction of an isolated conveyance. In this chapter, we adopt more popular usage and refer to a "peripheral canal" rather than an isolated conveyance.

Proponents of a peripheral canal argue that it provides several potential benefits. First, it insulates the state's water supply from the risk of Delta levee collapse. In the event that a major levee collapse increased salinity levels in the Delta to the point that water in the Delta was unusable, the existence of an entirely isolated facility would permit the transport of fresh water from Sacramento south. Similarly, the canal would reduce the costs to export users of treating exported water, since its passage through the Delta currently contributes much of the salinity and other pollutants, which must be treated.

While the canal provides clear benefits for export users, its environmental effects, and hence the environmental benefits it might provide are highly uncertain. Stakeholders disagree regarding their potential existence and importance. Proponents of the canal argue that it would have three major ecosystem benefits. First, by routing exports around instead of through the Delta, the canal would eliminate problems with reverse flows as water is sucked south toward the pumps. Although the existing pumps would still be used, water would not be drawn across the Delta toward them. Second, exporting water through the canal would mitigate entrainment problems at the pumps, especially for the smelt whose habitat is downstream of the proposed new intakes.9 Finally, conveying water around the Delta would allow water managers greater flexibility in managing salinity. Today, fresh water is released from storage to manage salinity in the interior Delta so that water quality standards are met. If water exports were instead conveyed around the Delta, the salinity within the Delta could be allowed to fluctuate. Some biologists believe this fluctuation will favor the native Delta species that evolved in response to the natural salinity fluctuations in the system.

Stakeholders disagree about the effect increased salinity variability will have on fish populations. While agreeing that altered salinity standards and regimes could be beneficial, the draft BDCP urges caution. It states:

> Predictions of the response of various fish and other aquatic organisms to changes in the salinity regime, is uncertain. . . . Large-scale changes in the salinity regime within the estuary have the potential to result in large-scale biological benefits (increased species diversity and resilience) or to large-scale degradation (jeopardy of extinction) (BDCP 2008a, pp. 43–44).

Other groups disagree that a peripheral canal would provide any ecosystem benefits. Restore the Delta, a coalition of Delta residents and environmentalists, argues that building a peripheral canal is a poor solution because it would worsen water quality in the Delta. The diversion of freshwater into the canal would reduce the amount of freshwater flowing through the Delta, thus worsening water quality. Restore the Delta (2008) argues that this would “lead to the death of the Sacramento-San Joaquin Delta’s ecosystem.”

The canal would also have negative impacts on Delta residents and farmers. The fluctuating salinity that some biologists believe will help native fish species is a serious problem for Delta farmers and residents who rely on Delta waters for irrigation and drinking water. If all water exports were conveyed through a peripheral canal, carefully timed releases to maintain low salinity would no longer be necessary for water exports. Water quality in the Delta would likely become too saline for either irrigation or drinking water most of the year. The SDWA asserts that the peripheral canal "will destroy the southern Delta and so we must justify that death. This is why the Plan makes no reference to protecting southern Delta agriculture; it seeks to remove southern Delta agriculture" (2008b). One particularly important consideration for the southern Delta is that if through-Delta exports are eliminated, high quality fresh water from the Sacramento River will no longer be drawn southward, diluting the low-quality water from the San Joaquin River. While the SDWA focuses on the effects on its clientele, other in-Delta users will face negative impacts due to changes in water quality and flows.

The final option—-the "dual-conveyance" alternative—-is to pursue a mixed strategy under which a canal around the Delta would be constructed, but some through Delta exports would also continue. This approach involves improving the fortifications along a channel in the middle of the Delta in addition to building a canal. Exports would be routed through both the in-Delta channel and the canal. In the remainder of this chapter, we reserve the term "peripheral canal" for proposals that involve routing all exports through a canal and use the term "canal" to refer to a generic canal whether part of a single- or dual-conveyance system.

The PPIC Report argues that "There seems little reason to prefer a dual facility over a peripheral canal." Its authors believe that the environmental performance of a dual-conveyance system is unlikely to be better than that of a peripheral canal. Moreover, the dual-conveyance alternative would involve both building a canal and pursuing substantial upgrades to the existing levee system. As a result, it is likely to be more expensive. As stated in the report, “A dual conveyance alternative with significant investments to support through-Delta pumping is unlikely to be worth the additional costs, given the water quality and environmental risks of through-Delta pumping” (PPIC Report, pp. xi-xii).

In contrast, the Delta Vision Committee has recommended the dual-conveyance option over the peripheral canal. In the Strategic Plan, they point out “the need to maintain flows through the Delta for water supply and ecosystem health” and note that “A dual conveyance system offers extra insurance against such disasters by creating an additional path for water conveyance” (p. 101). They note that substantial additional analysis will be required to determine the feasibility and desirability of a dual-conveyance option. Such analysis should consider both single and dual-conveyance options.

Most stakeholders who are skeptical of the construction of a canal make little distinction between the stand-alone peripheral canal and the dual-conveyance options. Most environmental groups involved in the debate have stopped short of outright rejection of a peripheral canal, but remain concerned about the degree to which the desirability of such a canal is considered a foregone conclusion. For instance, the Bay Institute and the Natural Resources Defense Council (NRDC) (2008) argued in their comments on the second draft of the Strategic Plan that

A major change in Delta conveyance could have dramatic unintended consequences on Delta Vision’s co-equal goals. The process of developing specific proposals for facilities and operations, and the analysis of potential impacts, benefits and costs, has just begun. Delta Vision can best support this process by urging the careful development and analysis of alternatives, rather than by encouraging a rush to judgment.

Groups representing in-Delta interests have been more vocal in their opposition to the peripheral canal and dual-conveyance alternatives. In particular, they object to the Strategic Plan's identification of the dual-conveyance as the preferred alternative. In their comments on the fifth (and penultimate) draft of the Strategic Plan, the SDWA (2008b) stated:

> There can be no "preliminary" choice of an isolated or dual facility *until* all of the analyses have been done. Perhaps the PC [peripheral canal] costs $25 billion and creates warm stagnant zones on the Sacrament [*sic*] system which adversely affects the fisheries while creating no new water supply? Clearly it is premature to make any comments on what is best for fisheries or the State. The Plan suggests DWR and other [*sic*] investigate a dual facility. The Plan should recognize this reality and not assume DWR is capable of some sort of fair analysis of the issues.

Restore the Delta expressed concern that whether part of a joint system or not, the presence of a peripheral canal would drastically reduce state incentives to maintain and repair the levees that protect Delta communities today. Specifically, they argued that if a peripheral canal is built, "In the event of a natural disaster, the Delta would be written off in the same way that New Orleans was abandoned after Hurricane Katrina" (Restore the Delta 2008). Moreover, extensive newspaper reports in the *Sacramento Bee* and *San Francisco Chronicle* on plans to build a canal were met with a chorus of overwhelmingly negative comments denouncing the Southern California "water grab." In an online forum, a *Sacramento Bee* reader with the username "tgianco" wrote:

> I remember these debates from when I was a kid. We really need to start up Northern CA as the 51 state again. The people of Socal chose to live in a desert . . . that's their problem, not ours' or anyone else's (The Delta Debate: Are you ready for a Delta canal? 2008).

Despite this opposition to a canal, the governor's office plans to proceed with canal construction, likely as part of a dual-conveyance system as recommended in the Strategic Plan. The Implementation Report sets a target date of 2011 to begin construction of the facility. In fact, Mike Chrisman (chair of the Delta Vision Committee and head of the state's Natural Resources Agency) claimed that the state has the legal authority to build the canal without approval from the legislature or the voters. However, most observers agree that the plan is likely to end up in the courts, especially if the administration fails to seek approval (Weiser 2009).

Other Decisions

While the choice of a long-term strategy for Delta (water) exports is particularly critical, discussions over the Delta's future are not solely focused on exports. In this section, we discuss three additional decisions facing the state that will have a profound influence on the long-term health of the Delta and the state's water system.

The first decision concerns Delta governance. It is widely believed that the existing institutions responsible for managing the Delta have contributed to the current crisis. The Strategic Plan endorses this opinion, pointing out that under the current system "Everyone is involved; no one is in charge." Some groups charge that the entities responsible for protecting fish and the ecosystem in general have failed in that duty. For instance, the SDWA notes that

The agencies of the State charged with protecting endangered species and operating and regulating the State Water Project *never tried to comply with CESA;* ***never***. During the time

DWR knew that it did not have sufficient supply to fulfill its contracts, and while it increased exports to fill those contracts, it didn't comply with CESA, or more correctly never attempted to comply with the law (2008a, emphasis in original).

The Wanger decision described above that triggered massive reductions in water exports reached a similar conclusion. This decision called a biological opinion that allowed (but did not require) increased export volumes through the Delta "arbitrary and capricious" (Earthjustice 2008).

In response, many stakeholders believe that new governance institutions are necessary. The Implementation Report released by the Delta Vision Committee lists as one of its fundamental actions developing "an improved governance system that has reliable funding, clear authority to determine priorities and strong performance measures to ensure accountability to the new governing doctrine of the Delta: operation for the coequal goals" (p. 1). It further states that "Completion of this fundamental action is absolutely essential to the sustained operation and maintenance of all of these recommendations" (pp. 1–2).

Environmental groups are insistent that the institutions for governing the Delta must be changed. They believe that the existing governance structure has allowed too much managerial flexibility, which has been exercised in ways that are detrimental to the environment. Therefore, they are pushing for new institutions that restrict this flexibility. For instance, EDF argues that

> A bedrock element of environmental reliability is therefore a provision for automatic, non-discretionary changes in water project operations and other diversions in the event that the program elements above—such as water or money—do not materialize or the performance measures are not achieved by established deadlines (Koehler, et al. 2008).

As with other elements of the Delta debate, there is disagreement about how best to reform the governance structure. Current proposals call for the creation of a new governing body called the California Delta Ecosystem and Water Council (CDEW). While many believe that new leadership and rules are necessary, not all stakeholders support the idea of new governing bodies. In particular, in its comments on the fifth draft of the Strategic Plan, SDWA (2008b) states

SDWA strongly opposes the creation of a new super Delta agency or governing board. It is not possible to do away with the various federal and state regulatory authorities or to combine them with interests that have goals contradictory to their duties. . . . If we learned anything from the CalFed debacle, it should be that putting the regulators in with the regulated, and encouraging them to reach consensus is the worst possible approach.

A coalition of water export users known as the "Business Water Caucus" endorses the idea of governance change but expresses concern that changing too much will delay the implementation of other recommendations.10 In particular, they note

We continue to support the overall structure of the governance proposal but reiterate the need to limit the California Delta and Ecosystem Council to an oversight role, using the strategic plan to delegate specific and direct responsibility to implementing agencies, eliminating the cost and delay from yet another three-year planning process as envisioned by the CDEW plan (Birmingham, et al. 2008).

The Delta Vision Committee appears to agree with the need to act quickly. Although they acknowledge that governance is important, their plan suggests moving forward with canal construction while governance rules are developed. In response to this, The Nature Conservancy (TNC) announced that it supported the construction of a canal *conditional* on the development of new governance institutions more capable of safeguarding the Delta ecosystem. TNC's water program director for California, Anthony Sacarino, argued "The key to success lies in the governance structure. History has shown that the existing process for managing and regulating the Delta does not work. We are in critical need of a new, independent form of governance if we hope to meet the multiple objectives for the Delta, and we cannot afford to wait another year for this to happen" (The Nature Conservancy 2009, emphasis in original). Thus, some environmental interests and some exporter interests favor institutional reform. This suggests that both groups feel that their interests have not been as well-served by current institutions as they might be by alternative ones. However, it does not by any means suggest that the two groups would support the *same* set of alternative institutions.

A second critical element of the debate concerns water infrastructure. Many water users believe that additional investments in water infrastructure beyond the construction of a peripheral canal or a fortified through-Delta system are essential. Much of the public debate centers on the construction of new storage facilities either upstream on the Sacramento River system or south of the Delta. Upstream storage would offer managers greater ability to optimize the timing of water flows into the Delta. Storage south of the Delta would enable large volumes to be exported through or around the Delta at times when it would have the smallest impact on the ecosystem, but still be available for water users at their preferred times.

Many water user groups, along with the governor and many members of the Assembly, believe that storage investments are necessary and must be part of a comprehensive solution to the state's water problems. Although environmental groups do not universally reject the notion of new storage, they urge caution and reject the notion that all possible surface storage plans should be pursued. In particular, the Bay Institute and NRDC argued that

> The draft recommends proceeding with surface storage options without any real criteria for prioritizing potential projects, any examination of the cost-effectiveness and financing of these projects, and a meaningful discussion of innovative storage alternatives. . . . The discussion of surface storage would be significantly strengthened by the addition of an action requiring a careful analysis of the cost-effectiveness of specific projects, the optimal sizing and location of potential projects and the relative cost of alternative approaches (Bay Institute and Natural Resources Defense Council 2008).

While storage investments have captured most of the political attention, additional investments in conveyance facilities outside the Delta proper are also under consideration. The PPIC Report argues that additional investments in expanding existing or constructing new conveyance facilities permitting more flexible movement of water between water user groups will be more cost effective than new storage.11

A third important element under discussion is expenditures on ecosystem restoration. One of the Strategic Plan's seven goals for the Delta is to "restore the Delta ecosystem as the heart of a healthy estuary." The BDCP rests heavily on the notion of ecosystem restoration, and a draft plan containing several specific restoration opportunities is available (BDCP 2008c). The idea of ecosystem restoration within the Delta has widespread support. However, in-Delta interests are concerned about many of the specific measures proposed in this plan. For instance, the Sacramento County Farm Bureau noted in its comments on the first draft of the Strategic Plan, which endorses the adoption of the BDCP, that it

> vigorously opposes ecosystem performance measures, which set targets for conversion of 300,000 acres of productive agricultural land to tidal marsh,

> active floodplain, seasonal wetlands, and channel habitat. This is unacceptable and will do major damage to Delta agriculture (Sacramento County Farm Bureau 2008).

Altogether, policymakers and stakeholders addressing the Delta's future must make several difficult and interconnected decisions about the best direction to take. In the next section, we develop a stylized model of the choices and their consequences for several key stakeholder groups.

The Model

In this section we develop a numerical model of the policy choices facing the state and the effects of each of these choices on the well being of several key stakeholders. Our goal is to create a comprehensive framework for evaluating stakeholder payoffs from various policy choices. To do so, we identify a set of vectors from which the state (policy makers) must choose. Each of the four policy options described above corresponds to a specific vector belonging to this set.

The model we develop has three basic components: policy choices, outcomes, and utilities. Figure 2 is a schematic of how these components relate. The first box denotes a set of policy choices, represented by a vector **x**. Following the PPIC Report, we focus on the state's choice of how much water to export. As shown in the diagram, policy choices induce a set of outcomes that are of interest to particular stakeholders, including financial, ecological, and employment impacts. In our model, the vector of outcomes resulting from the policy vector **x** is denoted by the vector $\mathbf{y} = \mathbf{f}(\mathbf{x})$. The final element of the model is a set of utility functions that define the well-being of several major stakeholder groups. These are given by the vector-valued function, **u**(**y**). In this analysis, we focus on five broadly specified stakeholder groups: urban users of exported water, the agricultural regions of the San Joaquin Valley that rely on exported water, environmentalists, state taxpayers, and in-Delta interests.

The remainder of this section elaborates on the details of each element in Figure 2 and concludes with a discussion of several caveats to (regarding) the model.

Policy Choices

As described above, our model focuses on the state's decision about how much water to export and the manner i(n) which it will be exported. We define two continuous variables that represent the state's policy choices:

- *ThruExports*—the quantity of water exported through the Delta
- *PCExports*—the quantity of water exported around the Delta through a canal.

Each of the choices discussed above in subsection 2.2.1 can be represented using these two variables. Table 1 summarizes how each alternative is modeled in our framework. The values are chosen to be representative of the alternatives discussed in the PPIC Report. The PPIC Report does not include a precise plan for how to allocate exports between the canal and through Delta pumping for the dual-conveyance alternative; we divide the exports evenly between the two.12

Outcomes

As shown in Figure 2, policy choices map to outcomes that are of interest to particular stakeholder groups. In this section, we describe each of the outcomes in our model and explain how they are calculated as functions of policy choices. The functions presented in this section draw heavily on the analysis presented in the PPIC Report.

Many of the outcomes that affect stakeholders involved in the Delta debate are financial. In particular, different export regimes impose different types of costs that are borne by different stakeholder groups. Our model contains three groups that bear some financial burden for different alternatives: agricultural users and urban users that rely on Delta exports for some of their water, and the state's taxpayers. The five specific costs included in our model are:
costs due to reduced water exports, water treatment costs, levee maintenance costs, costs associated with a major collapse of the levee system, and repair costs following a major collapse. In the following several paragraphs we describe each of these costs and their allocation across users in detail.

The first major set of costs relates to the consequences of reduced exports. These costs are driven by reductions in total water exports rather than changes in export conveyance. We therefore compute two water use outcomes:

$$TargetExports = ThruExports + PCExports$$

and

$$ReductionShr = \frac{HistoricalExports - TargetExports}{HistoricalExports}$$

where *HistoricalExports* is a measure of the pre-Wanger level of exports from the Delta (approximately 6 maf per year). *TargetExports* measures the planned amount of total exports. As discussed below in 3.2.1, this level may or may not be achieved in practice. *ReductionShr* measures the portion of exports that are no longer allowed; a value of 1 indicates a complete cessation of exports and a value of 0 indicates restoration of pre-Wanger levels.13

We rely on the analysis in the PPIC Report to calculate the cost of export reductions. The report's authors used a model of the state's water demands and infrastructure to estimate the scarcity costs imposed by reductions in exports from the Delta. They computed the total scarcity cost associated with a discrete set of export levels. To convert these discrete points into a continuous function relating total scarcity cost to export reductions, they used the following functional form:

$$C(CutShare) = CostNX * CutShare^{\phi},$$

where *CostNX* is the cost of ending all exports, and ϕ is a parameter determining the curvature of the relationship between scarcity costs and export reductions.

There are several continuous cost variables in our model. We calibrate each of these variables to discrete cost estimates obtained from the PPIC Report. We adopt its method of extrapolating from discrete numbers to continuous functions, defining

$$Cost_i(NewValue) = BaseCost_i \left(\frac{NewValue}{BaseValue_i}\right)^{Exp_i},$$

where *NewValue* is the value whose cost we want to compute, $BaseCost_i$ represents a baseline cost (drawn from the PPIC report) for a value $BaseValue_i$, and Exp_i determines the curvature of the relationship. This functional form will be either convex or concave, depending on whether Exp_i is larger or smaller than 1.

The PPIC Report's conclusions are driven by aggregate costs of scarcity. We use information provided in the report's Appendix G to allocate these costs between the two stakeholder groups in our models that are responsible for them: agricultural users south of the Delta and urban users in both Southern California and the Bay Area.14 We therefore construct two separate functions: $Cost_{agExport}(CutShare)$ and $Cost_{urExport}(CutShare)$ with the form given above. Note that in these functions, the value being changed is the cut share, not the value of exports. The base value is a 100% cut or the cessation of all exports. Thus, these functions have the form

$$Cost_i\left(CutShare\right) = CostNoExports_i CutShare^{Exp_i},$$

In these constructed functions, the exponent $Exp_{agExport}$ is much lower than $Exp_{urExport}$. Both exponents indicate that the cost of cuts increases at an increasing rate. The rate of increase is faster for urban users, because urban users can absorb small cuts more easily. Therefore, the relative difference in cost between a small cut and a large cut is greater for urban users than for agricultural ones.

For each of the remaining cost types, given the lack of any information suggesting otherwise we assume the share of total cost paid by each stakeholder is independent of the aggregate cost. We define a vector φ_i giving the share of that cost borne by each stakeholder. We use the notation φ_{ij} to denote the share of cost *i* borne by stakeholder *j*. The total cost paid by stakeholder *j* is thus

$$C_j = \sum_{ij} \varphi_{ij} Cost_j$$

The first such cost is treatment of water exported through the Delta. We scale the baseline level of treatment costs from the PPIC report to a specific level of through Delta exports using the function $Cost_{treatCost}\left(ThruExport\right)$. For our base case simulations, we set the value of $Exp_{TreatCost}$ to 1, thus assuming away any economies or diseconomies of scale in treatment costs. We allocate half of the computed cost to agricultural users and half to urban users. Although agricultural users use more water than urban users, their treatment standard is lower.

If water is exported through the Delta, additional resources will need to be spent on maintaining the Delta infrastructure, particularly the levees. The primary purpose of these expenditures is levee maintenance to keep the Delta water fresh enough for export. Therefore, this cost depends on the degree to which water is exported through the Delta. As with other costs, we scale using the function $Cost_{MaintainCost}(ThruExport)$. Since a high portion of the costs must be paid for even small levels of exports, we set the value of $Exp_{MaintainCost}$ to be very low (0.1 for our base case simulations).

Another cost component is the cost of constructing a canal if one is built. Current plans call for the vast majority of these expenses to be paid by the water users dependent on Delta exports. We allocate 45% of the costs to each of the water user groups (agricultural users south of the Delta and urban users receiving water exports) and allocate the remaining 10% to taxpayers. Because current plans call for building a canal capable of conveying far more than current export levels in order to enable large export volumes during wet periods, we assume that the cost of canal construction is independent of the target level of canal exports.

While most interest groups focus primarily on the direct financial impacts of any policy choice, they are concerned about other considerations as well. The PPIC Report predicts that large reductions in exports would lead to water transfers from San Joaquin Valley agriculture to urban water uses. Although the water right holders themselves would be compensated for these transfers, San Joaquin Valley agricultural interests are concerned about the impact on regional employment as well. Using the PPIC's modeling results, we compute an outcome variable related to agricultural employment:

$$AgEmploy(TotalExports) = BaseJobs - JobLossNX * CutShare$$

where *BaseJobs* is the current level of agricultural jobs in the San Joaquin Valley and *JobLossNX* is the level of job loss predicted if all exports were stopped.

The long-term success or failure of any policy proposal is intimately connected to its environmental performance. While there are many elements of ecosystem performance, we follow the PPIC Report in focusing on the survival probabilities of two bellwether fish species: fall-run Sacramento River salmon and Delta smelt, and utilize the Report's definitions of what survival means. Formally, there are two outcomes related to ecosystem performance: ρ_{salmon}, the probability that salmon populations will recover enough to support a commercial fishery, and ρ_{smelt}, the probability that Delta smelt populations will recover allowing the species to avoid extinction. As discussed above, fish are likely to be affected by exports either through or around the Delta and by the aggregate quantity of water flowing into the Delta. We thus introduce a new outcome variable, *DeltaInflow* measuring the quantity of water flowing into the Delta from the Sacramento River. Its value is given by:

$$DeltaInflow = SacFlow - PCExports$$

where *SacFlow* is the flow of water in the Sacramento River after upstream diversions.

We model both probabilities as functions of the two export variables and the inflow level in the following fashion:

$$\rho_k(ThruExport, PCExport) = \alpha_k + \beta_k DeltaInflow^2 + \gamma_k ThruExport^2 + \delta_k PCExport^2 ,$$

for k = smelt, salmon. We specify quadratic functions in order to reflect the reality that these relationships are almost certainly nonlinear, but no data are available regarding the precise nature of the nonlinearity. Specifying quadratic functions allows the importance of exports through the Delta and exports through the peripheral canal for fish survival to be much more sensitive to their relative magnitudes, as well as their absolute magnitudes, than would be the case for affine functions. The values of the parameters in these functions were calibrated to match the survival probability estimates presented in the PPIC Report. Because we had a limited number of points for calibration, we were unable to include both linear and quadratic terms.

Event Uncertainty

One of the challenges facing stakeholders seeking to identify a solution is that future events are uncertain regardless of the policy chosen. Our model considers two uncertain events: the recovery of fish populations and a major levee collapse.

Figure 3 shows a schematic of these uncertain events and how they contribute to our utility calculations. Although we do not discuss precise utility functions until the next subsection, the figure uses the notation $V(\bullet)$ to refer to the utility generated for a particular interest group by an alternative.

The selection of a policy vector described corresponds to setting a target value for the level of exports as shown at the top of the figure. As discussed above, for any export regime, there is some probability that fish populations will recover. If this occurs, the target level of exports can be achieved. However, there is also a probability that at least one species will not recover, triggering ESA-mandated cutbacks. 15

Following the PPIC, we hypothesize that if fish populations do not recover, exports will be reduced by a constant percentage we call *EcoCutShr.* We therefore have three updated levels of exports:

$$TExC = (1 - EcoCutShr) * ThruExport ,$$

$$PCExC = (1 - EcoCutShr) * PCExport ,$$

and

$$TotalExC = TExC + PCExC .$$

Note that *TotalExC* can also be written as $(1 - EcoCutShr) * TargetExports$, as we do in Figure 3.

We assume that reductions in exports occur if either species fails to show noticeable population improvements. For notational compactness, we create an outcome variable called *Cutbacks* representing the probability these exports occur. Its value is given by:

$$Cutbacks = 1 - \rho_{salmon} * \rho_{smelt} .$$

Following a reduction in exports, fish survival probabilities must be updated to reflect the reduced deliveries. We therefore introduce two new survival outcomes ($\hat{\rho}_{salmon}$ and $\hat{\rho}_{smelt}$) where

$$\hat{\rho}_k = (1 - Cutbacks) * \rho_k(ThruExport, PCExport) + Cutbacks * \rho_k(TExC, PCExC).$$

The reduction in exports also triggers an updated value for water scarcity costs given by:

$$\hat{C} = (1 - Cutbacks) * C(TotalExport) + Cutbacks * C(TotalExC).$$

Because of this variability in outcomes, the flow of utility generated by a target export policy is computed using expected utility as shown in the third box of the diagram.

The second uncertain event concerns whether and when a major collapse of the levee system will occur. We follow the PPIC Report in assuming that the construction of a canal insulates the state from this risk. Such a levee failure would impose several major costs on the system. First and foremost, there would be a large immediate cost due to the substantial disruption of the water supply system. We assume that this loss is borne if a canal is not built; the presence of a canal of any size insulates the state against this cost. Moreover, we hypothesize that individual water users would not bear these costs; instead, following a disaster of that magnitude, the state would step in and cover these expenses as occurred when the levees protecting the Jones Tract collapsed.16

In the aftermath of a massive failure, the state would face another decision about what recovery strategy to choose. In the dual-conveyance case, we assume that all exports are shifted to the canal post-collapse. In the through Delta case, we follow the PPIC Report and consider three possible options: build a canal, repair the Delta levees and continue through Delta pumping, or stop exports. We adopt the PPIC's approach in computing the cost of all three alternatives and choosing the one that has the smallest total cost.17 We predict that the state would choose to build a peripheral canal in such a scenario, as does the PPIC Report.

Because collapse will occur at some unknown time in the future, we compute pre- and post-collapse flows of utility. The expected utility is then the discounted flow of pre- and post-collapse utility plus the discounted immediate *CollapseCost,* with the expectation taken over the time to failure. In the next subsection, we describe the individual stakeholder utility functions.

Stakeholders and Utility Functions

In introducing the outcome variables in the previous subsection, we briefly discussed the interest of various stakeholders. In this section, we develop formal utility functions for each of the five stakeholder groups included in our model.

Our first stakeholder group represents the state's taxpayers. We assume that taxpayers are concerned with reducing the state's total expenditure liability and are risk neutral. This gives us a taxpayer utility function of:

$$U_{Tx} = BaseTxBenefit - C_{Tx}$$

where *BaseTxBenefit* is a constant representing the state's base level of benefit from tax expenditures used to support the water sector. We specify *BaseTxBenefit* to equal California's current state budget. We assume that taxpayers are risk neutral with respect to changes in this expenditure. As a result, the model's predictions are independent of the precise value of this constant.

Our second stakeholder group includes all urban users who depend on the Delta for a portion of their water supply. This group aggregates interests in Southern California with those in the Bay Area.[18] This stakeholder group is concerned with minimizing the cost of meeting its water supply needs. We use the following utility function:

$$U_{Ur} = U_{Ur}\left(BaseUrBenefit - C_{Ur}\right)$$

where *BaseUrBenefit* represents an estimate of the benefit to urban users of receiving their current water supply.

Our remaining stakeholders each have constant elasticity of substitution (CES) utility functions[19] with the general form:

$$U_j(x, y) = \left(xWgt_j x^{\omega_j} + \left(1 - xWgt_j\right) y^{\omega_j}\right)^{\gamma_j / \omega_j}$$

where x and y represent outcomes of interest to the stakeholder, $xWgt_j$ describes the stakeholder's willingess to trade one objective for the other, ω_j measures the substitutability between objectives, and γ_j is an exponent between zero and one measuring the stakeholder's level of risk aversion.

Our third stakeholder group represents interests within the Delta, including local residents, farmers, and recreational users. In the context of the policy decisions we model, these users are primarily concerned with the quality of water in the Delta and the amount of levee maintenance that occurs. Although we do not model water quality directly, it is highly correlated with the amount of water flowing into the Delta. Since Delta interests primarily use water upstream within the Delta from where the export pumps are located, the amount of water exported through the Delta has little impact on the quality of their water. Using a general utility function form, Delta interests thus have utility of:

$$U_{Dt} = U_{Dt}\left(MaintenanceExpend, DeltaInflow\right).$$

As discussed above, agricultural groups are concerned about their farming profits and the level of agricultural employment.20 Using our general form again, the agricultural group's utility is given by:

$$U_{Ag} = \left[\left(1 - AgEmployWgt\right)\left(BaseAgBenefit - C_{Ag}\right)^{\omega_{Ag}} + AgEmployWgt * AgEmploy^{\omega_{Ag}}\right]^{\gamma_{Ag}/\omega_{Ag}}$$

where *BaseAgBenefit* is an estimate of the farming profit generated with current water export levels.

We adopt a similar structure for the environmental group's utility function. Here the primary concern is fish survival probabilities. As we predict survival probabilities for two different species, our utility function incorporates both species:

$$U_{Ev} = U_{Ev}\left(\rho_{salmon}, \rho_{smelt}\right) .$$

Because four of our five groups are risk averse, we calculate expected utility outcomes in our model, using the likelihood of each event as shown in Figure 3.

Modeling Caveats

A major challenge to the development of a model such as ours is that there is substantial ambiguity about the appropriate specification of the functions mapping policies to outcomes and outcomes to utilities. We consider two types of ambiguity in our analysis: scientific uncertainty and modeling ambiguity. The mapping from policies to outcomes is characterized by what we call scientific uncertainty. That is, in many cases science cannot offer precise predictions about how policy choices translate into specific outcomes because scientific experts disagree or are uncertain of the likely impacts. Disagreement about how fish populations will respond to various changes in water export regimes is a particularly notable example. In our analysis, we follow the PPIC Report's approach to scientific uncertainty. That is, for each of the parameters in the model above that are subject to scientific uncertainty, we consider a high and a low value and report a range of possible outcomes.

In addition to scientific uncertainty, we must address several kinds of modeling ambiguity. In particular, the utility functions specified in subsection 3.3 depend on parameters governing stakeholders' degree of risk aversion and their willingness to trade reductions in one objective for improvements in another. We have assigned specific values to these parameters, but our choices are somewhat arbitrary. Moreover, the exact parameters governing the curvature of specific cost functions are unknown. To address these issues, we perform sensitivity testing to determine the robustness of our policy rankings to the specific values of these parameters. Similarly, the specification of functional forms is subject to modeling ambiguity. We have chosen specific functional forms. Our choices are based primarily on their technical properties, such as convexity. We could address this ambiguity by using sensitivity analysis to evaluate the robustness of our policy rankings with respect to the choice of functional forms, as we do for parameters. However, we do not perform this exercise here.

The model presented here also simplifies reality in several important ways. First, it limits attention to a small number of broadly defined stakeholder groups. Second, the model focuses exclusively on water export strategies. As discussed in 2.2.2, decisions about water infrastructure, upstream diversion changes, and ecosystem restoration will have large impacts on the outcomes of interest to stakeholders. Including these choices requires information not available at the present time.

Results

Using the model presented in section 3, we compute expected utility values for each interest group for the four policy options identified in that section: continued through Delta pumping, construction of a peripheral canal, construction of a dual-conveyance system, and ceasing all exports. Specifically, for each realization of scientific uncertainty (see Table 2), we compute each group's expected utility, where expectations are taken over the uncertain events depicted in our event tree (Figure 3). Having made these computations, we use an affine transformation to normalize each group's utility function. Under the transformed utility functions, the highest possible expected utility value a group obtains is one, and the lowest possible utility value is zero. An implication of our normalization procedure is that our transformed utilities convey no information at all about whether the utility difference for a given group between the best possible and worst possible outcome is large or small. On the other hand, our transformed utilities reflect the same risk preferences as the original ones.

Our results are depicted in Figure 4. For each interest group, each of the four bars represents the range of possible expected utilities that the group obtains from one of the policies we consider, as scientific uncertainty is varied over the ranges specified in Table 2. The top (bottom) of each bar represents the normalized utility associated with the scientific uncertainty realization that is most (least) favorable for that particular group. Note that the degree of scientific uncertainty will be reflected in the length of each bar, while (subject to normalization) the degree of uncertainty over the events listed in Figure 3 will be reflected in the placement of the bars in the interval [0 , 1]. More concretely, consider the left-most bar in Figure 4, representing agricultural users' utility from the through-Delta policy. A mean-preserving spread of each of the intervals representing scientific uncertainty in Table 2 would have the effect of increasing the length of this bar. On the other hand, a mean preserving spread of the uncertainty represented in Figure 3 would have the effect of shifting down the entire bar; the more risk averse are the agricultural users, the greater the downward shift.

We now discuss Figure 4 in detail. The left-most four bars give the range of utility values for the agricultural stakeholders for each of the four policy alternatives. We see that the agricultural stakeholders prefer the peripheral canal alternative as it generates relatively high expected utility values in all cases. The dual-conveyance alternative is less desirable than the peripheral canal because, depending on parameter values, a wider range of expected utility values are possible, and both the best and worst expected utilities are lower than the corresponding values for the peripheral canal. At its best, the through-Delta alternative performs nearly as well as the canal alternatives for agricultural stakeholders, but at its worst, the lowest expected utility is significantly below the lowest expected utility for the canal alternatives. Moreover, our analysis assumes that the state's taxpayers will bear the costs associated with a disastrous collapse of multiple levees. If the agricultural users were to be liable for some of these expenses, the through Delta alternative would perform worse. The no export alternative generates the smallest range of expected utility values, but provides low expected utility throughout the range for two reasons: large scarcity costs are imposed by the need to replace water export supplies or fallow land, and reduction in water supplies leads to a decline in agricultural employment.

The next group of four bars reports the urban stake holder's expected utility ranges. The pattern is quite similar to that of the agricultural group. Stopping exports is clearly the least preferred alternative for this group as well, although urban users are less negatively affected than agricultural users. Urban users pay a premium to replace water supplies but are not affected by a reduction in employment.

The middle group of bars represents the expected utilities of the taxpayer group. It is important to note that in our model the taxpayer group is only concerned with minimizing state expenditures. This group strongly dislikes continuing through Delta exports because taxpayers bear the financial burden of mitigating the immediate impacts of water supply disruption in the event of major levee collapse. The final bar in this group is only a horizontal line, not a shaded region. This occurs because the no export alternative involves no financial outlay by the taxpayers under any resolution of scientific uncertainty. The costs of reducing exports are borne entirely by the urban and agricultural water users who must replace the lost supplies or adjust their use. The canal alternatives are slightly worse for the taxpayer, because we assume that the state will pay some portion of the costs of constructing a canal.

As we would expect *a priori,* the environmental group strongly prefers ceasing all exports and dislikes continuing through Delta exports the most. Because environmentalists are modeled as being exclusively concerned with fish survival, this ordering is driven by the varying fish survival probabilities. Our results indicate that the environmental group is essentially indifferent between the two canal alternatives. Although the dual-conveyance has a broader range of expected utility outcomes than the peripheral canal does; its best outcome has a higher value and its worst outcome has a lower value than the corresponding values for the peripheral canal alternative. This result is dictated by our survival function calibration, which followed the PPIC Report and required the baseline environmental performance of the peripheral canal and dual-conveyance alternatives to be identical.

Our final stakeholder group represents in-Delta interests. This group has a strong preference for continuing at least some through Delta pumping because this would guarantee that levee maintenance would continue and significant quantities of fresh Sacramento River water would flow into the Delta. The through Delta alternative is preferred to a dual-conveyance alternative because more maintenance occurs when all exports are routed through the Delta. Stopping exports altogether is preferred to constructing a peripheral canal. Neither the peripheral canal nor stopping exports results in continued levee maintenance, but stopping exports all together maintains freshwater flows into the Delta.

Figure 5 presents the same information as Figure 4, reorganized by grouping policy alternatives together and using different colored shading to indicate each stakeholder group. This grouping facilitates the identification of policy alternatives likely to be acceptable to a broad number of groups. Looking at this figure, we see that stopping all exports and continuing through Delta exports perform poorly for at least two stakeholders (agricultural, urban, and in-Delta interest for the former, and taxpayers, environmentalists, and perhaps the two export user groups for the latter). The single conveyance peripheral canal plan performs well for all groups except in-Delta interests. The dual conveyance alternative emerges as a possible compromise. It performs less well for the agricultural and urban users and the taxpayers, but is still an improvement on either stopping exports or continuing through Delta pumping. Moreover, it represents a substantial improvement for in-Delta interests.

To assess the robustness of our conclusions to changes in the parameters we had to specify somewhat arbitrarily in the absence of information regarding the appropriate values from the PPIC report or elsewhere, we varied the values of several key parameters and recomputed utility levels. These experiments indicate that our conclusions are robust to many of these changes. One key parameter is the degree to which levee maintenance expenditures vary with the amount of through-Delta exports. Our baseline results were calculated assuming that maintenance costs are proportional to the level of exports. If, however, this relationship is concave so that most of the maintenance costs are paid even with smaller levels of through Delta exports, the dual-conveyance alternative performs worse for taxpayers and the water export users. Figures 6—8 demonstrate how these groups' expected utility varies with changes in Exp_{Maint}, the parameter governing this relationship.

Counter-intuitively, increasing stakeholder groups' risk aversion generally increases the expected utility they receive, and is especially likely to raise the utility of the worst possible parameter value outcome. This occurs because the sources of risk included in the utility calculations are fish survival and levee failure probabilities. The values in Table 2 indicate that the worst values for these probabilities are actually quite certain—a 95% probability of levee failure and a 5% survival rate for smelt. Increasing stakeholder groups' level of risk aversion thus makes them willing to choose a lower level of average utility in exchange for less variation in utility outcomes. Consequently, the expected utilities from the parameter realizations that yield low but predictable utility are closer to those that yield higher, but less predictable utility.

Conclusions

The results presented in Figure 4 and Figure 5 suggest that among the export strategies available to the state, the dual-conveyance option may be the most politically feasible. At first glance, this may seem to conflict with the PPIC Report's claim that "there seems little reason to prefer a dual facility over a peripheral canal." In reality, however, the results are not contradictory; they simply reflect different modeling approaches.

The PPIC Report explicitly sought to avoid politics and focused on two criteria: maximizing ecosystem performance and minimizing statewide costs. In doing so, the report implicitly weighted the financial gains of each group equally. In contrast, we do not make any comparisons across stakeholders; we simply identify the range of impacts each alternative has for each stakeholder group. The dual-conveyance alternative emerges as a possible compromise because it avoids large losses for any individual group.

Thus far, the political process has tracked our predictions quite well. The Strategic Plan selected the dual-conveyance option as its preferred alternative noting that dual-conveyance "recognizes the need to maintain flows through the Delta for water supply and ecosystem health." Our results are consistent with the interpretation that the Blue Ribbon Task Force was sensitive to the political nuances and may have chosen dual-conveyance in part to ensure in-Delta interests that the Delta itself would not be totally abandoned.

Although our findings are consistent with the evolution of the political process to date, the model in its current form excludes some important policy considerations. In future work, we plan to extend the model to incorporate additional policy options and stakeholders, as well as refining the definitions of how the model's components are related. One example of such an extension would be to incorporate the possibility of reduced upstream diversions of Sacramento River water via water trading between upstream users and Delta exporters. In order to do so, an upstream user group would need to be included as a stakeholder, and the relationships between Delta inflows, outflows, and fish populations would need to be refined.

An advantage of the model methodology employed in this chapter is that the incorporation of such extensions is relatively straightforward. The basic structure of the model presented in Figure 2 is very flexible. Once the necessary numerical information is obtained, new elements can be added to **x**, **f**(**x**), and **u**(**y**) relatively easily. Our approach thus facilitates exploring which extensions or variations have significant impacts on the results.

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Figures

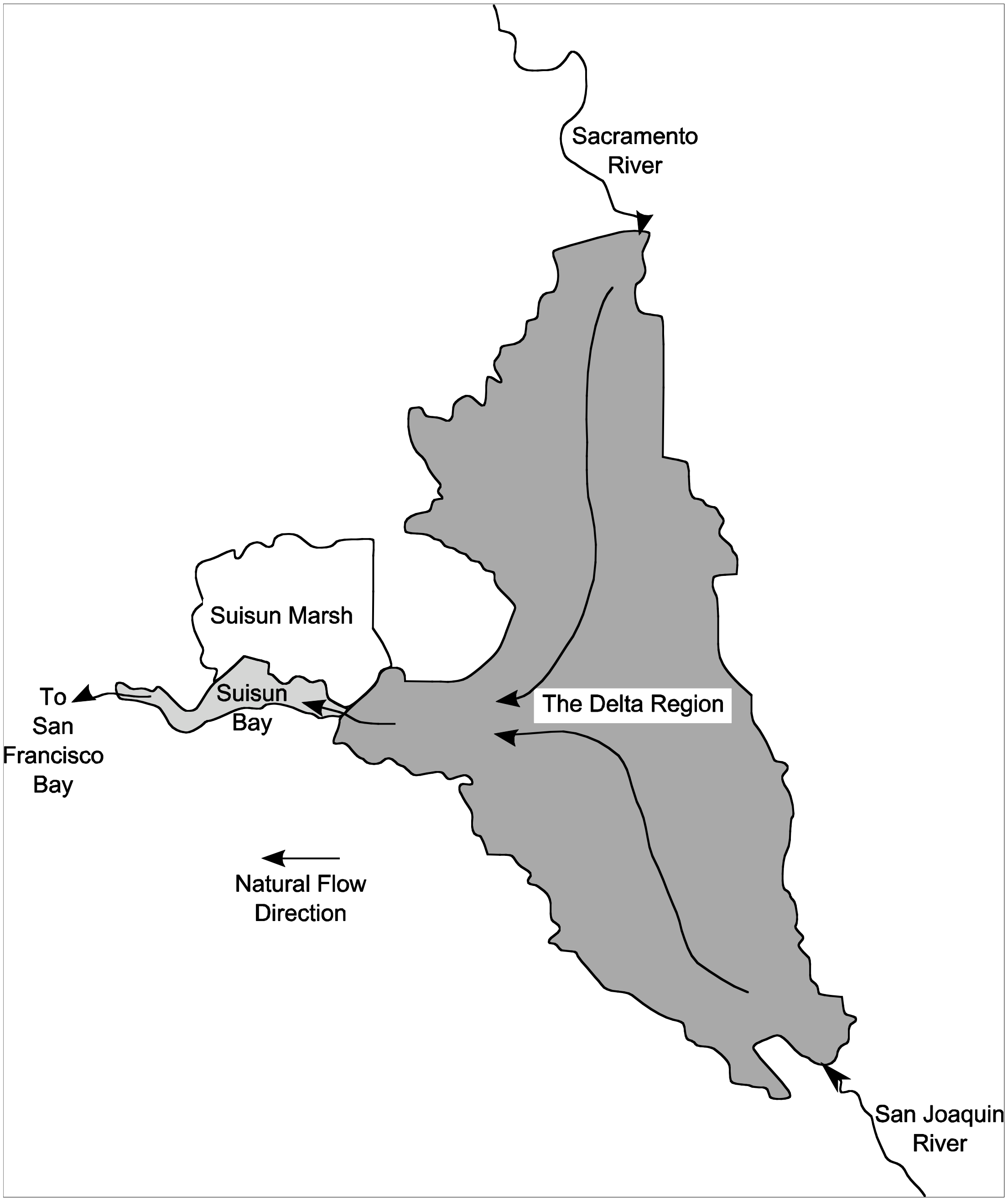

Figure 1: Delta Region (Data sources: California Spatial Information Library 2008; Delta Vision 2008)

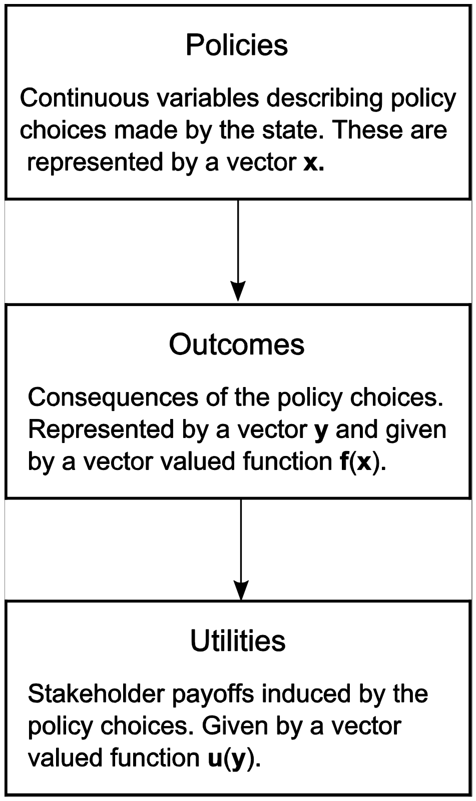

Figure 2: Model Schematic

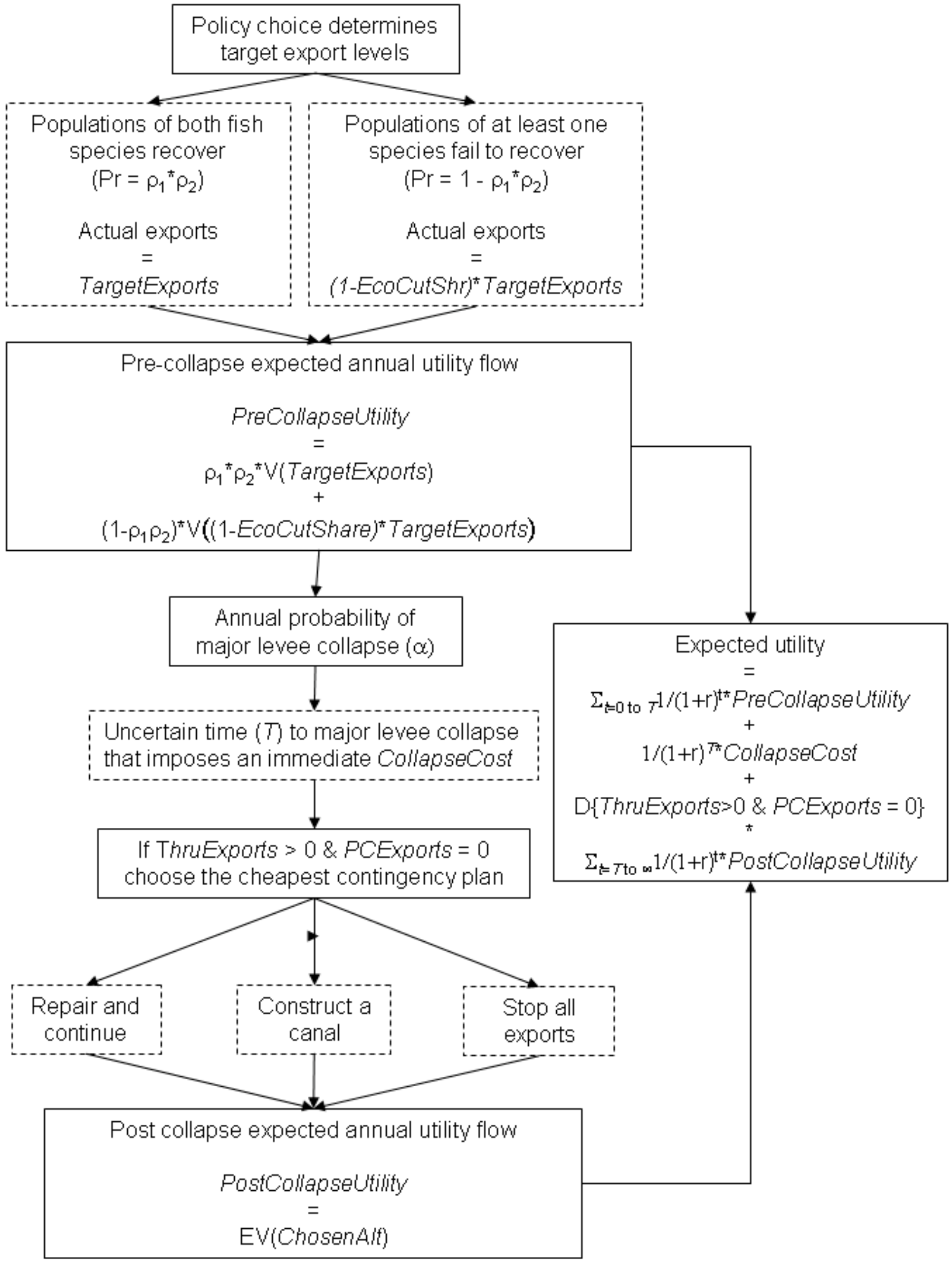

Figure 3: Event Tree

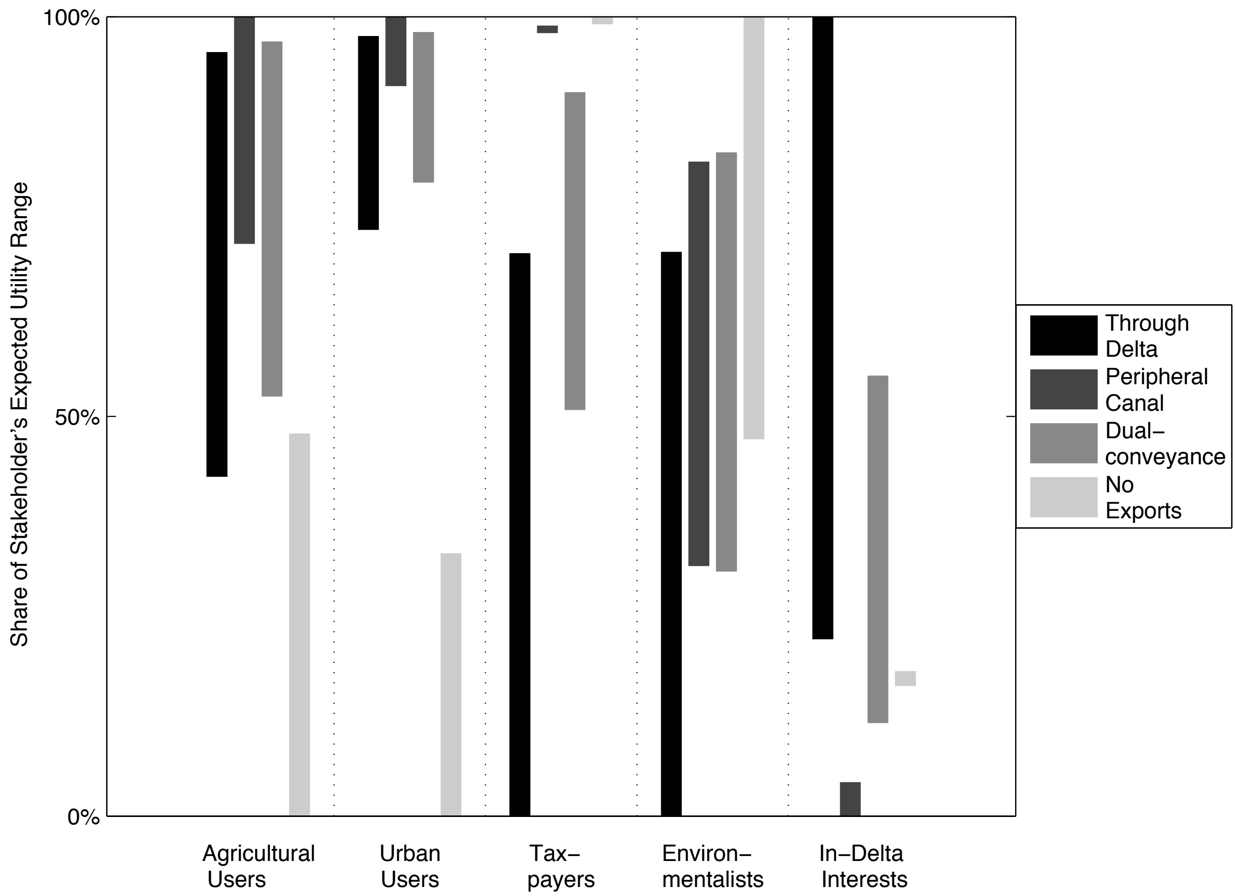

Figure 4: Expected Utility of Policy Alternatives by Stakeholder

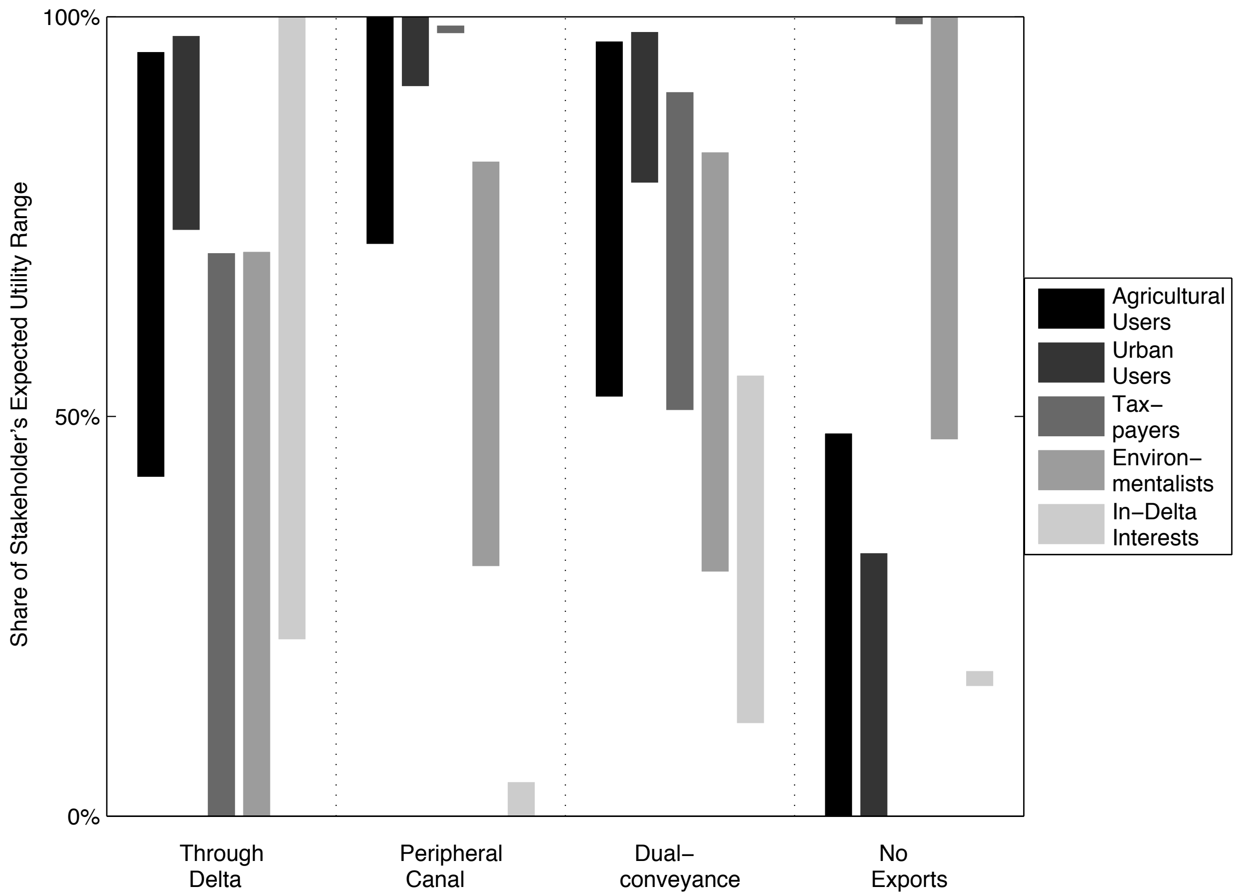

Figure 5: Stakeholder Expected Utility by Policy Alternative

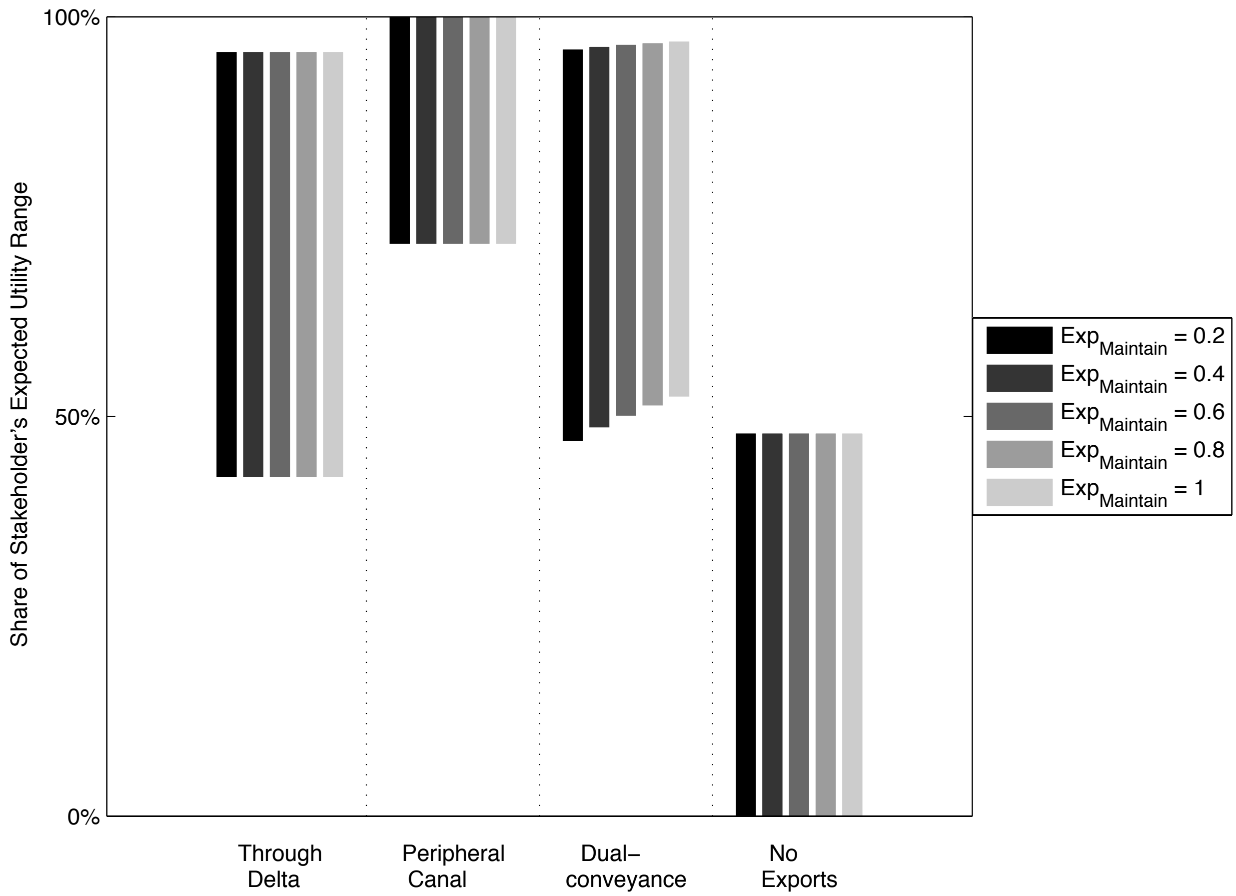

Figure 6: Impact of Exp_{Maint} on Agricultural Stakeholder

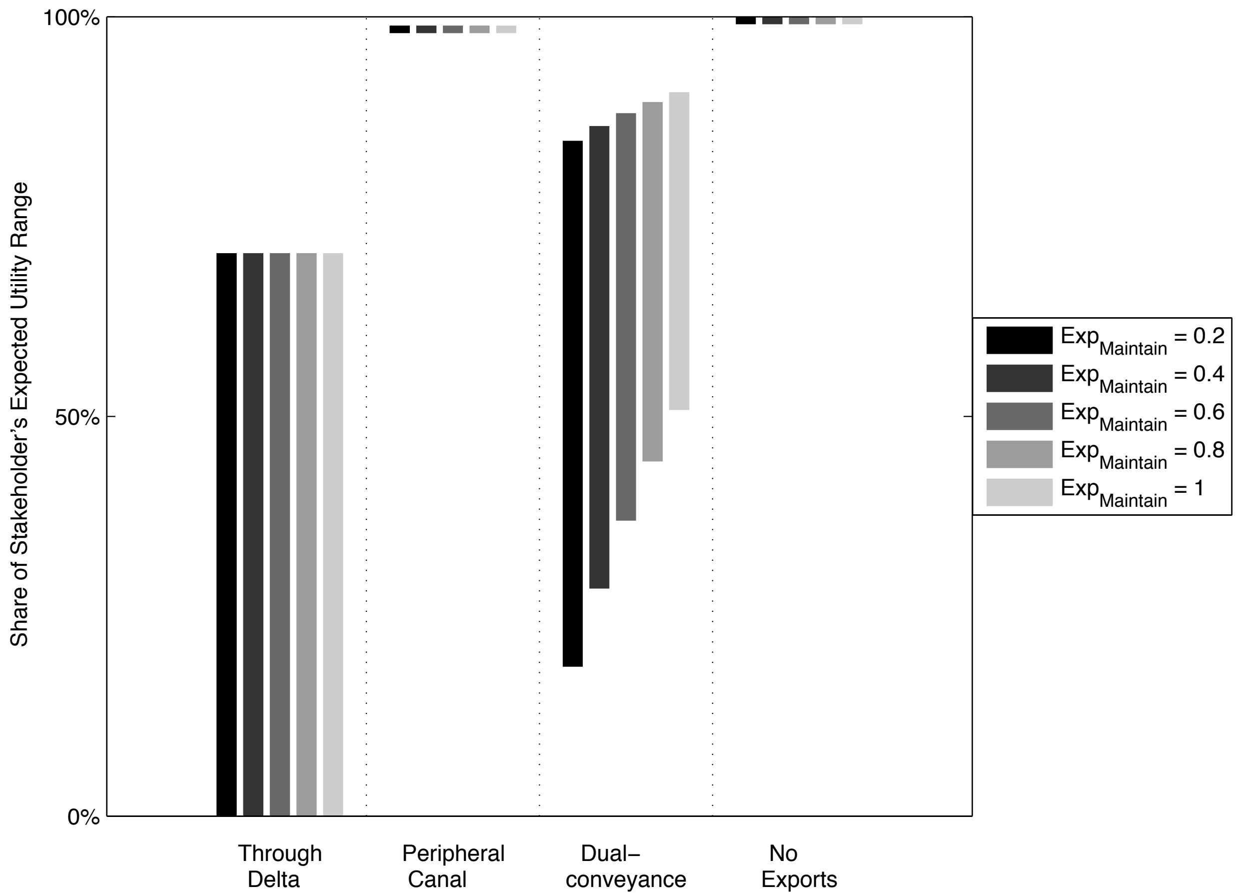

Figure 7: Impact of Exp_{Maint} on Taxpayer

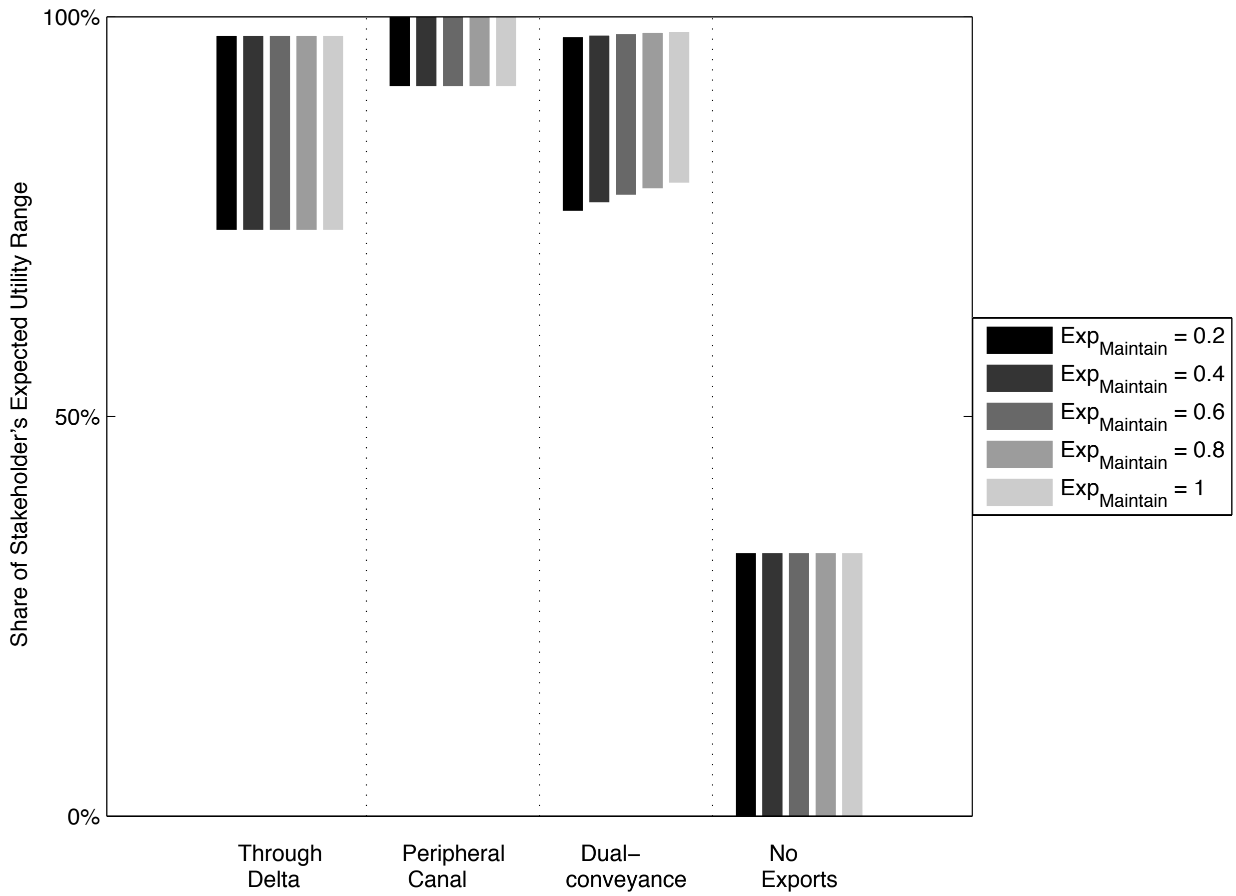

Figure 8: Impact of Exp_{Maint} on Urban Stakeholder

Tables

Table 1: Values Specified for Modeling PPIC Policy Choices

PPIC Policy Option	ThruExports (maf)	PCExports (maf)
Continue through Delta exports	6	0
No exports	0	0
Peripheral canal	0	6
Dual-conveyance	3	3

Note: These values refer to targeted export volumes and are prior to ecosystem driven export reductions.

Table 2: Scientific Uncertainty Ranges

Parameter Name	Low Value	High Value
CollapseCost ($ billion)	7.8	15.7
RepairCost ($ billion)	0.2	2.5
ConstructionCost ($ billion)	4.75	9.75
TreatCost ($ billion/yr)	0.3	1
ϕ_{ag}^{*}	1.58	3.95
ϕ_{ur}^{*}	3.17	6.52
ReductionShr	10%	40%
Collapse Probability	34%	95%
$CostNX_{ag}$ ($ billion/yr)*	0.49	0.96
$CostNX_{ur}$ ($ billion/yr)*	1.10	1.54
MaintainCost ($ billion/yr)	1	2
α_{smelt}^{*}	45.19	97.53
α_{salmon}^{*}	77.53	158.63
β_{smelt}^{*}	-0.04	-0.10
β_{salmon}^{*}	-0.10	-0.21
γ_{smelt}^{*}	-1.93	-2.31
γ_{salmon}^{*}	-2.31	-3.86
δ_{smelt}^{*}	-0.78	-1.10
δ_{salmon}^{*}	-1.10	-1.98

Source: 2008 PPIC Report.
*Calibrated (See Appendix).

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1 By contrast, for example, when a government invokes eminent domain to acquire an individual's house, market prices for comparable houses provide a starting point to determine the "appropriate" degree of compensation

2 The agencies that signed the original Memorandum of Understanding creating the Bay Delta Conservation Plan process include: California Bay Delta Authority, California Department of Water Resources, California Department of Fish and Game, U.S. Bureau of Reclamation, U.S. Fish and Wildlife Service, NOAA Fisheries, Kern Country Water Agency, Metropolitan Water District of Southern California, Zone 7 Water Agency, Santa Clara Valley Water District, San Luis and Delta-Mendota Water Authority, and Westlands Water District.

3 Strictly speaking, the Delta is an estuary, not a true river delta, but following popular usage, we refer to the Delta throughout this chapter.

4 In 2006, a legal settlement reached under the threat of litigation and strong pressure from both the judge and elected officials created an obligation to restore San Joaquin River flows to allow the re-introduction of salmon to the river (Friant Water Organization 2006).

5 As discussed below, recent court rulings have reduced water exports to a significantly lower level.

6 According to one analysis, the average short-term economic impact of these cuts is $500 million annually. Urban users in the South Coast region are expected to be hit especially hard in the short run. Over the long run as urban users are able to adjust to the new cuts, losses fall to approximately $140 million annually. However, if the state were to enter a long drought, losses could be as high as $3.2 billion annually in the short run and nearly $900 million in the long run (Sunding, et al. 2008).

8 Economic analysis suggests that repairing the Jones Tract was a sound financial decision. The PPIC Report estimated the total value of assets on the tract at $550 million.

9 There is some concern about entrainment of salmon in the new intakes on the Sacramento River. A variety of state-of-the-art fish protection technologies are being considered. Building adequate fish protection into a new system from the beginning is likely to be more effective than trying to re-engineer the fish protection system at the South Delta pumping plants,

suggesting that the peripheral canal may aid the smelt while the possible negative effects of its intakes on salmon can be mitigated to some extent.

10 Birmingham et al. (2008) was signed by individuals affiliated with the following groups: California Chamber of Commerce, Kern County Water Agency, Metropolitan Water District of Southern California, San Luis & Delta-Mendota Water Authority, Santa Clara Valley Water District, Southern California Water Committee, Tulare Lake Basin Water Storage District, Water Resources Subcommittee of the California Building Industry Association, and Westlands Water District,

11 The PPIC Report specifically mentions "the Hayward intertie, the Hetch-Hetchy Aqueduct, Mokelumne Aqueduct, Colorado River Aqueduct, and the proposed New Don Pedro intertie" (Tanaka, et al. 2008, p. 21).

12 While a 50–50 decision is an arbitrary choice, altering the allocation of exports between the canal and the through-Delta options is unlikely to affect the qualitative nature of our results. Intuitively, this is the case because the dual-conveyance option has some of the effects of each conveyance method on players' utilities.

13 It is conceivable that increases in the efficiency of conveyance due to the adoption of a peripheral canal may increase total "effective" water exports for a given amount of water diversions. We abstract fromthis issue here, and assume that pre-Wanger exports are the maximum feasible exports.

14 The information provided in the Appendix provides direct allocation of some costs to these stakeholder groups. For other costs, we estimated the allocation between the two groups. Another consideration is that the costs provided in the modeling results do not reflect payments

for water transfers between groups. We generate rough estimates of the size of transfer payments by comparing the willingness to pay of water purchasers and the willingness to sell of water buyers.

15 Strictly speaking, ESA-mandated cutbacks will occur in the future. Following the PPIC Report, we abstract away from the time required to construct a canal and implicitly assume that its impact on fish happens instantaneously.

16 It is quite possible that in the event of a major failure, California and/or the Delta would be declared a disaster area and the federal government would cover some of the costs of collapse. This change would compress the observed utility range for the taxpayers and increase the area of overlap between continuing through Delta pumping and the dual-conveyance alternative.

17 These computations incorporate the possibility of ESA-mandated export reductions for either the repair-and-continue scenario or the peripheral canal construction scenario.

18 The PPIC Report estimates no impact on urban users located within the Central Valley proper. In the aggregated results, there appear to be small impacts on both San Joaquin Valley and Tulare Basin urban interests. The impact on Tulare Basin urban interests is not present in the detailed results and was thus not used in our analysis. The detailed results reveal that the impacts identified as San Joaquin Valley urban impacts refer to increased costs borne by two Bay Area entities: the San Francisco Public Utilities Commission and the Santa Clara Valley Water District.

19 A utility function displaying constant elasticity of substitution requires that a proportional change in the price of two goods results in a proportional change in the quantities of

the two goods consumed. The general expression for a constant elasticity of substitution utility function for two goods x_1 and x_2 is

$$U\left(x_1, x_2\right) = \left(p_1 x_1^{\omega} + p_2 x_2^{\omega}\right)^{/\omega}$$

where p_1 and p_2 are the prices of the two goods, Ω is the constant parameter measuring the substitutability of the two goods for the consumer, and Γ is a parameter between 0 and 1 that represents the consumer's degree of risk aversion.

20 We focus on agricultural employment because it receives substantial attention in the press. The value is computed using a multiplier related to agricultural output. Thus, our results would be qualitatively similar if we instead used agricultural output itself, or a measure of all agriculturally-related economic activity or employment.