

2 **Conflict Resolution for Sacramento-San-Joaquin Delta with**
3 **Stability and Sensitivity Analyses Using the Graph Model**

4 **ABSTRACT**

5 The goal of this paper is to resolve the strategic long-term dispute for the Sacramento-San
6 Joaquin Delta California using the Graph Model approach for conflict resolution. To facilitate
7 the analysis, a Decision Support System (DSS) has been developed, incorporating multiple-
8 criteria decision analysis, stability and equilibrium analysis, and uncertainty analysis using
9 the info-gap technique. The DSS has been used on the Sacramento-San Joaquin Delta
10 conflict. After specifying the stakeholders with their preferences and possible decisions, the
11 DSS identified the most robust solution, considering the possible actions and counteractions
12 of all stakeholders. Solution robustness was then tested under the uncertainty associated with
13 stakeholders' perspectives, and under cooperative and non-cooperative attitudes. Based on its
14 simple modeling and powerful analytical features, the DSS proved to be useful in modeling
15 complex disputes, determining most robust solution, and examining the effect of uncertainty.

16

17 **Keywords:** water disputes, conflict resolution, graph model, decision support systems,
18 multiple criteria decision analysis, Sacramento-San Joaquin Delta, Computer applications.

1. INTRODUCTION

In a water conflict, different interest groups can be involved as decision makers, where each decision maker can make choices unilaterally and the combined choices of all players together determine the possible outcomes of the conflict. Instead of unilaterally moving, decision makers also may choose to cooperate or form coalitions. In such situations, Game theory techniques, such as the Graph Model for Conflict Resolution, offer a useful and precise language for discussing conflicts. A systematic study of a conflict provides insights about how the dispute can be efficiently modeled and resolved (Madani, 2010).

Game theory is basically a mathematical study of competition and cooperation. It shows how strategic interactions among players result in overall outcomes with respect to the preferences of those players. Such outcomes might not have been planned by any player (Stanford Encyclopedia of Philosophy, 2006). Games are defined mathematically by a set of players, a set of strategies (options) available to them, and the players' payoffs for each combination of such strategies (possible outcomes of the game). The payoffs to players decide the decisions made and the type of the game being played. If the payoffs are equal to zero or a constant then the stakeholders have opposing interests and are playing a zero-sum-game or a constant-sum game; whatever one stakeholder wins, the other stakeholder loses. Non-zero-sum games, in which the sum of payoffs does not equal zero or a constant, have more complications, and likely requires cooperation.

In a typical game, decision makers (players), have conflicting goals and try to overcome one another by anticipating each other's decision. The game is determined as a consequence of the players' decisions. Game theory analyses the strategies players use to maximize their payoffs. A solution to a game prescribes the set of decisions that each decision maker takes at the end. An advantage of game theory over classical quantitative optimization methods is its capability to simulate the actions and counteractions that take

44 place during the negotiation, until a final resolution emerges and is accepted by all
45 stakeholders (Madani, 2010).

46 Disputes about water resources are among the most difficult disputes to resolve and
47 often involve multiple nations. Many researchers have attempted to analyse water conflicts in
48 a game-theoretic framework. Hipel et al. (1993) provided a resolution of the strategic conflict
49 related to discovering carcinogen in the groundwater that supply Elmira city in Canada.
50 Adams et al. (1996) used Rausser-Simon non-cooperative model for developing a framework
51 for non-cooperative, multilateral bargaining and analysis of water policy negotiation in
52 California. Dinar and Howitt (1997) developed cooperative solution concepts for evaluating
53 schemes for allocation of joint environmental control cost among polluters in California.
54 Lippai and Heaney (2000) developed cooperative solution concepts for efficient and
55 equitable allocation of impact fees for urban water systems among zones, user classes, and
56 demand types. Simon et al. (2007) used Rausser-Simon non-cooperative model for modeling
57 negotiations over irrigation quotas, water price, and reservoir sizes among seven aggregate
58 players. Ambec and Ehlers (2008) developed cooperative solution concepts for efficient
59 sharing of river among satiable agents (countries). Madani and Lund (2011) investigated the
60 water disputes for San Francisco-San Joaquin delta using Monte-Carlo game theoretic
61 approach. Obeidie et al. (2002) provided a systematic study of a conflict over the proposed
62 export of bulk water from Canada. Raquel et al. (2007) developed a cooperative solution
63 concept for balancing the economic benefits versus negative environmental impacts from
64 agriculture production. Wang et al. (2008) developed cooperative solution concepts for
65 equitable and efficient water allocation among users at the basin level in Canada.

66 The graph model (Fang et al. 1993) is a comprehensive decision technology has been
67 applied to a range of different conflicts, including local and international trade disputes (Hipel
68 et al. 2001). In a recent research (Kassab et al. 2006), the graph model was used to resolve a

69 construction conflict between an owner and a contractor. The graph model mathematically
70 describes how stakeholders (DMs) interact with one another in terms of negotiation moves
71 and countermoves, based on their preferences.

72 This paper introduces the graph model for conflict resolution (Fang et al. 1993) as an
73 effective method for modeling and resolving water disputes. To facilitate its application, a
74 decision support system (DSS), called “congress”, has been developed based on the early
75 work of Kassab et al. (2009). The DSS is then applied to the water dispute in the Sacramento-
76 San Joaquin Delta (California). The DSS helps to select the optimum decision and to examine
77 its robustness under uncertainty in the decision makers’ preferences.

78

79 **2. CASE STUDY**

80 The Sacramento-San Joaquin Delta is part of the largest estuary on the West Coast of
81 the United States, and is a home to a various fish and wildlife. It also a major source of
82 California’s water supply, channeling water from Northern California’s watersheds to two-
83 thirds of the state’s households and millions of acres of farmland in the Central Valley. This
84 area is currently in a serious, long-term crisis. Many of the Delta’s native fish populations are
85 experiencing rapid reductions, five are listed as either endangered or threatened species.
86 Many Delta islands are artificially protected by aging levees. The old weak levees defending
87 these islands are subject to increasing water pressure from tides and floods. A major
88 earthquake would cause a catastrophic failure of the levee system. The Delta currently has a
89 system that abstracts water from the Sacramento River in the north, transporting it through
90 the Delta to massive pumps at the Delta’s southern edge. The pumps convey this water to
91 users all-over California, from the Bay Area in the north to the Central Valley and Southern
92 California. This water export system has been effective for over 50 years, and has been a
93 large source of income. However, recent federal court rulings reacting to the decline in native

94 fish populations reduced water exported from the Delta substantially. Accordingly, the
95 efficiency of water supply system of California is becoming less reliable (Lund et al., 2008).

96 Among various policy initiatives now undertaken to consider the Delta's issues, the
97 Delta Vision initiative has been set out by Governor Arnold Schwarzenegger; this initiative
98 has established co-equal objectives for future Delta management: conservation of the
99 ecosystem and creation of a reliable water supply for California. To achieve these objectives,
100 four key options for Delta water exports are considered: (a) Continue to pump and export
101 water through the Delta; (b) Build a peripheral canal to convey water around the Delta; (c)
102 Operate a "dual conveyance" system, combining the two previous strategies; or (d) end
103 water exports.

104 Risks come with each of the suggested option. On the one hand, continuing the
105 pumping through the Delta will worsen the situation for the endangered species. On the other
106 hand, ending all water exports may be the best solution for the endangered fish species, but is
107 very costly for California's economy. Figure 1 summarizes the performance of each
108 alternative in terms of two criteria discussed by Lund et al. (2008): the fish population
109 viability (considered as the environmental sustainability criterion); and the economic cost (as
110 the water supply reliability criterion). As shown in Figure 1, the performance of each
111 alternative under the two criteria involves considerable uncertainty, reflected by large in the
112 figure. Therefore, there is a need for a technique which can suggest the final outcome of this
113 multi-criteria problem where the performances are uncertain.

114

115 **3. DECISION SUPPORT SYSTEM (DSS) IMPLEMENTATION**

116 To facilitate the analysis of the water conflict for the Sacramento-San Joaquin Delta, a
117 decision support system (DSS), called "**conflict /Game\ resolution**" or "**conGres**" has been
118 developed at the University of Waterloo based on the work of Kassab et al. (2006b) and

Kassab (2009). As shown on Figure 2, the DSS integrates three techniques: (1) the elimination method (MacCrimmon 1973), which is a flexible multiple criteria decision analysis (MCDA) technique used to shortlist the decision alternatives; (2) the graph model for conflict resolution (Fang et al. 1993) to simulate the conciliation process that takes place; and (3) the information gap (info-gap) theory (Ben-Haim and Hipel 2002; Ben-Haim 2006) to help choose the best decision in the presence of the uncertainty associated with the stakeholders' preferences. Figure 3 shows the main interface of "conGres" as applied to the Sacramento-San Joaquin Delta case study, with the following steps showing the details of the implementation, for the goal of identifying the best solution.

Step 1: Define Stakeholder and their options

The Delta problem has two decision makers (DMs) with conflicting concerns: the water exporters who are concerned with sustainability of water exports; and the environmentalists who are concerned with native fish population viability. Each of these two DMs can accept any of the four options mentioned earlier (a, b, c, d), as shown in Figure 4 and listed in Table 1. Therefore, there exists a set of $4 \times 4 = 16$ "solution states" (or possible resolutions) that combine the decisions of the two DMs.

For example, decision state 6 (highlighted on top of Figure 5) represents a decision in which both DMs agree to building a peripheral canal to convey water around the Delta.

Step 2: Shortlist feasible solutions

Given 16 decision states, it is important to recognize and eliminate any solution with infeasible combinations of options and to focus only on the most promising ones. The elimination method provides the ability to eliminate some of the alternatives that do not meet stakeholders' threshold values of acceptance. Figure 6 shows possible cooperative outcome,

occurring when both DMs select the same strategy. Based on the game structure suggested by Madani and Lund (2011) shown in Figure 6, twelve options were eliminated. The DSS allows the user to set any number of criteria to use for the elimination process. After the user evaluates each decision state in terms of these criteria, the DSS ranks the solution states. Accordingly, the user can eliminate the lower ranked options. Following this process, only the four solutions in which both parties agree to a certain solution are feasible, therefore producing the short list in Figure 7.

Step 3: Carry out conflict resolution analysis

In this step, the mechanism of the graph model for conflict resolution is used, and the process examines the stability of the shortlisted solutions with respect to the DMs' preferences. Following the Graph Model approach of (Fang et al., 1993), the relative preferences of each DM in the shortlisted solutions are first specified. To do that, this study uses the cardinal matrix specified by Lund et al. (2008) and shown in Eq. 1. The numbers on the left and right columns of the matrix indicate the average utilities of the DMs, from the four alternatives. In this ordinal matrix, higher values represent higher preference of the DM. Based on these values, it is possible to rank the alternatives for each DM.

$$\text{Cardinal Form Matrix} = \begin{matrix} & \begin{matrix} \text{Exporters} & \text{Environmentalists} \end{matrix} \\ \begin{bmatrix} 1.205 & 17.5 \\ 0.550 & 25.0 \\ 0.750 & 2.50 \\ 2.000 & 45.0 \end{bmatrix}_{4 \times 2} \end{matrix} \quad (1)$$

Once the preferences were determined and entered as shown in Figure 7, the Graph model uses the stability concepts (Nash (R), General Metarationality (GMR), Symmetric

Metarationality (SMR), Sequential Stability (SEQ)), listed in Table 2, to test each solution in terms of stability and equilibrium (i.e., stability for all DMs). For mathematical definitions, all information can be found in Fang et al. (1993) and Kassab et al. (2006a). Each stability concept has a different perspective. For instance, a decision state is Nash stable for one DM if the DM cannot unilaterally move to more preferred state. When a decision state is found to be stable for all the stakeholders, it represents an equilibrium situation, i.e., a decision state that has high potential of satisfying all parties.

Using the DSS for this case study, the shortlisted solution were further examined based on the stakeholders' preferences shown at the bottom of Figure 7. Based on the stability analyses tests, solution 2 was determined to be the optimum one and is in equilibrium with respect to all the stability concepts, as shown on Figure 8. Solution 2 "Tunnel" received the highest number of score of 9500, followed by option 3 "dual conveyance" with a score of 9250 as shown in Table 3. Further, the "no export" is the least favourable solution.

Step 4: Accounting for uncertainty

In this step, the uncertainties associated with ambiguity in stakeholder preferences are considered and its impact measured on the final resolution of the conflict. To specify the degree of uncertainty, Table 1 includes an uncertainty range for the performance of each alternative, which gives a good representation of the variability in the preferences. Based on these ranges, the DSS uses the info-gap theory (Ben-Haim 2006) to furnish the user with the ability to consider uncertainties. The info-gap method runs a systematic procedure for investigating the robustness of a decision under the uncertainty of the stakeholder preferences (Ben-Haim and Hipel 2002).

In this case study, uncertainty analysis associated with stakeholders' preferences was performed. Table 4 lists the percentages of the assumed uncertainty level for each of the

DM's preference values. Both the Water Exporter and the Environmentalists are assigned a value of +10% uncertainty to their preferences. Once the uncertainty level was specified, the DSS then performs a number of experiments (the default is 100), varying the preferences randomly within the uncertainty range. It then presents the results in the form of a histogram. The results indicate the robustness of solution 2 as the best final resolution, as shown in Figure 9. The results of this paper match the results obtained from Madani and Lund. (2011), where Monte-Carlo game theoretic approach with uncertainty were used.

4. SUMMARY AND CONCLUDING REMARKS

This study introduced the graph model for the water dispute in Sacramento-San Joaquin Delta problem. This area faces a serious water exports and decline fish which considered as a endangered species. This proposed DSS was used to find the optimum solution based on stakeholders preferences. In the Sacramento-San Joaquin Delta problem, the 16 alternatives were reduced to only 4 feasible solution. In addition, using conflict resolution with info-gap theory led to solution 2 as the best solution. Uncertainty analysis with $\pm 10\%$ variability for environmentalists and water exports and 100 experiments were considered. This solution is to build a peripheral canal "Tunnel", conveying water around the Delta. The solution was successful in achieving equilibrium in four stability concepts of Nash, GMR, SMR, and SEQ. In conclusion, with cooperation between the decision makers, building the tunnel is the most likely solution to replace the existing water export. It was found that the second likely and reliable solution is to have a dual conveyance "tunnel". Having no-export solution is not possible for this problem, as the agriculture industry in the Sacramento-San Joaquin Delta is a profitable business. The developed DSS, "congress", proved to be practical and can be used for variety of disputes. The elimination process is one of the great advantages, particularly in larger disputes that involve a large number of infeasible solution states. The simplicity of the

DSS makes it a viable tool for applying conflict resolution, stability analyses, and robustness analysis. This study ignores other issues, which may indirectly affect this conflict, such as water allocation among other users, agricultural cropping rotation, hydropower , and climate change. This paper is also did not focus on the other source of water such groundwater and desalinated water.

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1. APPENDIX

Table 1. Performance of Delta alternatives under two criteria (Madani and Lund 2011).

Alternative	Average annual cost (\$ billion/year)	Likelihood of fish Population (%)
a- Continue pumping through Delta	0.55 - 1.86	5 - 30
b- Tunnel	0.25 - 0.85	10 - 40
c- Dual Conveyance	0.25 -1.25	10 - 40
d- No exports	1.5 - 2.5	30 - 60

Table 2. Solution concept for conflict resolution.

Solution concept	Description
Nash stability (R)	No other decisions bring a better payoff.
General metarationality (GMR)	If a better option is decided, opponent's counter-actions are safe.
Symmetric metarationality (SMR)	If a better option is decided, opponent's counter-actions are safe and not harmful to opponent.
Sequential stability (SEQ)	If a better option is decided, opponent's beneficial counter-actions are safe.

Table 3. Best solution with decision makers Payoff and Equilibria.

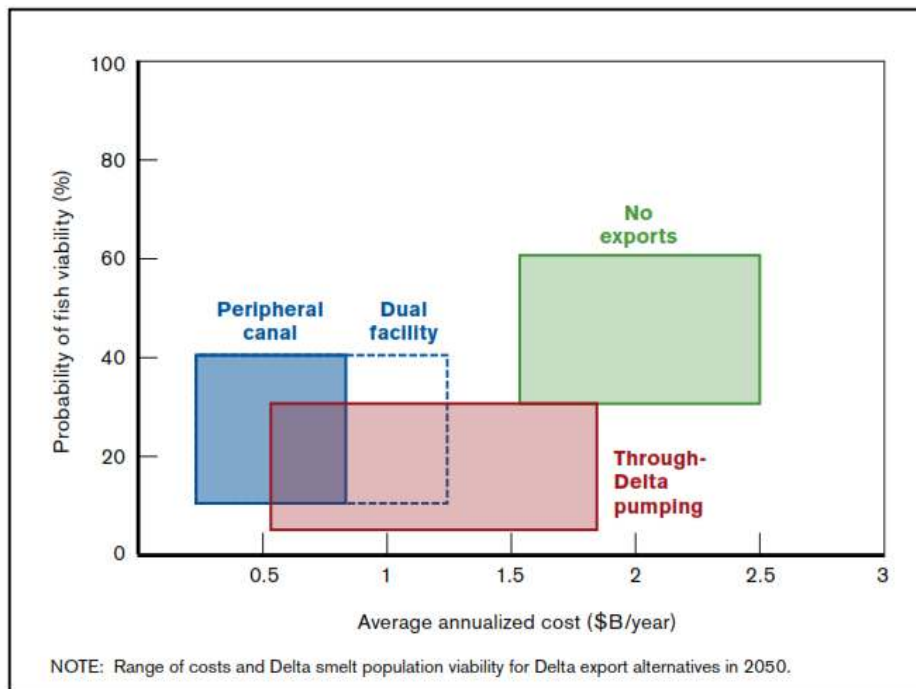
Option	Environmentalists Payoff	Water Exporter Payoff	Scores	Best Solution	Equilibria
1	Continuing (1)	Continuing (1)	8750	4th	R, GMR, SMR, SEQ
2	Tunnel (2)	Tunnel (4)	9500	1st (Best)	R, GMR, SMR, SEQ
3	Dual Conv. (2)	Dual Conv. (3)	9250	2nd	R, GMR, SMR, SEQ
4	No export (3)	No export (1)	9000	3rd	R, GMR, SMR, SEQ

289 Table 4. Uncertainty and stakeholder.

Stakeholder	Uncertainty (0-100%)
Environmentalists	±10
Water Exporter	±10

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291



292

293 Figure 1. Performance of San Joaquin Delta water export alternative under two criteria
 294 (adopted from Lund et al. (2008)).
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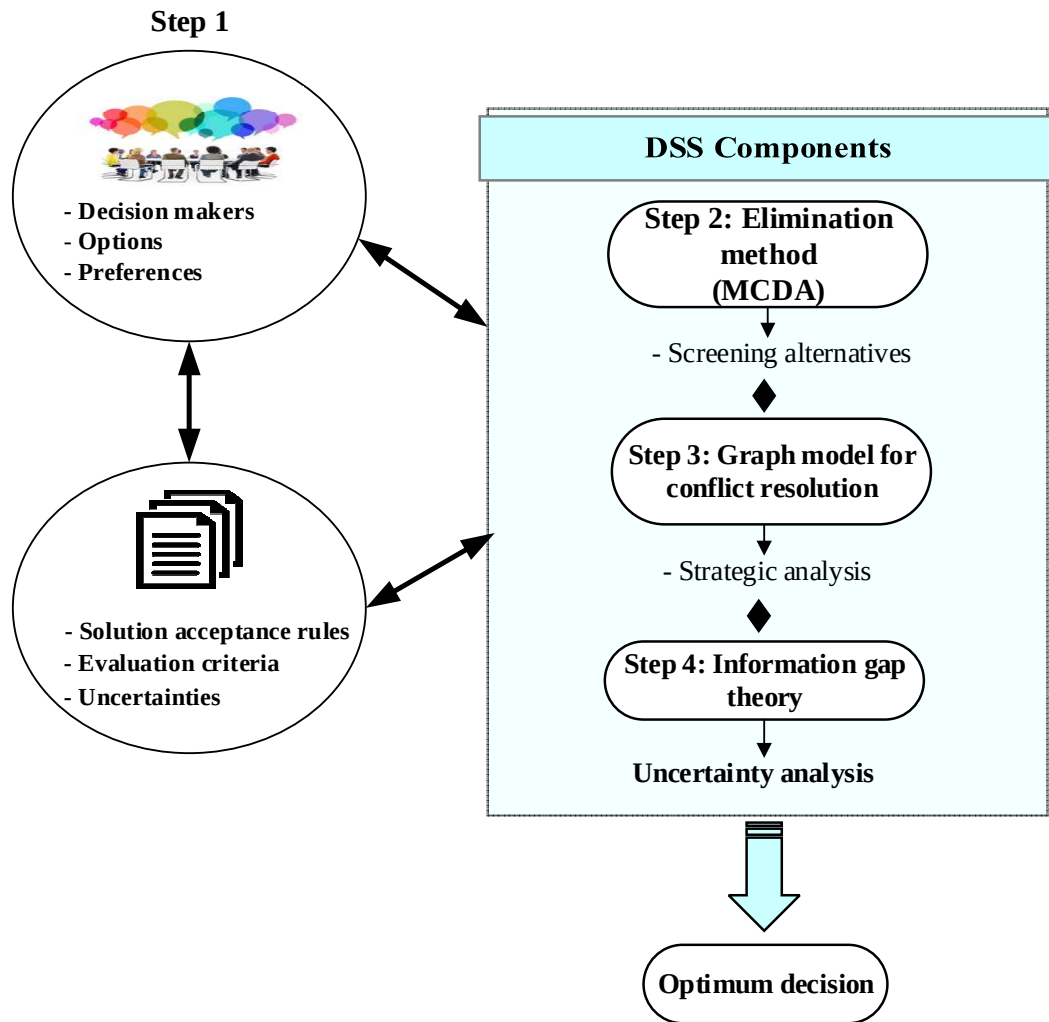


Figure 2. Components of the decision support system (DSS) for conflict resolution.

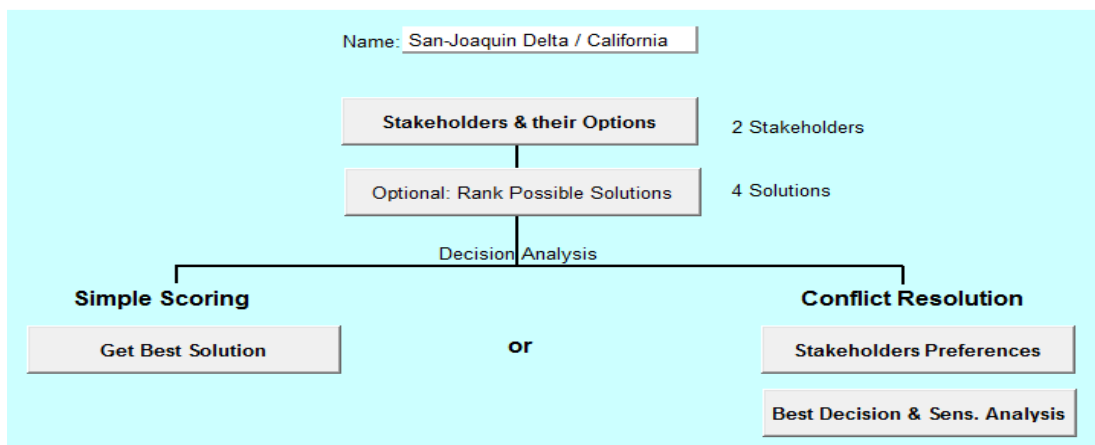


Figure 3. Graph Model Chart for San-Joaquin Delta.

Main Menu		StakeHolders and their Options				
StakeHolders:		Use the Add / Del buttons to specify StakeHolders, then enter their Mutually Exclusive decision options.				
Add Del						
Stakeholder	No. of Decision Options	Option 1 Desc.	Option 2 Desc.	Option 3 Desc.	Option 4 Desc.	Option 5 Desc.
Environmentalists	4	Continuing through	Tunnel	Dual Conveyance	no exports	
Water Exports	4	Continuing through	Tunnel	Dual Conveyance	no exports	

Figure 4. Stakeholders and their discrete options.

Main Menu		Alternative Solutions											
		Total Solutions= 16											
		Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10	Soln 11	Soln 12
Environmentalists		Continuing	Tunnel	Dual Conveyance	no exports	Continuing	Tunnel	Dual Conveyance	no exports	Continuing	Tunnel	Dual Conveyance	no exports
Water Exports		Continuing	Continuing	Continuing	Continuing	Tunnel	Tunnel	Tunnel	Tunnel	Dual Conveyance	Dual Conveyance	Dual Conveyance	no expo
1. Set Criteria & Acceptance Thresholds		2. Score each solution w.r.t. each criteria (0-100) or (A, B, C)											
Default		Weight	Ranked Criteria	Add	Del	Should be	Desired Value						
		2	Conservation of the ecosystem			>=	C						
		1	Creation of reliable water supply for Cal			>	6						
Rank:		1	2	15	3	14	4	5	6	7	16	8	9
		Note: Blue cells show unsatisfactory scores.											

Figure 5. Solution states and the elimination method.

		Environmentalists					
		A	B	C	D		
Water Exporters	A	2,1	2,1	2,1	2,1	Ordinal Matrix Form =	$\begin{bmatrix} 2 & 1 \\ 4 & 2 \\ 3 & 2 \\ 1 & 3 \end{bmatrix}_{4 \times 2}$
	B	2,1	4,2	2,1	2,1		
	C	2,1	2,1	3,2	2,1		
	D	2,1	2,1	2,1	1,3		

Figure 6. Game structure with cooperative outcomes (adopted from Madani and Lund 2011).

Main Menu		Alternative Solutions			
Total Solutions= 4					
Environmentalists		Soln 1 Continuing	Soln 2 Tunnel	Soln 3 Dual	Soln 4 no exports
Water Exports		Continuing	Tunnel	Dual	no exports
Preferences		Enter the stakeholders' preferences in the above solutions (0-100 scale).			
Environmentalists		1	2	2	3
Water Exports		2	4	3	1

Figure 7. Shortlisted decision states (after elimination) with stakeholders' preferences

Main Menu		Optimize Decision Using Conflict Resolution	
Out of :	4	Solutions	
Solution No. :	2	Find the Best Solution	
Has a Score of :	9500	Sensitivity to Prefs.	
Solution Details:			
Decision	Payoff	Stakeholder	
Tunnel	2	Environmentalists	
Tunnel	4	Water Exports	
Equilibrium Tests:			
Solution is NASH Stable with respect to: Environmentalists (i.e., no other decisions bring a better payoff).			
Solution is NASH Stable with respect to: Water Exports (i.e., no other decisions bring a better payoff).			
Solution is NASH Equilibrium			
Solution is GMR Stable with respect to: Environmentalists (i.e., if a better option is decided, opponents' counter-actions are safe).			
Solution is GMR Stable with respect to: Water Exports (i.e., if a better option is decided, opponents' counter-actions are safe).			
Solution is GMR Equilibrium			
Solution is SMR Stable with respect to: Environmentalists (i.e., if a better option is decided, opponents' counter-actions are safe and not harmful to opponent).			
Solution is SMR Stable with respect to: Water Exports (i.e., if a better option is decided, opponents' counter-actions are safe and not harmful to opponent).			
Solution is SMR Equilibrium			

Figure 8. Decision optimisation using conflict resolution.

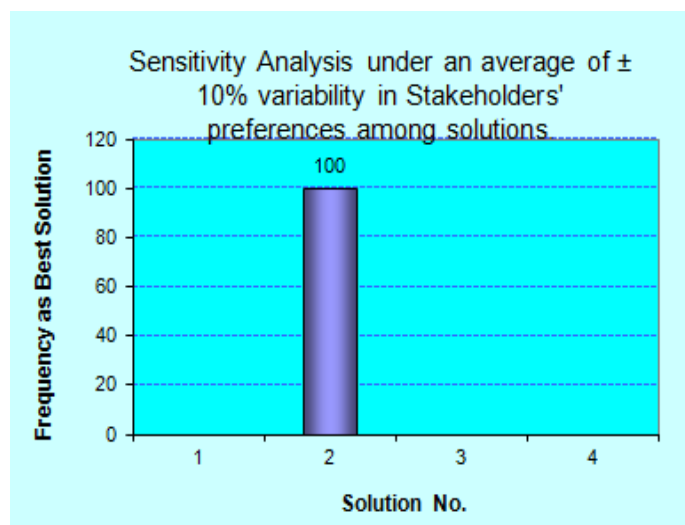


Figure 9. Sensitivity analysis result.