California's Sacramento-San Joaquin Delta Conflict: from Cooperation to Chicken

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Abstract

California's Sacramento-San Joaquin Delta is the major hub of California's water supply system and is central to the ecosystem of many native threatened and endangered species. Conflicts over the Delta have evolved over more than a century. This paper traces changes in this conflict in game theoretic terms, with its implications for the region's physical and ecological decline and governance. The Delta is not a zero-sum problem and win-win resolutions may exist if stakeholders cooperate. Game theory provides some insights on potential win-win solutions. The Delta problem has had a Prisoner's Dilemma structure, where stakeholder self-interest makes cooperation unlikely within a reasonable timeframe, especially given a lack of trust, reliable information, and the many stakeholders involved. However, the core of the game is changing as the unsustainable future becomes more widely apparent. Today's Delta problem has characteristics of a Chicken game, where cooperation is unlikely because parties deviating from the status quo are likely to bear more of the costs of a long-term solution. The state of California may be the victim (or chicken) of the Delta game, bearing the greatest costs, if it continues to rely on a policy of leaving parties to develop voluntary cooperative resolution without a sufficient mechanism for enforcing cooperation.

Keywords: Game theory, conflict resolution, Delta, CALFED, California, Chicken, Prisoner's Dilemma.

1. Introduction

California's Sacramento–San Joaquin Delta (Figure 1) is the state's major water hub supplying 25 million urban residents, roughly two million acres of farmland, and a unique ecosystem with more than 750 species of flora and fauna (State of California, 2007). Today's Delta differs greatly from its original 500,000 acres of tidal marshland and is now a subsiding land, supporting a diverse agricultural, recreational, residential, and economy. Sea level rise, land subsidence, earthquakes, climate change, floods, invasive species, and continued declines in native species have caused many to judge today's Delta land and water uses as "unsustainable" (Lund et al., 2007; 2010; Suddeth et al. 2010).

The diking and draining of the Delta's marshlands for agriculture began in the 1850s and induced subsidence of its peat soils, which continues today. Land subsidence (up to 7.6 meter in places) and sea level rise have increased seepage into islands, the likelihood of levee failures, and the costs of island flooding. Upstream and in-Delta water diversions, water operations, and land use changes have affected the Delta's water flows, quality, and suitability for different fish species. Major earthquakes – the greatest unavoidable threat to the Delta - can lead to simultaneous failure of many subsided islands, followed by large-scale inland flooding, sea water intrusion, interruption of water supplies for Southern California, the San Joaquin Valley, and the Bay Area, and disruption of power, shipping lines, and thousands of roads, bridges, homes, and businesses, which can cost tens of billions of dollars (URS Corporation and J.R. Benjamin and Associates, 2009). Climate warming is leading to higher sea levels, and less snow and more rain in California's watersheds shifting the runoff peak to winter and making flooding more likely. The Delta's native aquatic species are also declining. Aquatic and terrestrial species from other regions are invading the Delta, threatening the remaining native species and changing the ecosystem's structure. Today, nonnative species dominate the Delta, new species continue to arrive, and several fishes, including the delta smelt and several salmon runs are at risk of extinction (Lund et al., 2007, 2010).

All resource problems have a human component. Today's Delta crisis is not solely caused by physical, hydrological, and biological drivers (California DWR, 1986, 1989, 1995; Deverel and Rojstaczer, 1996; Deverel et al., 1998; Ingebritsen et al., 2000; Torres et al. 2000; CALFED, 2004; Mount and Twiss, 2005; Lund et al., 2007, 2010). Today's Delta crisis also originates from institutions, management, and expectations which are incompatible with how this system is inevitably changing. Debates on how to manage the Delta's water and land for conflicting agricultural, recreational, urban, and environmental interests have continued for almost a century. Conflicts among Delta stakeholders have led to California's failure in developing an effective resolution (Hanemann and Dyckman, 2009). To mediate the conflict and to fix the Delta, the CALFED Bay-Delta Program (CALFED) was created in 1994 (Lund et al., 2010). This "unique" collaboration among 25 state and federal agencies "to improve California's water supply and the ecological health of the San Francisco Bay/Sacramento-San Joaquin River Delta" (State of California, 2007) largely failed in addressing its primary goal. The lack of consensus on management strategies and options has led to lawsuits, pitting water exporters against both environmental interests and those who use water within the Delta (Lund et al., 2010).
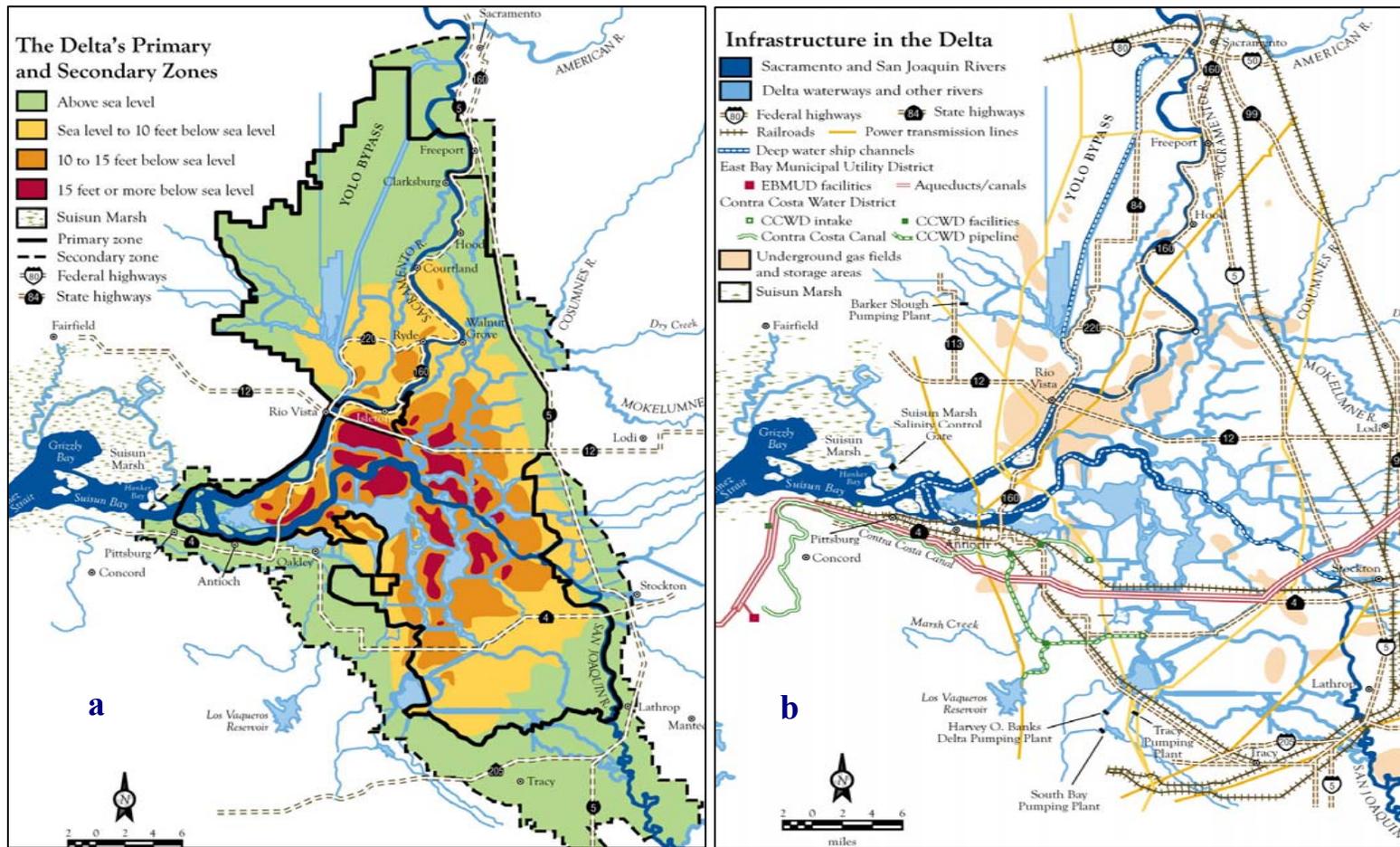
Figure 1- California's Sacramento–San Joaquin Delta (a-land subsidence; b- infrastructure) (Lund et al., 2007)

This paper uses game theory concepts to interpret the history of the Delta conflict, why the CALFED framework failed in making major strategic decisions, and prospects for the future. Game theory is the mathematical study of self-interested competitive and cooperative moves and countermoves for problems with more than one decision-maker. It often usefully describes the interactions of stakeholders whose individual behaviors result in worse conditions for all parties, despite a common interest in reaching a potential win-win solution (von Neumann and Morgenstern 1944; Myerson 1997; Camerer 2003; Madani 2010). Game theory has been applied to a variety of water and environmental resources problems in the past (Dinar et al. 1986; 1992; Dinar and Howitt 1997; Hipel et al. 1997; Carraro et al. 2005; Parrachino et al. 2006; Zara et al. 2006; Madani 2009; 2010; Hipel and Walker 2010). The mathematical study of stakeholder moves and countermoves within a simplified conceptual model of the Delta conflict highlights reasons for the failure of recent state and federal consensus policies for the Delta: "to encourage the main parties – agricultural and urban water diverters, and fisheries and other instream-protection interests – to work out a solution among themselves, rather than imposing one externally" (Hanemann and Dyckman, 2009). Parties to the Delta conflict are generally *self-optimizers,* as opposed to *global-optimizers*, giving priority to their own objectives rather than broader state or national objectives, resulting in failure of strategic governance which relies primarily on cooperation.

2. Delta in the 20th Century

The Delta's history can be separated into four periods of development, cooperation and conflict (Jackson and Paterson 1977, Lund et al. 2010; Moyle et al. 2010), summarized in Table 1. This paper focuses on the three most recent periods, beginning with cooperation among upstream, in-Delta, and water export interests in constructing upstream dams and water export facilities, starting in the 1930s. The paper discusses the changing Delta conflict during these periods from a game-theoretic perspective, identifying the structure of the conflict, and predicting possible resolutions of the game. The paper also discusses the stability of the status quo (the outcome if stakeholders do not change their strategies), and suggests how the state of California might act to change the game's structure to reduce future costs.

Table 1. Eras of Sacramento-San Joaquin Delta Management and Conflict

Era[*]	Description
a. Diking and Drainage *(1850-1910)*	Cooperation in land development
b. Upstream Water Diversions *(1910-1950)*	Conflict over water use; Cooperation for dam development
c. In-Delta Diversions and Fighting for More *(1950-1990)*	Conflict over water allocation
d. Deteriorating Delta *(1990-present)*	Conflict over water, cost, and risk allocation

[*] Dates are approximate

a) Diking and Drainage of the Delta (1850-1910). Initial European settlement of the Delta involved diking and drainage of most tidal marshland for agriculture and channelization for navigation and flood control (Thompson, 1957). This was a largely cooperative period when the early development of agriculture and transportation coincided with the Delta's relatively ample water supply and location near San Francisco and on route to the goldfields. Substantial

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cooperation arose from these developments being in the interest of local landowners as well as larger statewide interests in economic development.

b) Upstream Water Diversion Conflicts and Cooperation for Upstream Dams (1930s). In the early 1920s, well before major Delta water diversions, expanding upstream water diversions for agriculture greatly reduced summer inflows to the Delta. This brought major intrusions of saline water from the ocean far into the central Delta, with harm to in-Delta farming and local urban water users. Lawsuits were filed, with the courts finding that restricting the many upstream diversions to protect water quality for far fewer Delta diversions would be unreasonable (Young 1929; Matthew 1931a, b; Pisani 1986). However, salinity intrusion into the Delta also posed problems for developing major water export projects from the Delta and raised the need to control Delta salinity (Figure 2).
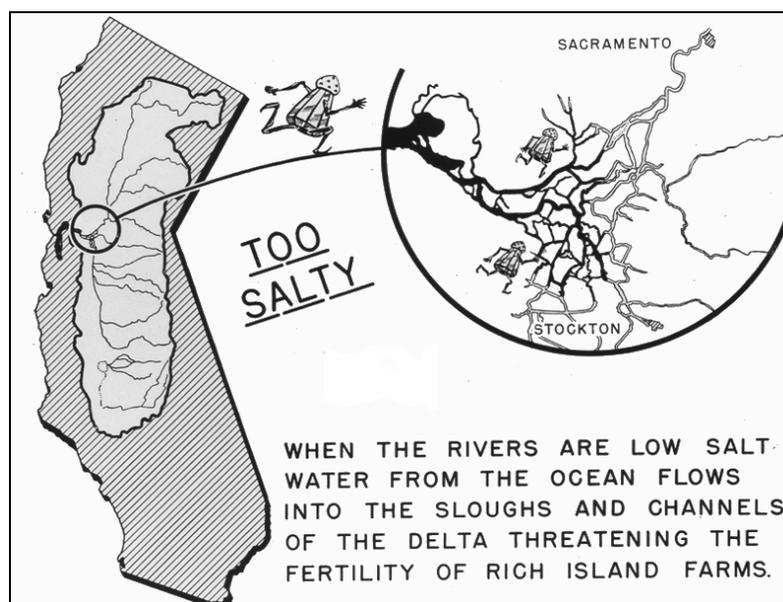

Figure 2- Salinization of the Delta as viewed before dam development (1945 USBR report)

This Delta crisis of the 1930s led to consideration of two major options, a physical barrier just east or west of Suisun Marsh to prevent salt water intrusion or a "hydraulic barrier" of freshwater outflows regulated by proposed upstream dams. Over a decade of discussion and analysis led to the decision to employ a "hydraulic barrier" to salinity intrusion, mostly based on costs, benefitting upstream diverters, in-Delta farmers and urban users, and future water export users, with the federal government (under the Central Valley Project) and export water users paying for the construction and operation of dams which provided export water supplies, water supplies for Delta outflows (the "hydraulic barrier") (Matthew 1931a, b), and improving the reliability of flows for water users upstream of the Delta. Despite implementation disputes, lawsuits, and controversy, the major parties to the Delta disputes of this time found a cooperative strategic solution for the Delta. The hydraulic barrier was less costly overall than a physical barrier. Export water users and the federal government were willing to pay for the dams and facilities needed to implement this solution. In-Delta users benefitted from this solution, over the then-status quo, without making major payments. And upstream water diverters in the Sacramento and San Joaquin basins continued to divert water without interruption, with additional flood

control and water delivery benefits from the water supply dams needed for the hydraulic barrier. At the time, there was enough water for all parties and the hydraulic barrier, the Delta islands were not yet deeply subsided, and there was little concern for native species.

Success in developing a cooperative solution to the Delta problem in that era was due to several factors lacking today:

1- Homogeneity of stakeholder interests: Without today's environmental and land subsidence concerns, the major concern was Delta salinity. Restricting salinity in the Delta was in the interests of all major in-Delta and water export stakeholders.

2- Availability of a mutually beneficial solution: All parties agreed that the hydraulic barrier (or even the physical barrier) solution could improve on the then-status quo and that export water users would pay for this solution. Rather than questioning the need for change, the parties were concerned with the cost of the solution and its allocation.

3- Supply exceeding demands: The dam regulation of flows would provide enough water for the hydraulic barrier, upstream diversions, and in-Delta users. This solution required no user to decrease its water use, and agricultural and urban water quality in the Delta would be improved.

4- Perceived benefits exceeded perceived costs. The physical barrier was found to be more costly than the hydraulic barrier (Matthew 1931b). Seeking reliable water supply and lacking environmental concerns, all parties felt building more dams and water facilities would benefit both the state and Delta users. The parties perceived benefits to be substantially higher than the costs, with benefits from water supply storage, flood control, hydropower, and navigation.

5- State and federal availability to develop large-scale water management infrastructure. The organization and analysis of this problem was largely undertaken by state and federal engineering agencies (Matthew 1931a, b). These agencies had technical and financial resources to develop and compare alternatives, and political willingness and legal authority to do so, within a broader political context involving stakeholders.

c) Fighting-for-more Era (1960s-1980s): Cooperation in dam construction and regulation of Delta outflows led to conflict as major water exports began and led to disputes over water abstractions and allocation. From the 1960s through the 1980s, the Delta was seen as a more complex problem, mostly involving the allocation of water between Delta outflows (seen as important for fish and western Delta urban and agricultural diverters), upstream water diverters, and growing water exports.

During this period, little incentive existed to cooperate and conflicts were common and vocal, as illustrated by the 1982 campaign against the proposed peripheral canal to divert water from the Sacramento River upstream and around the periphery of the Delta. A peripheral canal with growing demands in water importing regions was perceived as a threat to already established water uses upstream and in the Delta, particularly when combined with growing environmental concerns and water demands both upstream and in the Delta.

This period was a turning point in the Delta history, where the introduction of environmental needs and lack of enough water to satisfy all parties disrupted cooperation incentives and transformed the problem into a perceived zero sum game of water allocation among upstream, Delta, and export water users, with little attention paid to the Delta's broader sustainability. In a zero-sum game, gains to one party can only occur with losses to other parties.

d) Deteriorating Delta - Birth of CALFED (post-1980's): During this period more serious conflicts over sharing the Delta's water arose. These conflicts intensified with growing concerns about environmental deterioration and water needs. More multi-faceted problems in the Delta and California's water system became apparent in the 1988-92 drought, with particular attention on endangered species, water allocations, and the need to fix the deteriorating Delta. From this period emerged the CALFED Bay-Delta Program, a process to develop consensus solutions on how to fix the Delta, largely financed with state and federal funds. During this period, parties had observed the Delta problem symptoms, which alerted the parties to the unreliability of the Delta. Parties agreed that the Delta had problems and needed to be fixed. However, CALFED failed to develop a collaborative solution for several reasons, mainly the lack of external incentives for agreement (Bobker, 2009; Doremus, 2009; Hanemann and Dyckman, 2009).

3. Is the Delta Problem a Zero-Sum Game?

Some have suggested that the current Delta problem is a zero or constant-sum game (Hanemann and Dyckman 2009), with parties having strong mutually opposing interests and where improvements for one party inevitably imply losses for others. (In game theory, zero-sum games have the sum of all player payoffs equaling zero, and are equivalent to constant-sum games.) Such a finding suggests that increasing the benefit (water volume) to one party in the Delta necessarily decreases benefits to others, so a consensus bargaining solution cannot exist. It has been argued that except for the amount of water becoming available through water conservation, the total available water to the Delta users is constant, so the problem is a zero-sum game. Sharing the costs of solving Delta problems also is said to be a constant-sum game, where reducing the cost to one party increases costs to other parties. This inherently non-cooperative situation is said to be a major reason for the failure of CALFED or other consensus approaches to the Delta (Hanemann and Dyckman, 2009) – that cooperative solutions simply do not exist.

Here, using a cooperative game theory Nash-Harsanyi solution (Harsanyi, 1959 and 1963), we argue that the Delta problem may not be a zero-sum game, and that mutually beneficial solutions might exist. The Nash-Harsanyi bargaining solution generalizes the Nash bargaining solution (1953) for an *n*-player game. Based on this solution, Ω is a unique solution to the *n*-player bargaining game under several axioms:

$$\Omega = \max \prod_{i=1}^{n} (x_i - d_i) \qquad (1)$$

subject to:

$$\sum_{i=1}^{n} x_i \leq S \quad \text{(resource availability constraint) (2)}$$

$$x_i \geq d_i \qquad \text{(individual rationality constraint) (3)}$$

$$x_i,\ d_i \geq 0 \qquad \text{(non-negativity constraint) (4)}$$

where x_i is the benefit share to player i under cooperation; d_i is the share to player i when acting individually (non-cooperation), S is the total available resource, and $(x_i - d_i)$ is the gain to player i from cooperation.

If this bargaining model is applied to the Delta problem, assuming that parties bargain over the shares (water volumes received) in a given time step (say a year), suggests the game has no solution other than $\Omega = 0$, with $x_i = d_i$ where water allocations remain at the status quo, the game is a zero-sum, and parties have no incentive to cooperate. The individual rationality constraint (Equation 3) dictates that an increased share for one party should not decrease the share to any other party. Thus, when all water is initially allocated, shares cannot change from the status quo and the problem remains a zero-sum game. However, applying the above formulation to the Delta problem with these assumptions may be misleading for two reasons:

1 - The parties do not simply bargain over their share during a long period (say a year). Instead, they bargain over shares over smaller time steps (e.g. day, week, month, etc.). Also, parties do not play each game separately, meaning that they do not bargain over water shares in a given time step (say a month) without considering their shares at other times (Madani, 2009). Therefore, the bargaining consists of multiple bargaining games, each individually being a zero-sum game with no compromise resolution ($\Omega = 0$), if played separately. However, if linked feasible solutions expand to create the possibility that parties accept a *strategic loss* in less important time periods to gain in more important time periods, so that all parties might gain overall (Madani, 2009), provided the parties have different preferences for water deliveries over time. A party to the Delta conflict (i) may be willing to strategically lose x units of water in month n in exchange for y units of water ($y < x$) in month m if and only if he can increase his utility ($U_n(x) < U_m(y)$).

2 - For the Delta, parties bargain over more than just water volumes. Similar to water, other resources and costs are to be allocated for the Delta, including land of various types, water qualities of different types, monetary costs of actions and economic losses, and risks and uncertainties, all occurring over time. Each party has different preferences for mixed water, economic, land, and uncertainty outcomes over time. The linkage of these allocation games (each separately a zero-sum game) expands the set of feasible solutions and increases the possibility of a non-zero solution, where everyone gains from cooperation.

These allow the Delta bargaining problem to be formulated as follows based on the extension of the Nash-Harsanyi bargaining solution to n-player k-linked games (Madani 2009):

$$\Omega = \max \prod_{i=1}^{n} (\sum_{j=1}^{k} U_{i,j}(x_{i,j}) - U_{i,j}(d_{i,j})) \qquad (5)$$

subject to individual rationality and resources availability constraints, where for player $i=1, 2, ..., n$ and time step $j=1, 2, ..., k$:

$U_{i,j}(x_{i,j})$ is the utility of player i in the cooperative case at time j from its new share $x_{i,j}$; and $U_{i,j}(d_{i,j})$ is the utility of player i in the non-cooperative case at time j from its current (regulated) share $d_{i,j}$.

Since the utility of player *i* at time *j* ($U_{i, j}$ *(*$x_{i,j}$*)*) is not necessarily linear or homogeneous with the received amount of water, the Delta bargaining game is not essentially zero-sum as the sum of players' utilities depends on how total available water is shared among the players between time steps. Such nonlinearity together with linkage of the games allows for exchange of water, land, water quality, cost, risk, and other asset and liability shares over time and seems likely to include in win-win solutions ($\Omega > 0$).

The overall Delta problem seems unlikely to be a zero-sum game, as the Delta's water, cost, land, and risk sharing are all linked with multiple decisions over time and heterogeneous preferences for this mix of attributes among the parties to the conflict. This expanded bargaining problem seems likely to have a mutually-beneficial solution, and be a non-zero cooperative game overall. Nevertheless, transaction costs arising from the strong and frequent conflicts among numerous interests may prevent achieving a cooperative solution even within a non-zero sum structure, as happened in the CALFED framework. The next section discusses why a bargaining solution is unlikely within a reasonable timeframe for a consensus framework relying on broad voluntary agreement.

4. Possibility of Cooperation with a Non-Decaying Delta

The Delta bargaining problem may have a mutually-beneficial resolution *if* parties all decide to cooperate. However, the Delta stakeholders may never reach a cooperative resolution in a reasonable timeframe within a consensus framework. For simplicity, we consider only two historically-opposed bargainers over the Delta, noting that the overall result seems unlikely to change with more stakeholder groups, given the symmetric structure of the game.

Figure 3 shows the simplified Delta problem in a matrix form for two major players: Water Exporters seek more water from the Delta, and Environmentalists, concerned with the Delta ecosystem, seek more Delta outflow (less export). Each cell contains two values. The first value (left) is the Water Exporters' payoff and the second value is the Environmentalists' payoff. Here, payoffs are ordinal, with higher values being more desirable, and represent a player's utility of water under that outcome. The strategies for Delta Exporters are given on table's left and on the table's top for Environmentalists.

In this Delta game (Figure 3) each player has two options: cooperation or no-cooperation. The party who decides to cooperate will modify its current share (the quantities of water, land, costs, and risks over various time periods) and a player who selects no-cooperation will continue to receive its current share as before. For this game, the outcome most preferred by each party is getting a free ride, with the other party reducing its regulated water and resource shares (outcome (DC, C) for Water Exporters and outcome (C, DC) for Environmentalists). The second most preferred result (outcome (C, C)) occurs when both parties cooperate. As discussed previously, if both parties cooperate, a bargaining solution may become available (trading becomes possible) with higher payoffs for both players (a win-win solution) compared with the status quo (outcome (DC, DC)). Each player prefers non-cooperation (DC, DC) to cooperation (which reduces its share) as long as the other party does not cooperate ((C, DC) for Water Exporters and (DC, C) for Environmentalists).
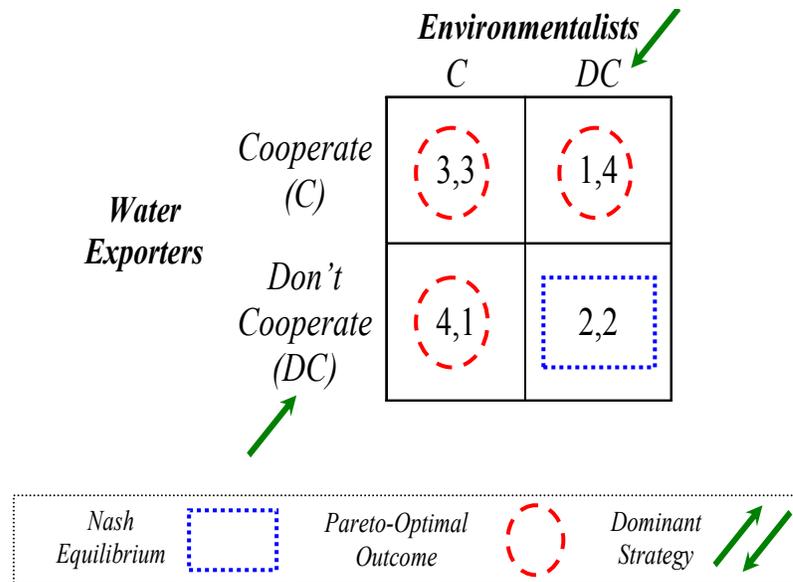
Figure 3- The Delta game within the CALFED framework

The Delta problem illustrated in Figure 3 has a Prisoner's Dilemma (PD) structure, which can result in tragic undesirable outcomes (Hardin, 1968; Madani, 2010). Even though the parties can gain more from cooperation ((C, C) is Pareto-optimal), non-cooperation (DC) is the strictly dominant strategy. Pareto-optimal situations are those in which it is impossible to make one player better off without making at least another player worse off. A strategy is dominant for a given player if, regardless of what the other players do, the strategy results in higher payoff for that player than any other strategy. Depending on whether "higher" is defined with weak (higher or equal) or strict inequalities (just higher, not equal), the strategy is termed dominant or strictly dominant, respectively. No matter what strategy the other player selects, each player is always better off choosing non-cooperation (4> 3 and 2> 1). Thus, the status quo, a Pareto-inferior non-cooperative outcome (DC, DC), is a Nash equilibrium and the most likely result to the conflict. An outcome is a Nash equilibrium if no player can improve its payoff by changing its decision alone (Nash, 1951). Similarly, CALFED and other such consensus processes are often unsuccessful in finding a cooperative solution, having some players preferring the status quo to non-binding cooperation.

In a classical Prisoners' Dilemma game (PD), communication among the players, explaining the problem to the parties, and binding contracts or other forms of trust might lead to cooperative and win-win resolutions where parties mutually agree (in a binding way) to cooperate for a Pareto-optimal outcome. Achieving a cooperative win-win resolution was the objective of CALFED. Collaboration through negotiation and collective decision-making among stakeholders were expected within the CALFED framework, perceiving that a collaborative process could alter the outcomes perceived by the stakeholders by: 1) uncovering new and mutually beneficial opportunities; and 2) encouraging an exchange of information and perhaps a degree of social learning from interaction among stakeholders to help shift each party's perception of its individual payoff (Hanemann and Dyckman, 2009). Both mechanisms functioned in CALFED, along with early promises of sizable state and federal financial support. So why was CALFED still unsuccessful? Based on the discussions so far, CALFED might have succeeded in promoting

a cooperative resolution. However, such an achievement should not be expected in a reasonable timeframe, given the conflict's PD structure with so many parties (a cooperative resolution within a PD structure becomes less likely as the number of players increase (Axelrod and Keohane, 1985; Oye, 1985; Axelrod and Dion, 1988)), lack of information, trust, a non-binding long-term framework, and insufficient support and motivation from the State. In such a situation, players prefer to act individually, resulting in the Pareto-inferior outcome.

The difficulties of obtaining a consensus to cooperate in a reasonable time period are illustrated in Figure 4, showing the probability of n parties agreeing to a solution if each party has the same high probability of being agreeable. For a large complex problem, such as the Delta, with many parties and many parties whose traditions and internal dynamics reduce their likelihood of cooperating even under favorable circumstances, the average probability of agreement is less than one, the overall probability of a consensus agreement becomes rather small. Here the probability of agreement is merely the probability of individual agreement raised to the number of parties involved.
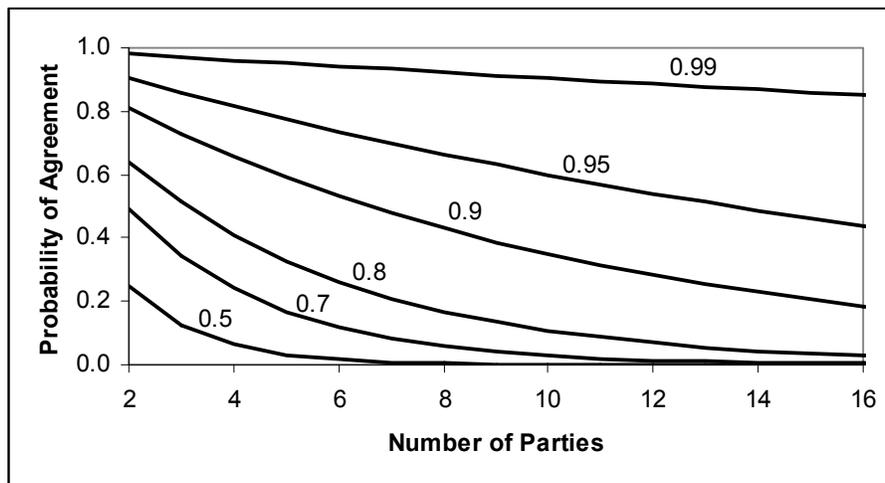

Figure 4 - Probability of Consensus with Number of Parties and Probability of Agreeability

Above, the Delta problem was modeled as a 2-player game. In practice, there are dozens to potentially thousands of stakeholders. However, the analysis results and the PD aspect of the game would not change with more players, due to symmetry. The non-cooperative strategy would still strictly dominate for all stakeholders involved (except for the state of California, if considered as a player) and the status quo non-cooperative solution would be an equilibrium and the most likely outcome.

5. Possibility of Cooperation with an Alternative Plan

Some proposed Delta solutions do not force any party to decrease its share of water. Two major proposals for the Delta are investment in levee repairs and construction of a peripheral canal or tunnel. For a broader look at the Delta problem, Figure 5 shows the Delta game after a new option - Alternative Plan (AP) – is added. Here, the players must choose between reducing their share from the Delta, implementing an alternative plan which has some costs (but no reduction in shares), or the sticking to the status quo. Table 2 summarizes each outcome and the

corresponding ordinal rank for each player. The ranking of outcomes is based roughly on the history of stakeholder positions in the Delta conflict. The best outcome for each player is the outcome where the Delta problem is addressed by the other player without any contribution from themselves, no matter what strategy is adopted by the other player (Reduction (R) or Alternative Plan (AP)). Thus, outcomes (BAU, R) and (BAU, AP) are equally preferred by Water Exporters and (R, BAU) and (AP, BAU) are equally preferred by Environmentalists.
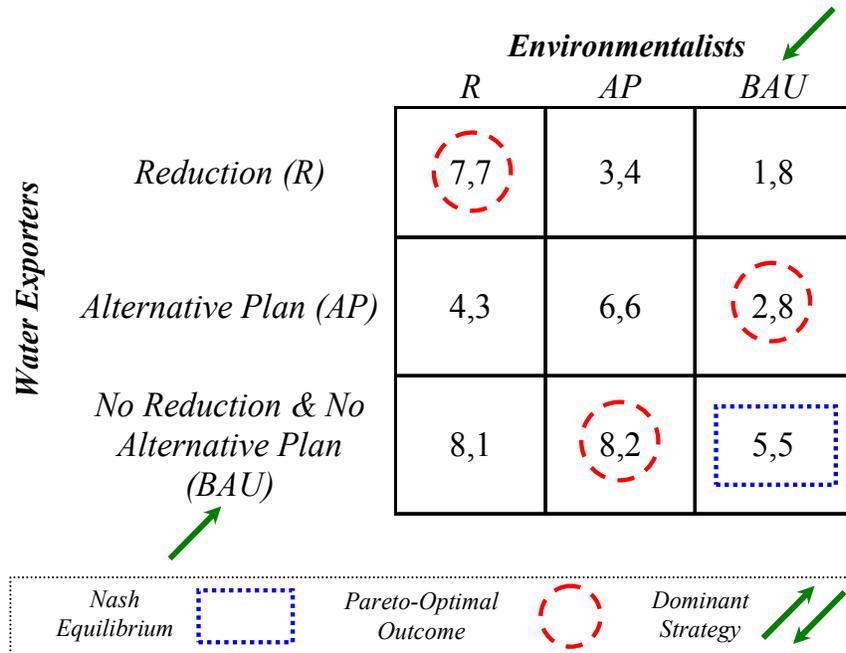

Figure 5- The Delta game with inclusion of an alternative plan for fixing the system

Based on the structure of the game and players' preferences for the available outcomes, the Reduction (R) strategy is strictly dominated by the business-as-usual (BAU) strategy, meaning that no natter what the other player does, a player is always better off choosing BAU rather than R (8> 7, 8> 3, and 5> 1). Thus, it is possible to remove Reduction (R) from the strategy set of players. Figure 6 is the simplified version of Figure 5 after one round of iteration (removing R from the game) and ordering the players' payoff for the remaining 4 possible outcomes. The structure of the simplified game (Figure 6) is similar to the Delta game without the AP strategy (Figure 3). The game retains a PD structure and the cooperative Pareto-optimal outcome (AP, AP) is less likely for this structure from the tendency to seek a free-ride and the strict domination of the non-cooperative strategy (BAU). Even providing players with an option other than share reduction cannot resolve the problem. This Delta problem has a Prisoners' Dilemma core which makes cooperation difficult.
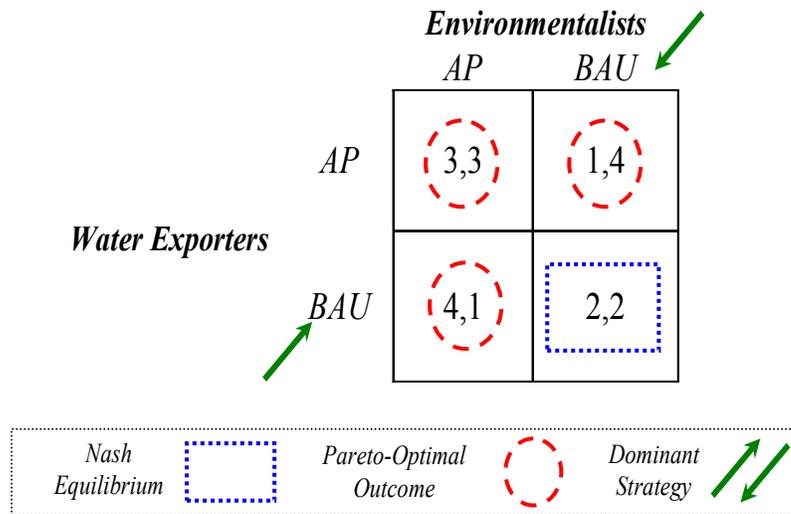
Figure 6- Simplified version of the Delta game with inclusion of an alternative plan for fixing the system (PD game structure)

Table 2- Ranking and description of the possible outcomes of the Delta game (with inclusion of an alternative plan for fixing the system)

Outcome	Rank (for Player $i \neq j$)	Description
(BAU, R) (BAU, AP)	8	The Delta problem is addressed by share reduction or alternative plan by the other player (player $j \neq i$) while player i keeps to receive at least its current share without contribution to costs of the alternative plan implementation.
(R, R)	7	Both parties are willing to cooperate and reduce their shares. As a result they may be able to increase their utilities by trading, which may not include share reduction necessarily (no side-payments).
(AP, AP)	6	Both parties share the cost of implementing an alternative plan without reducing their water shares.
(BAU,BAU) Status Quo	5	Both players neither reduce their shares nor pay for implementing an alternative plan. The delta will function as is (business-as-usual).
(AP, R)	4	Player i does not reduce its share and keeps to receive at least its current share while player j reduces its share. However, player i takes care of all costs associated the alternative plan without any contribution by the other player.
(R, AP)	3	Player i reduces its share while the other player takes care of all costs associated with implementing an alternative plan without reducing its share.
(AP, BAU)	2	Only player i pays the costs of implementing the alternative plan while neither of the players reduces its share.
(R, BAU)	1	Neither of the players pays for implementing an alternative plan, but player i reduces its share while the other player does not.

Thus, the Delta problem, at least in a static form, seems unlikely to be resolved in a timely manner within any framework relying on voluntary cooperation of stakeholders, considering the preferences and numbers of the players, their *self-optimizing* attitude, lack of binding

agreements, and their perceptions about the Delta's future. The next section examines the effects of the Delta's continuing decline on the prospects for agreement on a common solution.

6. The Unsustainable Delta and its Transition Problem

As real-world conflicts evolve, so do their corresponding game-theoretic structures, players' payoffs, and possible outcomes (equilibria of the game) (Madani, 2010). Knowledge of such changes can provide insights into the problem. The Delta game has evolved over time and the problem structures discussed so far are likely to change as the Delta's condition continues to deteriorate. Decline or collapse of the current system with drastic costs to stakeholders is expected without some major changes in policy (Lund et al., 2007; 2010). If the unreliable future of the Delta is common knowledge to all players, the Delta conflict (Figure 3) develops a new structure (Figure 7, where C (cooperation) implies agreement to a strategic change and DC implies continuing with the current declining situation).

Figure 7- The Delta chicken game within the CALFED framework with an "unsustainable Delta"

The Delta transition problem (Figure 7) has a Chicken game structure. The Chicken game is an anti-coordination game with no dominant strategy and two non-cooperative Nash equilibria in which one party loses to the other ((DC, C) and (C, DC)). Outcomes (DC, C) and (C, DC) are Pareto-optimal, but not equitable (fair) and one outcome (C, C) is the only cooperative outcome of the game which is both Pareto-optimal and equitable. This is similar to the 1950s teenage driver game (immortalized in films) of two cars heading towards a precipice at top speed, with the "winner" being the last driver to veer from the cliff.

In this problem (Figure 7) the payoff values provide little initial incentive for cooperation, and ultimately the best strategy is doing the opposite of the other player. Similar to the PD problem, parties like to free ride. If one party decides to cooperate, it takes on more responsibility for changes and costs for the Delta; the other party then benefits most by not cooperating. A fair cooperative outcome for the conflict can alleviate the Delta crisis (C, C) but is less likely as each party prefers to wait, hoping that another party takes care of the problem. A good individual tactic in this game is to send strong signals of unwillingness to cooperate (Madani, 2010) and waiting as long as possible to force others to deviate from a non-cooperative strategy. In the

Delta Chicken game, the risk of high future costs from non-cooperation (DC, DC) (Delta failure) is so high that eventually one player prefers to change its strategy and lose in the battle to minimize future costs. Lack of trust and clear information about the future (such as when the Delta will fail) and having many stakeholders together promote non-cooperation in the game. In a chicken game, players with less risk tolerance are more likely to lose. In this game, the knowledge of increased possibility of high costs due to natural disasters, such as earthquakes or floods, can encourage players to veer from non-cooperation and avoid more dramatic costs.

When stakeholders' perceptions about the Delta's future change and unsustainability becomes widespread, adding an alternative AP strategy to the Delta game transforms the problem to Figure 8. Although each stakeholder prefers that others solve the problem for them (free-ride), the status quo (failing Delta) is not preferred to the outcome where that stakeholder should solve the problem on its own. Thus, the non-cooperative resolution (BAU, BAU or crash) is the worst outcome for both players.

Figure 8- The Delta game with inclusion of an alternative plan for fixing the system with an "unsustainable Delta"

Although this game (Figure 8) is not a simple two-by-two Chicken game, the Chicken structure remains. The cooperative resolution to the game ((R, R) or (AP, AP)) is unlikely. Similar to the Chicken game, there are two equilibria, with one loser ((BAU, AP) and (AP, BAU)). Again, given the payoff values in the game, there is no incentive for cooperation and the costs of the non-cooperative status quo are so high that one party (loser) will eventually deviate from its non-cooperative strategy and implement the alternative solution without concessions from the other player (the "winner"). Interestingly, no likely outcome of the game ((BAU, AP) and (AP, BAU)) includes mutual concessions. Due to symmetry of the problem, including more players (except for the state of California) will not change the results. The chicken core remains present and the game eventually has winners and losers, or only losers.

Cooperative solution of the Delta problem is extremely difficult. Even as some environmentalists find that the status quo is not in the interest of native fish, there is always incentive for the least risk-sensitive stakeholders to remain the last to agree to a cooperative solution, as a way of exacting greater concessions of policy or resources from others. Because a major Delta disaster is likely from random events such as an earthquake or flood, the risk-sensitivity of different stakeholders becomes especially important.

7. State Involvement in Resolving Conflict

The state of California has shown interest in voluntary agreement among the Delta stakeholders, achieved by encouraging the main parties to devise solutions among themselves. So far, the presented game structures reflect this policy and exclude the state of California or other potential strong authorities as a player. The problem structure and game results might change with State involvement. Figure 9 shows the unsustainable Delta game (Figure 8) when California is added. (Without unsustainability, the game is a prisoners' dilemma, where the state's dominant strategy is also non-cooperative, and status quo is the likely outcome). Since the game has 3 players, more than one matrix is needed to show the game in a normal (matrix) form. Each cell now has three values, from left to right, representing the payoffs of Water Exporters, Environmentalists, and State government. California's options are given below each matrix. California has two options: California can 1) Interfere (I) in the game and bear a share of the cost of an alternative solution or compensate the player which reduces its share to create an incentive for concessions; or 2) Not interfere (NI), letting the parties solve the problem among themselves. (State interference can also consist of attempting to compel parties to agreement, at some cost and risk.) Since California has two options, two matrices are needed to represent the game in a normal form. For this new game, the best outcome for any individual player is a free ride, and the Delta problem is solved by concessions from other players. The worst outcome leaves the Delta unattended, an outcome resulting from non-cooperation (BAU, BAU, NI). Players rank the other outcomes based on their share of the cost. For instance, the cooperative outcome (AP, AP, I), in which parties share the cost of the alternative plan, is better than any other outcome in which only one party makes all of the concessions. The players are indifferent between outcomes which yield the same result. For example, except for the non-cooperative outcome, the State is indifferent between all the possible outcomes in which the Delta problem is alleviated at no cost to the State (8 outcomes).

In this problem (Figure 9), parties have no dominant strategy. The game has 3 Nash equilibria, in which only one party tries to solve the Delta problem by implementing an alternative plan on its own, without any contribution by others. These equilibria are outcomes (BAU, BAU, I), (BAU, AP, DI), and (AP, BAU, DI). Again, characteristics of the Chicken game persist, even for the State. Cooperative outcomes are unlikely (besides the 3 Nash equilibria which are also Pareto-optimal, there are 3 cooperative Pareto-optimal outcomes) and one party will end up giving a free ride to the other two. The party least tolerant of risk seems destined to make the most concessions (chicken out). The notion that the state or federal government might bail out Delta stakeholders after a failure can prolong the chicken game, even past the point of collapse, introducing a form of *moral hazard* among stakeholders.

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8. Discussion: Urgency of State or Federal Action

Figure 10 shows how the Delta game's structure has evolved since the since 1930s. Cooperation in the early 20th century was possible due to the homogeneity of the stakeholders' interests and the availability of enough water to satisfy all demands. Later, the introduction of environmental needs and unavailability of water to satisfy all demands encouraged the stakeholders to adopt non-cooperative behaviors and compete for gaining more from the Delta, with less concern for the Delta's future. As potential improvements from cooperation became apparent, CALFED was formed as a largely consensus process. However, within a Prisoner's Dilemma structure non-cooperation remained a dominant strategy and a cooperative solution failed to develop. Realization of the continuing decline and unsustainability of the Delta, have produced a new structure. The Delta solution problem now has a Chicken game structure, where Delta failure is the only possible result if stakeholders adhere to non-cooperative strategies.

	Environmentalists		
Water Exporters	R	AP	BAU
R	13,13,7	7,9,4	3,14,5
AP	9,7,4	11,11,6	5,14,3
BAU	14,3,5	14,5,3	14,14,2

California: *Interfere (I)*

	Environmentalists		
Water Exporters	R	AP	BAU
R	12,12,8	6,8,8	2,14,8
AP	8,6,8	10,10,8	4,14,8
BAU	14,2,8	14,4,8	1,1,1

California: *Don't Interfere (DI)*

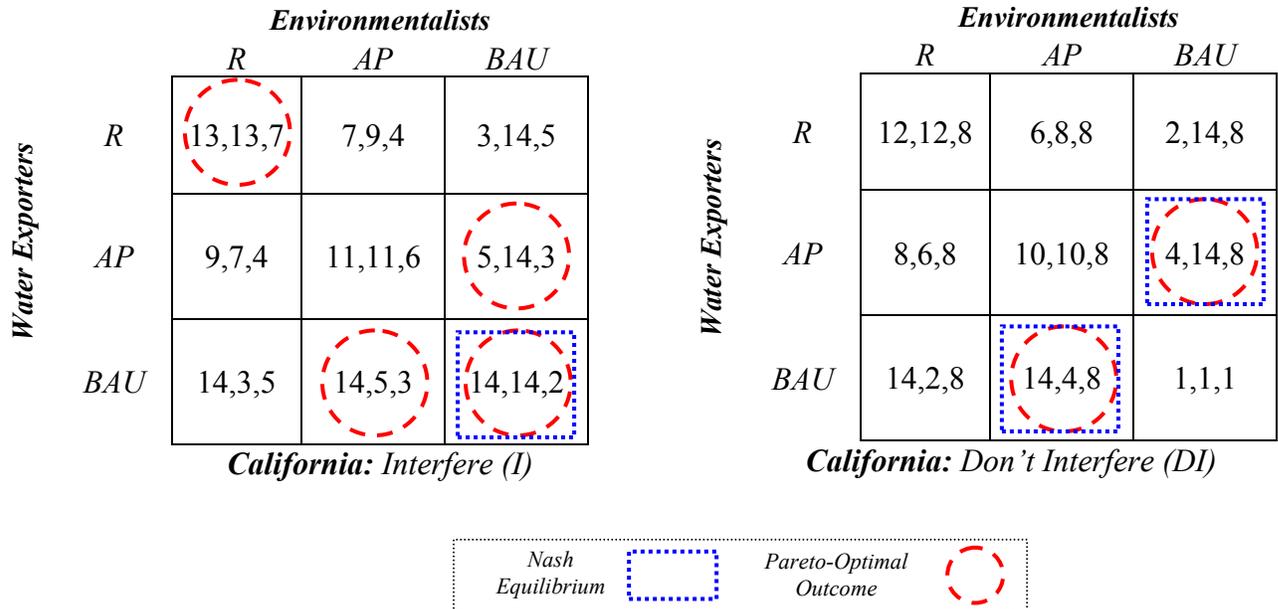| Nash Equilibrium	Pareto-Optimal Outcome

Figure 9 - The unsustainable Delta game with the state of California added

Given the improbability of local parties coming to an effective consensus solution, the state and federal strategy of not intervening or imposing an external solution may result in high losses to taxpayers from eventually paying most for the Delta's transition, perhaps in unfavorable circumstances after an earthquake or flood. State and federal involvement to foster a solution might involve a new Delta governance mechanism which enforces or entices a more cooperative resolution. Otherwise, at least one party, particularly the state, will lose substantially. Some groups will have more chance to win due to their lesser sensitivity to risks from continuing the status quo. Outside the cooperative games illustrated here, some parties are also likely to seek external non-cooperative solutions, such as court decisions, to compel concessions from other parties, as is occurring for the Delta. Although, court orders to reduce water exports do not resolve the problem completely and cannot bring stability to the conflict, they can reduce utility and increase risk for other parties.
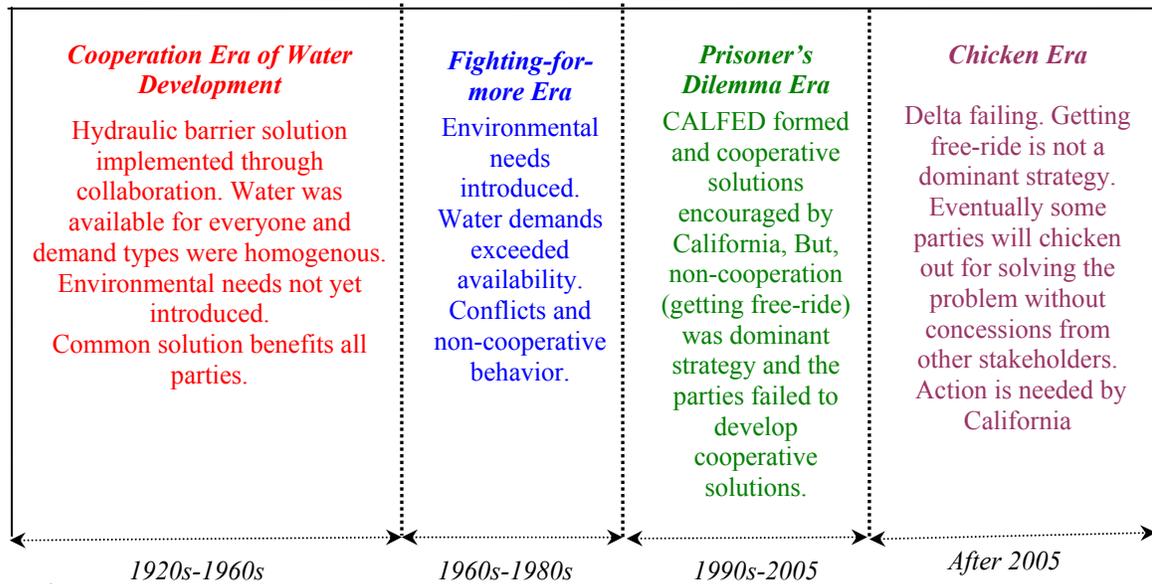
Cooperation Era of Water Development	Fighting-for-more Era	Prisoner's Dilemma Era	Chicken Era
Hydraulic barrier solution implemented through collaboration. Water was available for everyone and demand types were homogenous. Environmental needs not yet introduced. Common solution benefits all parties.	Environmental needs introduced. Water demands exceeded availability. Conflicts and non-cooperative behavior.	CALFED formed and cooperative solutions encouraged by California, But, non-cooperation (getting free-ride) was dominant strategy and the parties failed to develop cooperative solutions.	Delta failing. Getting free-ride is not a dominant strategy. Eventually some parties will chicken out for solving the problem without concessions from other stakeholders. Action is needed by California
1920s-1960s	*1960s-1980s*	*1990s-2005*	*After 2005*

Figure 10 – Delta problem's evolution over time

The Delta problem has evolved since the late 20th century and has had two different game-theoretic structures (Prisoners' Dilemma and Chicken). This difference is driven by the knowledge that the Delta is deteriorating unsustainably for almost all stakeholders and results in different decision equilibria among stakeholders. Knowledge of the conflict's evolution can assist decision makers and may lead to different behaviors. From the analyses so far, the state of California (perhaps with the federal government) might want to enforce cooperation through legal, financial, and regulatory incentives or compulsion or risk losing the most from waiting for the parties to solve the problem on their own. Within the Delta Chicken game, parties wait to cooperate until the situation is so bad that other parties chicken out and pay more of the transition cost, often incurring higher costs overall. If a party is going to chicken out in the future, it is better off to chicken out today at a lower cost of "fixing" the Delta than is likely in the future. If California fails to enforce or entice cooperation among the parties, it may become the victim of the game itself, having to incur greater costs from outright failure. Water exporters, who are wealthier than other parties of the game, also seem likely to become the final Chicken, especially with environmental lawsuits. Failing into a long-term solution is likely.

Financial incentives to cooperate can be useful. But, can state or federal government provide enough incentive? State payments might be proportional to the loss to the State from non-cooperation and Delta collapse. The same is true for cost sharing mechanisms for resolving the problem. Stakeholders' shares of Delta transition costs may be relative to their loss from Delta collapse. Parties to the Delta have different utility levels from the Delta's services, and all are decreasing with time. One mechanism shares costs based on benefits from the Delta. To better manage the Delta, the state might make parties report their benefits. If parties know they will pay according to their benefits, they tend to report low benefits. However, to prevent such behavior, compensation might be relative to a party's reported benefits. To minimize loss in case of receiving compensation or paying cost shares the dominant strategy is reporting benefits

accurately. Alternatively, the State could impose a Delta use fee on all water users which would be reduced substantially once agreement has been made.

9. Conclusions

The Delta problem has evolved over time, from cooperation to Chicken. In the early 20th century Delta stakeholders agreed to cooperative solutions to solve the Delta problem. Later fights over water allocations started and parties preferred to compete rather than cooperate. Yet, the Delta problem is not necessarily a zero-sum game. Since Delta stakeholders bargain based on their utilities from water, land, money, and risk over time rather than water shares alone, a cooperative win-win resolution which includes trading across resources and liabilities may be possible. However, the Prisoners' Dilemma structure of the conflict with many stakeholders leads parties to not cooperate. A cooperative win-win resolution for a static Delta is unlikely in a timely manner, especially with so many stakeholders. This is a structural reason for failure of consensus processes to agree to an available win-win solution and the default tendency to retain the status quo.

Stakeholders' preferred decisions are likely to change with greater understanding of the Delta's unsustainability. The Delta is not a static problem and is worsening with time from almost all perspectives. Such changes transform the core conflict from a Prisoners' Dilemma to a game of Chicken. The Chicken game is particularly devilish given the stochastic and potentially abrupt transition likely for the Delta. Nevertheless, a cooperative solution is unlikely without external interference. Many parties will prefer keeping the Delta as is until fear of Delta failure rises enough to make the least risk tolerant player adopt an alternative plan. The dominant strategy for the player who will be chickening out is to chicken out today, as its losses can be lower today than after a collapse. However, since no party is willing to be the chicken, they wait, hoping to win the game, either by forcing concessions from other stakeholders or concessions or aid from the state or the courts, with the game perhaps prolonged by expectations of state and federal aid in the event of collapse, in a form of *moral hazard*.

Including the state of California (or federal government) with two options did not fundamentally alter the game. For the cases examined, the Chicken characteristics remained and cooperation was unlikely. Adding the state to the game suggested that California can be the victim of the conflict and the loser of the game, bearing much of the cost of a Delta failure, due to its past failure to develop reliable mechanisms which enforce cooperation.

Whatever plan is adopted to fix the Delta in the coming decades, the Delta's sustainability is not guaranteed without powerful mechanisms which provide incentives for cooperation or penalties for deviation from cooperation. While recent efforts address symptoms of the problem, they do not solve the main cause of a lack of strong, responsible governing mechanisms. California must "govern" the Delta or eventually pay for absence of effective governance.

Acknowledgments

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