

California's Sacramento–San Joaquin Delta Conflict: From Cooperation to Chicken

Kaveh Madani, A.M.ASCE¹; and Jay R. Lund, M.ASCE²

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 the potential for win-win solutions. The Delta problem has had a Prisoner's Dilemma structure, in which stakeholder self-interest makes cooperation unlikely within a reasonable time frame. However, the core of the Delta conflict is changing as the unsustainable future becomes more widely understood. Today's Delta problem has characteristics of a Chicken game, where cooperation is in everyone's interest, but it 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 become the victim (or chicken) of the Delta game, bearing the greatest costs, if it continues to rely on leaving parties to develop voluntary cooperative solutions without a sufficient mechanism for enforcing cooperation. DOI: 10.1061/(ASCE)WR.1943-5452.0000164. © 2012 American Society of Civil Engineers.

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Introduction

California's Sacramento-San Joaquin Delta is the state's major water hub, supplying 25 million urban residents, approximately 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 it is now a subsiding land supporting a diverse agricultural, recreational, and residential economy. Sea level rise, land subsidence, earthquakes, climate change, floods, invasive species, and continued declines in native species have caused today's Delta land and water uses to be widely judged as "unsustainable" (Lund et al. 2007, 2010; Suddeth et al. 2010; Hanak et al. 2011).

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 m 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 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, 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 also are declining. Aquatic and terrestrial species from elsewhere 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; Madani and Lund 2011).

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 1998; Ingebritsen et al. 2000; CALFED 2004; Mount and Twiss 2005; Lund et al. 2007, 2010; Hanak et al. 2011). Today's Delta crisis also originates from institutions, management, and expectations that 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 stymied effective resolutions (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 its primary goal. The lack of consensus on management has led to lawsuits, and the pitting of water exporters against both environmental interests and those who use water within the Delta (Lund et al. 2010; Hanak et al. 2011).

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This paper uses game theory concepts to interpret the history of the Delta conflict, to address why the CALFED framework failed in making major strategic decisions, and to discuss prospects for the future. Game theory is the mathematical study of self-interested competitive and cooperative actions 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 potential win-win solutions (von Neumann and Morgenstern 1944; Myerson 1997; Camerer 2003; Madani 2010; Madani and Hipel 2011). Game theory has been applied to various water and environmental resources problems (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 2010, 2011; Hipel and Walker 2010; Madani and Hipel 2011; Madani and Lund 2011). The mathematical study of stakeholder moves and countermoves within a simplified conceptual model of the Delta conflict suggests 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 decision-making, which relies primarily on cooperation.

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; Hanak et al. 2011), as 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 outcomes. 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 conflict’s structure to reduce future costs.

1. *Diking and drainage of the Delta (1850–1910)*. Initial European settlement 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 cooperation arose from these

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

2. *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 ocean water 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 1984). However, salinity intrusion into the Delta also posed problems for developing major Delta water export projects and raised the need to control Delta salinity.

This Delta crisis of the 1930s led to consideration of two major options, a physical barrier downstream 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 on the basis of costs, benefiting 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 that 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. In-Delta users benefitted from this solution, over the then-status quo, without making major payments. In addition, 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 less deeply subsided, and there was little concern for native species.

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

- a. 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,
- b. 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,
- c. 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 gave improved agricultural and urban water quality,
- d. 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 that building more dams

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

Era	Description
1. Diking and drainage (1850–1910)	Cooperation in land development
2. Upstream water diversions (1910–1950)	Conflict over water use; Cooperation for dam development
3. In-delta diversions and fighting-for-more (1950–1990)	Conflict over water allocation
4. Deteriorating delta (1990–present)	Conflict over water, cost, and risk allocation

Note: Dates are approximate.

and water facilities would benefit both the state and Delta users. The parties perceived benefits to be substantially more than the costs, with benefits from water supply storage, flood control, hydropower, and navigation, and

- e. State and federal availability to develop large-scale water management infrastructure. The organization and analysis of this problem was largely 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,
3. *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 Delta. A peripheral canal with growing demands in water importing regions was seen to threaten water uses upstream and in the Delta.

This period was a turning point in the Delta history, in which 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 to the Delta's broader sustainability. In a zero-sum game, gains to one party can only occur with losses to other parties.

4. *Deteriorating Delta—Birth of CALFED (post-1980s)*. During this period more serious conflicts arose over sharing the Delta's water. These conflicts intensified with growing concerns about environmental deterioration and water needs. More multifaceted problems became apparent in the 1988–1992 drought, with particular attention on endangered species, water allocations, and the need to fix the deteriorating Delta. The CALFED Bay-Delta Program emerged as a process to develop consensus solutions for 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, primarily the lack of external incentives for agreement (Bobker 2009; Doremus 2009; Hanemann and Dyckman 2009).

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 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, in which reducing the cost to one party increases costs to other parties. This inherently noncooperative 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.

In this study, using a cooperative game theory Nash-Harsanyi solution (Harsanyi 1959, 1963), it is argued 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 (Nash 1953) for an n -player game. On the basis of this solution, Ω is a unique solution to the n -player bargaining game under several axioms:

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

subject to

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

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

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

where x_i = benefit share to player i under cooperation; d_i = share to player i when acting individually (noncooperation); S = total available resource; and $(x_i - d_i)$ = 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 [Eq. (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). 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 2011). 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 2011), provided parties have different preferences for water deliveries over time. A party to the Delta conflict (i) may strategically forego 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. Other resources and costs also are allocated, including land of various types, various water qualities, 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 nonzero solution, where everyone gains from cooperation.

These allow the Delta bargaining problem to be formulated as follows on the basis of the extension of the Nash-Harsanyi bargaining solution to n -player k -linked games (Madani 2011):

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

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

$U_{i,j}(x_{i,j})$ 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 noncooperative case at time j from its current (regulated) share $d_{i,j}$.

Because 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 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 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 conflicting parties. This expanded bargaining problem seems likely to have a mutually beneficial solution and be a nonzero cooperative game; 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 such as the CALFED framework. The next section discusses why a bargaining solution is unlikely within a reasonable time frame for a consensus framework relying on broad voluntary agreement.

Possibility of Cooperation with a Nondecaying Delta

The Delta bargaining problem may have a mutually beneficial resolution if parties all cooperate; however, the Delta stakeholders may never reach a cooperative resolution in a reasonable time frame within a consensus framework. For simplicity, only two historically opposed bargainers over the Delta are considered, noting that the overall result seems unlikely to change with more stakeholder groups given the symmetric structure of the game.

Fig. 1 shows the simplified Delta problem in matrix form for two major players: Water Exporters seek more water exports, and Environmentalists, concerned with the Delta ecosystem, seek more Delta outflow (less export). Each cell has two values. The first value (left) is the Water Exporters' payoff; the second value is the Environmentalists' payoff. In this case, payoffs are ordinal, with higher values more desirable, and they represent a player's utility of water under that outcome. The strategies for Delta Exporters are rows and Environmentalists are columns.

In this Delta game (Fig. 1) each player has two options: cooperation or noncooperation. 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 noncooperation will continue to receive its current share. For this game,

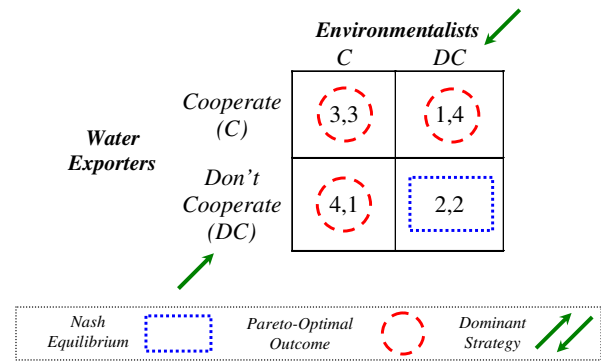


Fig. 1. The Delta game within the CALFED framework

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 outcome (C, C) occurs when both parties cooperate. 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 noncooperation (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].

The Delta problem illustrated in Fig. 1 has a Prisoner's Dilemma (PD) structure, which can have tragic, undesirable outcomes (Hardin 1968; Madani 2010). Even though the parties can gain more from cooperation [(C, C) is Pareto-optimal], noncooperation (DC) is the strictly dominant strategy and the parties' likely choice [how interactions of parties' self-optimizing actions may cause Pareto-inferior outcomes despite higher possible gains from the Pareto-optimal outcomes is explained in Madani (2010)]. 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 causes higher payoffs 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 noncooperation ($4 > 3$ and $2 > 1$). Thus, the status quo, a Pareto-inferior noncooperative outcome (DC, DC), is a Nash equilibrium and the most likely conflict outcome. 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, with some players preferring the status quo to nonbinding cooperation (as the Pareto-optimal solution is not a Nash equilibrium).

In a classical Prisoner's 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 win-win resolutions in which parties mutually agree (in a binding way) to cooperate for a Pareto-optimal outcome (Madani and Hipel 2011). Achieving a cooperative win-win resolution was the objective of CALFED. Collaboration through negotiation among stakeholders was 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 exchange of information and

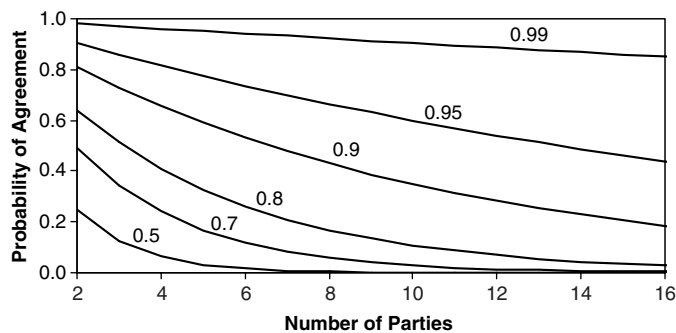


Fig. 2. Probability of consensus with number of parties and probability of agreeability

perhaps social learning from interactions among stakeholders to 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? On the basis of the

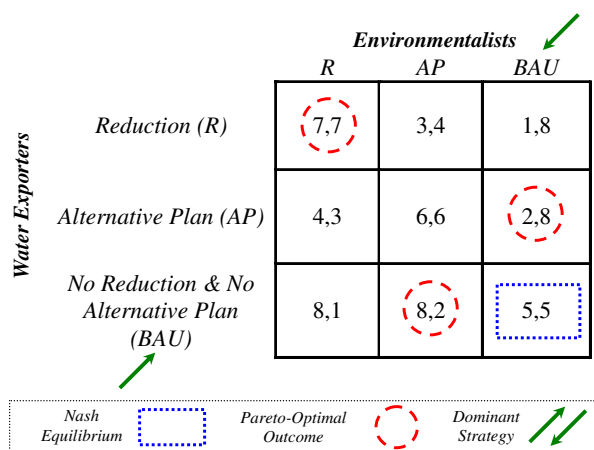


Fig. 3. The Delta game with inclusion of an alternative plan for fixing the system

discussions so far, CALFED might have succeeded in promoting a cooperative resolution. However, such an achievement should not be expected in a reasonable time frame 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 nonbinding 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 Fig. 2, 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, and 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.

Previously, the Delta problem was modeled as a two-player game. In practice, dozens to potentially thousands of stakeholders exist; however, the analysis results and the PD aspect of the game would not change with more players because of symmetry. The noncooperative strategy would still strictly dominate for all stakeholders involved (except for the State of California, if considered as a player), and the status quo noncooperative solution would be an equilibrium and the most likely outcome.

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, Fig. 3 shows the Delta game after a new option—Alternative Plan (AP)—is added. In this case, the players must choose between reducing their share from the Delta, implementing an alternative plan with some costs (but no reduction in shares), or sticking to the status quo. Table 2

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) and (BAU, AP)	8	The Delta problem is addressed by share reduction or alternative plan by the other player (player $j \neq i$) and 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) or 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; whereas, player j reduces its share. However, player i takes care of all costs associated with the alternative plan without any contribution by the other player.
(R, AP)	3	Player i reduces its share; whereas, 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; 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, whereas, the other player does not.

summarizes each outcome and the corresponding ordinal rank for each player. The ranking of outcomes is based approximately on the history of stakeholder positions in the conflict. The best outcome for each player is the outcome in which the 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.

Given 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 matter 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. Fig. 4 is a simplified version of Fig. 3 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 (Fig. 4) is similar to the Delta game without the AP strategy (Fig. 1). 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 noncooperative strategy (BAU). Even providing players with an option other than share reduction cannot resolve the problem. This Delta problem has a Prisoners' Dilemma core making cooperation difficult.

Thus, the Delta problem, at least in a static form, seems unlikely to be resolved in a timely manner within any framework relying on the 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. Next, in "Delta Unsustainability and Transition" the effects of the Delta's continuing decline on the prospects for agreement on a common solution are examined.

Delta Unsustainability and Transition

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 conflict 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; Hanak et al. 2011). If the unreliable future of the Delta is common knowledge to all players, the Delta conflict (Fig. 1) develops a new structure [Fig. 5, where C (cooperation) implies

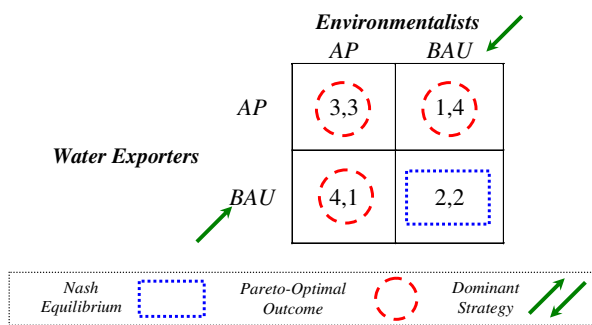


Fig. 4. Simplified version of the Delta game with inclusion of an alternative plan for fixing the system (PD game structure)

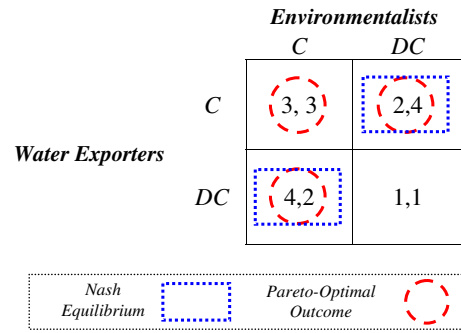


Fig. 5. The Delta chicken game within the CALFED framework with an "unsustainable Delta"

agreement to a strategic change and DC implies continuing with the current declining situation].

The Delta transition problem (Fig. 5) has a Chicken game structure. The Chicken game is an anticoordination game with no dominant strategy and two noncooperative 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 that is both Pareto-optimal and equitable. This is similar to the 1950s teenage driver game (immortalized in films) of two cars heading toward a precipice at top speed with the "winner" as the last driver to veer from the cliff.

In this problem (Fig. 5), 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 transition; the other party then benefits most by not cooperating. A fair cooperative outcome for the conflict (C, C) can alleviate the Delta crisis but is less likely as each party prefers to wait, hoping 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 noncooperation (DC, DC) (Delta failure) is so high that eventually one player prefers to change its strategy and lose now 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 noncooperation. 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 resulting from natural disasters, such as earthquakes or floods, can encourage players to veer from noncooperation and avoid more catastrophic future 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 Fig. 6. Although each stakeholder prefers that others solve the problem for them (free-ride), the status quo (failing Delta) is not preferred to the outcome in which that stakeholder should solve the problem on its own. Thus, the noncooperative resolution (BAU, BAU or crash) is the worst outcome for both players.

Although this game (Fig. 6) is not a simple two-by-two Chicken game, the Chicken structure remains. Cooperative resolution [(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, there is no incentive for cooperation, and the costs of the noncooperative status quo are so high that one party

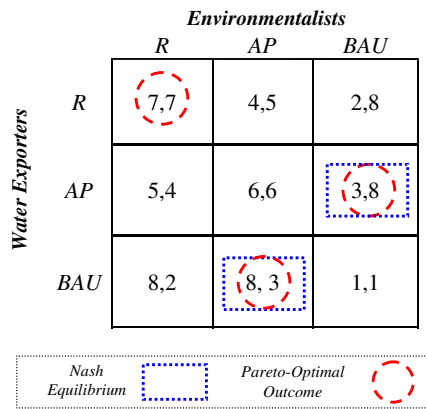


Fig. 6. The Delta game with inclusion of an alternative plan for fixing the system with an “unsustainable Delta”

(loser) will eventually deviate from its noncooperative strategy and implement the alternative solution without concessions from the other player (the “winner”). Interestingly, no likely outcomes [(BAU, AP) and (AP, BAU)] include mutual concessions. Because of the problem’s symmetry, 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.

While the Delta game may seem a repeated game in which parties play the same game many times, this game is not considered as a repeated game in the game theory context. When playing repeated games, players change their strategies over time and adopt a mixture of strategies on the basis of learning about the behavioral characteristics of the other players in the game, the consequences of adopting certain strategies, gaining more information, and building or losing trust. The Delta conflict is a continuous game (Madani and Hipel 2011) in which players can change their strategies over time. The game is played once but may take very long. The non-repeated game structure overall makes cooperation less likely as the

parties do not get a chance to learn from their actions. In other words, in this game parties cannot experience the costly consequences of noncooperation unless the Delta collapses.

State Involvement in Resolving Conflict

The State of California has shown interest in voluntary agreement among the Delta stakeholders and encouraged 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. The problem structure and results might change with State involvement. Fig. 7 shows the unsustainable Delta game (Fig. 6) when California is added. (Without unsustainability, the game is a prisoners’ dilemma in which the state’s dominant strategy is also noncooperative, and status quo is the likely outcome.) Because the game has three 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 payoffs to Water Exporters, Environmentalists, and State government. California’s options are given below each matrix. California has two options: (1) Interfere (I) in the game and bear a share of the cost of an alternative solution or compensate the player that 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 with the problem solved by concessions from other players. The worst outcome leaves the Delta unattended resulting from broad noncooperation (BAU, BAU, NI). Players rank the other outcomes on the basis of 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. Players are indifferent between outcomes that yield the same result; for example, except for the noncooperative outcome, the State is indifferent between all the possible outcomes in which the Delta problem is alleviated at no cost to the State (eight outcomes).

In this problem (Fig. 7), 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,

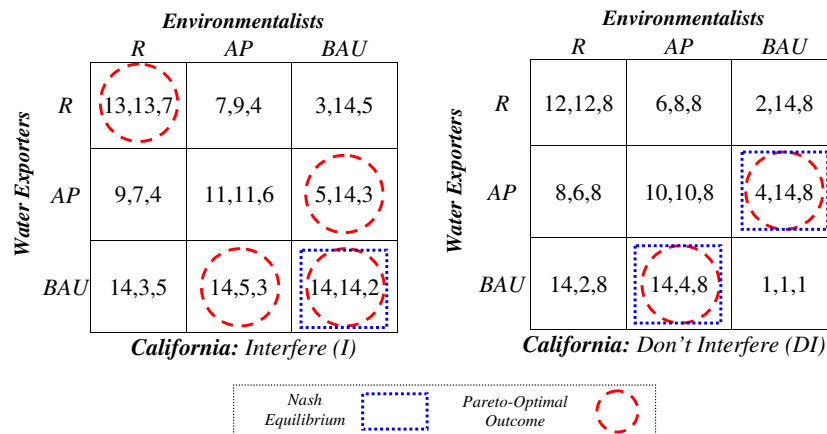


Fig. 7. The unsustainable Delta game with the State of California added

characteristics of the Chicken game persist, even for the State. Cooperative outcomes are unlikely (beside the three Nash equilibria which are also Pareto-optimal, there are three 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.

Urgency of State or Federal Action

The Delta conflict's structure has evolved the 1930s. Cooperation in the early 20th century was possible by the homogeneity of stakeholder interests and the availability of enough water for all demands. Later, growth in upstream and water project demands with reintroduction of environmental needs encouraged the stakeholders to not cooperate but compete with the zero-sum perception to gain 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, noncooperation remained a dominant strategy, and a cooperative solution failed to develop, especially as federal and state funding diminished.

Growing realization of the continuing decline and unsustainability of the Delta has produced a new structure. The Delta problem now has a Chicken game structure, in which Delta failure is the only possible result if stakeholders adhere to noncooperative strategies. Even if the cost of a solution increases with time, in addition to the attendant chance of catastrophe, any delay that shifts even 1% of the cost of a \$20 billion solution to other parties is worth \$200 million to a stakeholder. The greater incentive to shift responsibility to others rather than agree today makes agreement difficult, even where cooperation would serve all interests.

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 stronger Delta governance mechanism, which enforces or entices a more cooperative resolution; otherwise, at least one party (particularly the state) will lose substantially. Some groups have more advantages, because of their reduced sensitivity to risks from continuing the status quo. Outside the cooperative solutions just illustrated, some parties are also likely to seek external noncooperative 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.

The Delta problem has evolved since the late 20th century from a Prisoner's Dilemma game-theoretic structure to a Chicken game. 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 change 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 might be better 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 in developing a long-term solution also 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 noncooperation 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 have different utility levels from the Delta's services, and all currently suffer more with time. One mechanism shares costs on the basis of 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. To prevent such behavior, compensation might be relative to a party's reported benefits, encouraging more accurate reporting of benefits. Alternatively, the State could impose a Delta use fee on all users, which would be reduced substantially once agreement has been made. Given current state and federal financial conditions, relative to those of California's water utilities, imposed fees may be more available than subsidies. The state could also establish a deadline for a solution, after which state liability would be limited, increasing the costs of catastrophe to all users.

Conclusions

The Delta problem has evolved over time from cooperation to Chicken. In the early 20th century Delta stakeholders agreed to cooperative solutions. 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. Because Delta stakeholders bargain on the basis of their utilities from water, land, money, and risk over time rather than water shares alone, a cooperative win-win resolution that includes trading across resources and liabilities may be possible. However, the 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 Prisoner's Dilemma to a game of Chicken. The Chicken game is particularly devilish given the 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, because 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) 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 and loser in the conflict, bearing much of the cost of a Delta failure, attributed to its past failure so far to develop reliable mechanisms to enforce cooperation.

Whatever plan is adopted to fix the Delta in the coming decades, the Delta's sustainability is not guaranteed without powerful mechanisms providing incentives for cooperation or penalties for deviation from cooperation. Although recent efforts address symptoms of the problem, they have not yet solved a main cause—lack of effective and responsive governing mechanisms. California must “govern” the Delta or eventually pay for absence of effective governance.

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